MC
110.623/
1

INTERTECHNO '90

11 - 14 September 1990
BUDAPEST



ICFF International Conference on the Factory of the Future to realise

CIM Intelligent Computer Integrated Manufacturing



Scientific Society of Mechanical Engineers, Hungary

SCIENTIFIC SOCIETY OF MECHANICAL ENGINEERS
Hungary

I N T E R T E C H N O '9 0
Conference

ICFF International
Conference on the
Factory of the
Future
to realise

CIM Intelligent
Computer
Integrated
Manufacturing

11-14 September 1990
Budapest

Editors:

dr. Horváth Imre
Lehotzky József

MC 110.623/1
KÖNYVTÁR
R 2
1990

Publisher:
Gépipari Tudományos Egyesület
Budapest

ISBN 963 8094 23 0 Ö.

ISBN 963 8094 11 1 I.

ISBN 963 8094 32 X II.

CONTENT

Alander, J.T. (SF) 10
A modular, multipurpose, and multiarm assembly robot cell design

Andrzejewski, M., Gawlak, G. (PL) 20
Some problems connected with the computer aided planning of machining processes

Arndt, P., Müller, G., Richter, H-J. (GDR) 29
Little FMS - state of art, reliability and affectiveness

Arz, G., Lipoth, A., Merksz, I. (H) 38
Industrial robot - machine tool links

Basa, J. (H) 50
CAD/CAM softwares in practice

Palotás, B., Becker, L., Farkas, A. (H) 56
Some aspects of flexible automatisation of welding technology

Beilke, H-J. (FRG) 71
Flexible automated manufacturing of flat sheet metal components in low quantities

Bolla, L., Cser, I. (H) 81
Integrated cutting technology planning system

Cioci, M. (I) 89
Baküer Modular System

Cosic, I., Seslija, D., Tót, Z. (YU) 99
Contribution to the development of criteria for suitability of products for robotic assembly

Dalela, S. (IND) 109
Databse for extrusion process design

Furukawa, M., Kakazu, Y., Okino, N. (J) 119
Parametric design methods using Petri net for controlling design process

Glushkov, O.I., Menshchikov, A.A. (SU) 128
Open macros of geometric language

Grossmann, G. (GDR) 136
Flexible automation of material handling

Grund, K. (FRG), **Haidegger, G., Kovács, Gy.** (H) 141
Is MAP 3.0 ready for CIM implementations?

Haydoutova, J., Shishkov, I. (BG) 151
CIM oriented intelligent integrating environment

Horváth, L. (H) 157
The GLEDA computer-aided manufacturing process planning system

Horváth, I. (H) 169
Possibilities of artificial creativity in design

Hossain, A., Krajcsovics, Cs., Roman, Gy. (H) 179
Robot selector and 3D graphic modeling program

Ilinsky, D. (SU) 189
CAD-DAE system for footwear production

Iwata, Y. (J) 193
A study of normal force change under the stabilizing threshold in lathe chatter

Jiafu, B., Yimin, D. (PRC) 203
Research on fast algorithms of surface modelling and techniques of software realization

Jin, T., Li, S., Ge, Y. (PRC) 213
Research on a new on-line dynamic measuring device

Juhász, M., Bertal, N., Cser, I. (H) 221
Turning centers programming by GTIPROG/EC system

Kakazu, Y., Takatori, N. (J) 231
Dynamic jog shop scheduling by neural network

Kamimura, M., Fujii, S. (J) 241
Study on automatic teaching by learning - offline teaching for industrial robots

Kayaligil, M.S. (T) 251
Part-mix allocation between automated and conventional manufacturing: improved solution bounds

Klöpper, K. (GDR) 261
CAQ in flexible prefabrication of concrete elements

Knoll, I. (H) 267
Mutual effects in "Materials handling - logistics infrastructure"

Krajcsovics, Cs., Arz, G. (H) 277
Robot controller hardware for artifical intelligence applications

Kurutz, K., Kása, L., Rácz, G. (H) 283
Automation of material handling and transport controlled by digital systems

Lehotzky, J. (H) 288
Processing of sheet material in CIM environment

Lehotzky, J. (H) 294
Reliability in the factory of the future

Makszy, G. (H) 300
Developing CAD usage by logical steps

Matolcsy, M., Ivony, J. (H) 306
The first results with using CAD in bus-chassis design

Merke, P. (FRG) 314
Integrated shopfloor monitoring with german leitstand concept

Mezgár, I. (H) 323
An overview of models for advanced manufacturing

Mikami, S., Kakazu, Y. (J) 333
A theoretical approach to the design of CSG engine

Minagawa, M., Kakazu, Y. (J) 343
An approach to automatic dimensioning problem on modeled CSG

Palko, A., Vukov, P. (CS) 353
APR 2,5 robotic system and its application possibilities

Peng, W., Wu, N., Xue, J. (RPC) 364
On the determination of the part types and mix in FMS

Plenert, G. (USA) 369
International operations research methodologies

Poestges, A.W. (FRG) 372
Restructuring and reorganizing an existing EDP environment to optimize information logistics - an example of a successful CIM project within a major automotive supplier

Poths, W. (FRG) 381
Design in mechanical engineering and process plant construction
- a task of information processing -

Qiong, Z., Shifa, W. (PRC) 391
A digital-optical hybrid technique on image restoratiom of high-speed technical photography

Rainer, G. (A) 395
CAD/CAE/CAM applications and concepts in engine development

Sakovitch, G.V., Brylyakov, P.M., Gubarevitch, V.D., Verestschagin, A.L. (SU) 407
Production of diamong clusters by explosion and their practical application

Schlattmann, J., Jorden, W. (FRG) 422

Rempel, J., Schmidt-Weinmar, :, Schmidt-Weinmar, G.H. (CDN) 431
Adaptive control of production by simulation technique

Schmigalla, H., Beckmann, H-D., Schreiber, H. (GDR) 441
New methods of computer-aided data acquisition for CAD in facilities planning

Sekulic, S. (XU) 449
Graphical procedure for prognosis of the cutting-tool reliability, on flexible automatic lines, based on the number of work pieces machined with particular tools

Shiroma, Y., Iwato, K., Kakazu, Y., Okino, N. (J) 458
3-D solid modeling for swept volume of NC tool movement

Stams, D. (FRG) 468
CIM innovation process in the F.R.G.

Todorov, N., Matev, D. (BG) 476
Problems of the computer integration manufacturing in the machine building

Vajna, S. (FRG) 486
Influences on the economic efficiency of CAD/CAM systems

Vasak, P.J. (FRG) 495
Modern amangement in manufacturing

Volin, E.M. (SU) 505
Main aspects of phisical vapour deposition for resisting coatings on cutting tools

Wahl, M.G., Quibeldey-Cirkel, K. (FRG) 515
The electronic design interchange format EDIF - capabilities and evaluation

Warnecke, H-J., Kühnle, H., Ruchs, R-M. (FRG) 525
Production planning and control (PPC) with pull-prinziple and integrated bottle-neck-management

Watanabe, M., Furukawa, M., Kakazu, Y. (J) 536
Local modification of a free-formed surface preserving shape data

Weissenseel, H.G. (FRG) 545
A CAM application architecture and new methods for CAM-application development

Zeng, Q. (RPC) 557
Th expert system with fuzzy reasoning

Yoneda, T., Suzuki, I., Unno, K. (J) 564
CNC profile grinding of non-circular shapes

FOREWORD

INTERTECHNO '90 Conference
11-14 September 1990
Budapest, Hungary

The principal aim of conference INTERTECHNO '90 is to call together European scientists, researchers and specialists. The bridge selected as a symbol for the Conference represents the connection between East and West. The number of English and Russian language speakers shows that the conference may act as a bridge between them.

Papers presented for the conference are compiled into two separate volumes. The first on is in English, the anouther one is in Russian. We did not consider the nationality of the lecturers. To help the reader to find the needed paper we organized the papers according to the alphabetical letters of the (first) lecturer. Comprehensive table has been constructed to help finding paper on the ground of the curriculum of the conference.

In case of the interdisciplinary papers several classifications were possible. These are indicated, although the presentation can take place in one session only.

More than 150 papers were received. Therefore, the Scientific Organizing Committee had to select papers for oral and poster presentation, respectively.
Both volumes contain the papers in their original forms, as they were received from the authors.

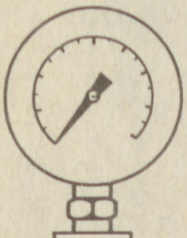
On the behalf of the Scientific Organizing Committee:

József LEHOTZKY dr. Imre HORVÁTH

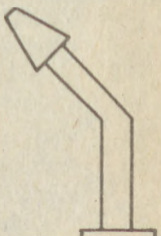
ALAGI ÁLLAMI TANGAZDASÁG MŰSZAKI IGAZGATÓSÁG

autogéntechnika

FŐMÉRNÖKSÉG



SZOLGÁLTATÁSAINK



— Gázhegesztés, lángvágás és rokoneljárásainak eszközellátása, -javítása, -pótlása
— Ipari és egészségügyi központi gázellátás-tervezése, -kivitelezése
— Negyedéves hegesztőeszköz-ellenőrző felülvizsgálat végzése
— Acetiléntől eltérő, más gázfajták alkalmazásához szükséges eszközök előállítása

LESELEJTEZETT FELSZERELÉSEIKET MEGVÁSÁROLJUK.
JAVÍTHATÓ ESZKÖZEIKET FELÚJÍTVA VISSZASZOLGÁLTATJUK.

autogéntechnika
FŐMÉRNÖKSÉG

Dunakeszi, Alagi-major 2120
Telefon: 06-27- 42-091
42-105
Telex 22-4039
22-6771

A modular, multipurpose, and multiarm assembly robot cell design

Jarmo T. Alander *

Abstract

A new modular multipurpose multiarm (M^3) assembly robot construction and high level control designed mainly for flexible assembly applications is introduced. The most common robot types used in industrial assembly application are today either scara or anthropomorfic ones designed to replace human workers in simple assembly and manufacturing jobs. However, these types contain revolute degrees of freedom, which much complicates the trajectory, speed, and collision avoidance control especially in highly automatic CAD/CAM applications and makes it nearly impossible to use robots concurrently in a cell. The traditional gantry type robot has simple linear geometry, which makes its motions trivial to be controlled. Collision avoidance calculations are also much easier even if we have several robots working together.

In this paper we propose a modular and multiarm assembly robot design based on orthogonal linear structure, which is among other things precise, stable, economic, and easy to control. The applications of M^3 range from simple palletizing manipulators to high precision, high speed multirobot assembly cells capable of handling as well tiny microelectronic components as long wires, tubes, bars or large sheet metal constructions using one or more arms at a time.

The controller is based on object-oriented database by which product model, sensor data as well as control programs are represented. There is no *a priori* limit to how much or what kind of information can be bind to any robot command. The idea of the control scheme is to use past sensor etc information to fine tune or adapt the cell in slightly changing situations or to detect and recover from errors. The controller is implemented on a PC network so that part of the control algorithms can be distribute e.g. some of the statistical analysis programs handling adaptation information can be well run on a background computer.

Most of the M^3 parts are currently under development or on prototype level. Every comment or suggestion concerning it is most welcome.

Keywords: adaptive control, AI, assembly robotics, CAD/CAM, CIM/CIE, collision avoidance, neural networks, object-oriented programming, Prolog

*Department of Compter Sci., Helsinki University of Tech., Otakaari 1, SF-02150 Espoo, Finland, phone 358-0-4513245, telefax 358-0-465077, email ja@cs.hut.fi

1 INTRODUCTION

In this report we review some of the problems of current robots and represent a new assembly robot construction called M^3 (Modular, Multipurpose, and Multiarm), which tries to solve some of these problems. The idea of M^3 have come from the many seemingly from hardware originating difficulties encountered with the currently existing robots when constructing high level control software for flexible assembly cells ([Ala88], [TA88], [AAR89], [AART89], and [AAH+89]):

- robots are slow as compared to automatic machines
- speed and trajectory control is difficult
  - collision detection is extremely difficult
- movements are unprecise
- work space is predetermined and fixed
- there are safety problems when operating robot cell
- on-line computational capacity is small
- monitoring, error detection and recovery is poor
- difficult to connect to other factory information systems
- many components are difficult to be grasped with only one hand (wires, pipes, sheet metal etc)

These are all well known problems and several correcting remedies have been proposed by so well robot industry and robot researchers:

- taller and stronger robot
- gripper/tool exchanger
- extra degrees of freedom
- more accurate conveyors
- paternoster stores
- vision system feedback
- multirobot systems
- expansion memory for controller
- more and higher level robot language instructions
- cell controller PC
- better product design

None of these seems to realize the very problem, however. Namely that robots are mainly designed to be human like and to directly replace human workers. It is difficult for a blind one handed robot to replace a two handed well seeing and hearing human operator having years of assembly experience.

In this report we suggest that this human imitation approach is in most assembly cases unreasonable and should be replaced by a flexible but more machine like approach, an approach that can be found in many assembly automatons in a hardwired form.

The key thing in automation development is product design. The products should be such that it is easy to find machines that are able to produce them. Handicraft is handicraft but industrial mass production can't rely on ancient manual methods or their poor mechanical imitations. On one hand we must develop simple and modular products to be easier to automatically produce and on the other hand we must develop flexible machines or robots that are good in corresponding simple production steps. The role of control in this scene is two fold: it must design how components and modules are combined into final products and gather experience on how the work actually is going. These two aspects of the process differ much in computational point of view, but they can be handled in unified way by using open object-oriented approach. In assembly applications adaptation, error detection and error recovery are essential if we are aiming at automatic unmanned production. These problems belong mostly to the area of artificial intelligence and they require much research. The open object-oriented approach will also somewhat help to solve some of these problems.

2 M3 CONSTRUCTION

The work space of an ordinary robot is usually predetermined and fixed and quite complicated in shape if rotational degrees of freedom are present. There does not seem to be any real advantages of these complicated motions or workspaces, on the contrary they make cell lay out more difficult to design and can cause unexpected movements and thus safety problems. There are some properties that every general and flexible assembly robot should fulfil. These include:

- linear motions that are
  - fast and
  - easy to control
- easy collision detection
- conveyor essential part of the robot system
- at least two arms for extensive components
- fast gripper exchange
- flexible construction

The mechanical requisites can be best met with an xyz-portal type construction. The most important motion control namely linear motion control is trivial, while all other

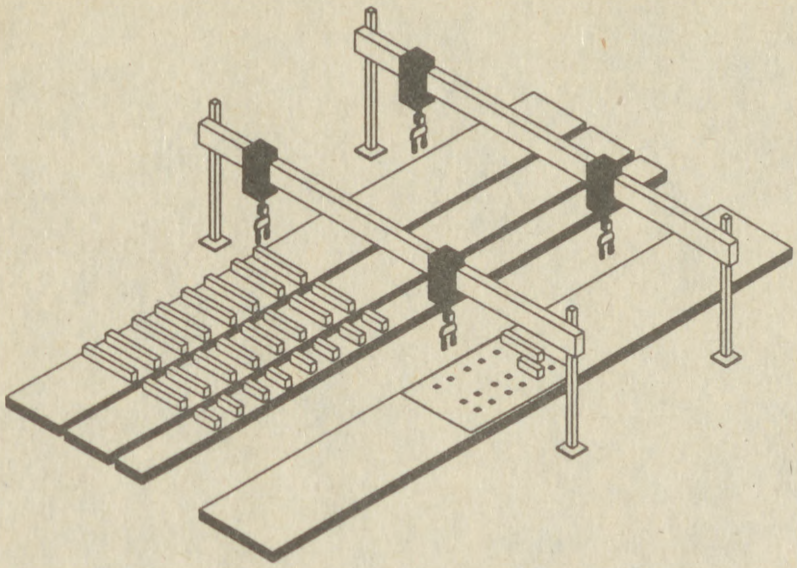


Figure 1: General overview of M^3 construction.

motion types are easily deduced from it. That is why M^3 resorts to it in a slightly modified form that is divided into two perpendicular sections (see fig. 1).

2.1 Degrees of freedom

The available degrees of freedoms are divided into two orthogonal sets upper and lower, of which the upper correspond to usual robot arms having x-, z-, and *roll*-motions and the lower set to conventional conveyors (y-motion). This division affects mechanical rigidity and allows shorter and lighter arms which in their turn allows faster operation with less power.

2.2 Scales

The M^3 concept should cover a wide range of products starting from a simple, slow and unprecise one degree of freedom stroke element to a multi arm high capacity, high speed, and high precision assembly cell. In table 1 you can see the approximate scales of some cell parameters.

Several arm can be driven by a common ball screw or similar mechanism. This guarantees multiarm synchronization when the arms are moving at the same speed to the same direction e.g. when we are using two arm to grip a component (fig. 2). On the other hand movement at different speeds or to opposite directions are not possible concurrently if only one ball screw is used.

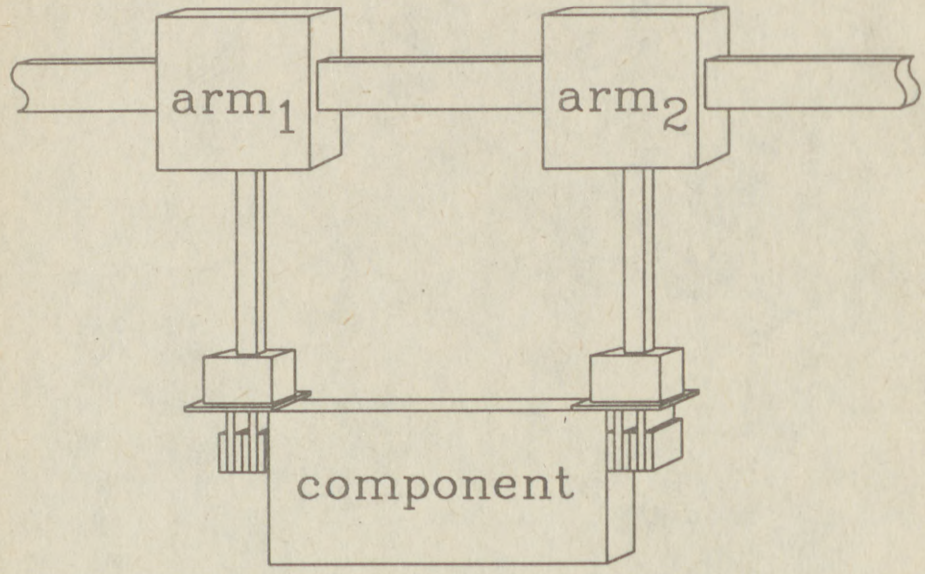


Figure 2: Two arms used as one large gripper.

quantity	*range*	*unit*	*ratio*
mechanical tolerances	1 – 0.001	mm	1:1000
degrees of freedom	1 – 50		1:50
speed	0.1 – 2	m/s	1:20
capacity	1 – 100	kg	1:100
price	10.000 – 50.000.000	FIM	1:5000

Table 1: Some of the M^3 cell parameters.

We can have at least in principle a large number of arms in one cell but it is usually better to divide a large cell into smaller ones having only a limited number of arms working together.

2.3 Flexibility

The real advantage of robots are their flexibility. We can use them in a wide variety of tasks. Potential applications of M^3 include palletizing, press/punch server, cable harness assembly (where we can use at least two arms), electrical/electronics assembly, and many many other assembly applications needing high precision and high capacity. M^3 structure is in many ways flexible:

- we can have as many modules as needed (modularity)
- multiarm constructions for large component gripping or gripper change
- multislide constructions for concurrent operations
- free slide length means flexible work space

2.4 Safety

Work spaces of individual arms are small and simple thin prisms that are clearly boardered by slides and columns. It is therefore rather easy to make the system safe to operate. Arms being simple and light weight do not require much power to move fast.

3 CONTROL SYSTEM

The list of properties that a flexible robot controller should fulfil is practically unlimited. The design of the control somewhat mirrors the design of the mechanical structure and vice versa. Among of the most important properties of control are:

- fastness,
- flexibility,
- general,
- safety,
- adaptation and learning,
- easy to integrate to the overall factory information system,
- and last but not least: easy programming.

It is reasonable to demand that the most primitive and frequently used linear motions are easily and precisely controlled. This is usually not the case with robots having unlinear rotational degrees of freedoms but the linear motion control is trivial with a portal type construction. The controller does not need much time to do the necessary scalings. Motions along curves are also easy, because they can be trivially reduced to piecewise linear motions.

If more than one arm is connected to one linear drive, the control is somewhat more difficult than corresponding separate arms but the control of motion altogether is not any great problem as compared to constructions having more complicated degrees of freedom.

3.1 Adaptive control

In order to have high robot cell reliability and thus high productivity we must use sensor feedback from the process. The current situation is such that even if the robot has already done in its life time say one million times some simple fixed job the one million and first round is exactly the same as its first round from the control point of view. There should be some kind of adaptation so that the robot system gradually learns from experience how to best do its job.

Neural network models have gained much attention as potential tools to solve difficult control problems. More about our adaptive control scheme will be published elsewhere [Ala90].

3.2 Object-oriented database

Our attempt has been to create a unified way to represent information in robot cells, something that could be comparable to the idea to use simple linear motions in the mechanical construction design side of the M^3. In order to create flexible and adaptive control we need powerful and flexible data management tools. One way to organize information is to use object-oriented approach. By the object-oriented method we can represent as well on-line sensor data as off-line product model data in an elegant way. We can proceed along this object-oriented approach still further by representing also robot commands by objects. After doing this decision it is easy to bind whatever parameters and sensor information to any robot command.

In order to gain enough flexibility we can't use any ordinary object-oriented language (e.g. [DMN68], [Str85]) in which classes and object are "hardwired". We must be able to change objects and classes if needed also on-line e.g. during some exhaustive error recovery action.

Because we have used PC Prolog [Cen87] as high level programming tool it was natural to develop object system on Prologs database. We call our open object-oriented interactive database system CONSULT. Its role is central and it is used as well data transfer format between different programs as selfsufficient database system. The building block of the database is Prolog relation having three fields:

```
d(object, attribute, [arbitrary, long, value, list])
```

The first field tells us to what object this relation belongs. The second field gives the attribute and the third field is an arbitrarily long list of attribute values.

In external form relations are written one relation per line using only blanks as field or list item separators. Only first line contain object name and the object is terminated by an empty line:

```
object1 attribute1 value1 value2
attribute2 1 2 3
is robot~program                    -- reference to class

object2 attribute1 11 23
attribute2 no~value
is robot~program text               -- reference to two classes
history hfile.hst
sensors sense.ref
```

In external form database can be arranged into ordered tree format which saves both time and memory space. In external tree format there are also higher levels for chronological ordering and version management, which are important if we want to have adaptation and deductive reasoning from done tasks.

3.3 Robot programs

Object-oriented approach have several benefits when applied to robot commands. The first is that we can bind in principle whatever information to any command. There can be the usual command parameters like speed and linearity, but there can be also pointers to product model and component data as well as sensor and statistical information. A lesser benefit is that we can arrange commands in class hierarchies such as move, control flow, and arithmetics commands.

The fundamental idea of computer programming is to execute extremely simple operations over and over again in loops and recursive calls in order to achieve complex results. In robotic applications we have much less (high level) commands to execute per time unit than in ordinary computations, but it is much more important to be aware what command have caused what effects and when, if we hope to control the overall functioning of the robot system. This action-response relation presupposes unambiguous binding between commands executed, execution time, and sensor signal sampling.

There does not need to be any binding between process status data and commands not affecting the process but similar bindings could be used to fine tune the programs themselves if needed. This gives us e.g. possibility to program the system by giving a main program and set of possible exchangeable subprograms to solve subproblems. The system can fine tune itself adaptively by choosing the best solution subprograms according to observed behaviour.

In this object-oriented scheme robot application program is a sequence of commands executed once and one after another per task. The only exceptions are commands in branch structures of which only one selected sequence is ever executed. In assembly

application the lack of loops does not much complicate things simply because there does not exist much loops in them. In this respect the most prominent exception is paletizing but even paletizing loops tend to be quite limited.

3.4 Multiarm synchronization

It is nearly impossible to use two ordinary robots to work together. E.g. movement synchronization and collision avoidance are very difficult simply because the actual movements are complicated and difficult to predict accurately. In M^3 the structure is such that it makes it much simpler to coordinate two or more arm to work together by controlling the distance between the arms.

3.5 Hardware

The principle of hardware design has been to use a network of computers. The number of network nodes depends on the application complexity, degrees of freedom etc. The network consists of different type of computer like PCs and work stations. This means that we have flexibility and also freedom to choose always up to date hardware. It is not difficult to foresee that within a few years the cost of memories and CPUs allows us to use considerably more memory and processor capacity in computations. The real bottleneck will be the software: how to create simple but powerful control methods.

4 DISCUSSION and FUTURE

In this report we have represented a new gantry type modular and multiarm assembly cell design. The construction solves some of the problems encountered when working with usual assembly robots. The construction is modular and flexible and it cover a wide range of potential applications.

The control of the suggested robot cell is based on open object-oriented programming that gives freedom to bind whatever information to every robot command to aid adaptation, error detection and recovery.

The principle of design has been to try to resort to simple but general ideas and methods. In a way M^3 thinking tries to be a counterpart of the instruction set reduction thinking in processor design (RISC see e.g. [PS81]) where it has been proven to be a good idea to make the processor as simple as possible while keeping the instruction set as general and easy as possible.

The other key principle has been to emphasize the importance of careful product design. Even the best and most flexible assembly automaton has many troubles if the product design has totally neglect the assembly phase and its reasonable limitation.

The most significant limitations that M^3 presupposes on product design are:

- no complicated movements (rotational degrees of freedom)
- relatively flat products
- one natural assembly direction

The M^3 -project goes on as subprojects working with different assembly problems and applications. Much work is still left to be done and it is hoped that we could work in collaboration with other research institutes to solve remaining problems. At least all comments and suggestions concerning M^3 are most welcome.

References

[AAH+89] Jarmo T. Alander, Antti Autere, Harri Hakula, Jyrki Riikinsaari, and Juha Tuominen. Automatic wire harness fabrication system prototype. In *Proceedings of the 10th International Conference on Assembly Automation*, Kanazawa (Japan), 1989. The Japan Society of Precision Engineering.

[AAR89] Jarmo T. Alander, Antti Autere, and Jyrki Riikinsaari. Computer aided design of fabrication of a car wire harness. In *Proceedings of 20th International Symposium on Automotive Technology and Automation (ISATA)*, volume I, pages 629–643, Florence (Italy), 1989.

[AART89] Jarmo T. Alander, Antti Autere, Jyrki Riikinsaari, and Juha Tuominen. Automatic car wire harness fabrication system. In *Proceedings of 20th International Symposium on Automotive Technology and Automation (ISATA)*, volume II, pages 1631–1644, Florence (Italy), 1989.

[Ala88] J. T. Alander. Automatic design and assembly of fuse boards. In C. W. Burckhardt, editor, *Proceedings of the 18th I.S.I.R. International Symposium on Industrial Robots*, pages 157–168, Lausanne (Switzerland), 26. - 28. 4. 1988. International Federation of Robotics, IFS Publications.

[Ala90] J. T. Alander. Object-oriented adaptive signal processsing in robot control. In *Proceedings of the International Symposium on Signal Processing and its Applications (ISSPA 90)*, Gold Coast (Australia), 1990. (submitted to).

[Cen87] Prolog Development Center. *PC-Prolog version 3.0.* H. J. Holst Vej 5 A DK-2605 Brøndby, 1987.

[DMN68] O. Dahl, B. Myhrhaug, and K. Nygaard. *Simula 67 Common Base Language.* Norsk Regnesentral, Oslo, 1968.

[PS81] David A. Patterson and Carlo H. Séquin. RISC I: A Reduced Instruction Set Computer. *SIGARCH Newsletter*, 9(3):443–457, 1981.

[Str85] Bjarne Stroustrup. *The C++ Programming Language.* Addison-Wesley, Reading, 1985.

[TA88] J. Tuominen and J. T. Alander. A model based automatic design and assembly of cable bundles. In C. W. Burckhardt, editor, *Proceedings of the 18th I.S.I.R. International Symposium on Industrial Robots*, pages 353–364, Lausanne (Switzerland), 26. - 28. 4. 1988. International Federation of Robotics, IFS Publications.

SOME PROBLEMS CONNECTED WITH THE COMPUTER AIDED PLANNING OF MACHINING PROCESSES

Michał Andrzejewski, Grzegorz Gawlak
Technical University of Poznań
Institute of Mechanical Engineering
Piotrowo 3, 61-138 Poznań, POLAND

1. INTRODUCTION

In the Institute of Mechanical Engineering of the Technical University of Poznań a system of computer aided planning of machining processes has been elaborated. This system aims at:

a/ conversational processing aid of planning of real technological process of operations performed on conventional machine-tools under the conditions of small lot, lot and large-lot production by:
- automatic selection /with the possibility of modification by the production engineer/ of the normal cutting tools and cutting data,
- semi-automatic planning /with the possibility of modification/ of cuts and their sequence, machining allowances, on the basis of typical shapes of work surfaces and/or typical technological processes,
- fast making of technological proceses variants in ordes to optimize them,
- rapid updating of technological processes and standards;

b/ rationalization of operation of production preparation of technical and organizing services by:
- eliminating of routine production engineers activities,
- possibility of planning wear of cutting tools, energy consumption etc.,
- emition of technical documentation and different kinds of specifications;

c/ automatic calculation of operation time;

d/ creation and storage of a data base of products of the enterprise for technological-organizing preparation and production managing aims.

2. STRUCTURE OF THE SYSTEM

The structure of the system of computer aided planning of machining processes is shown in Fig.1. The system is composed of six blocks which are the reflection of the planning process and three additional blocks realizing automation of this

process.

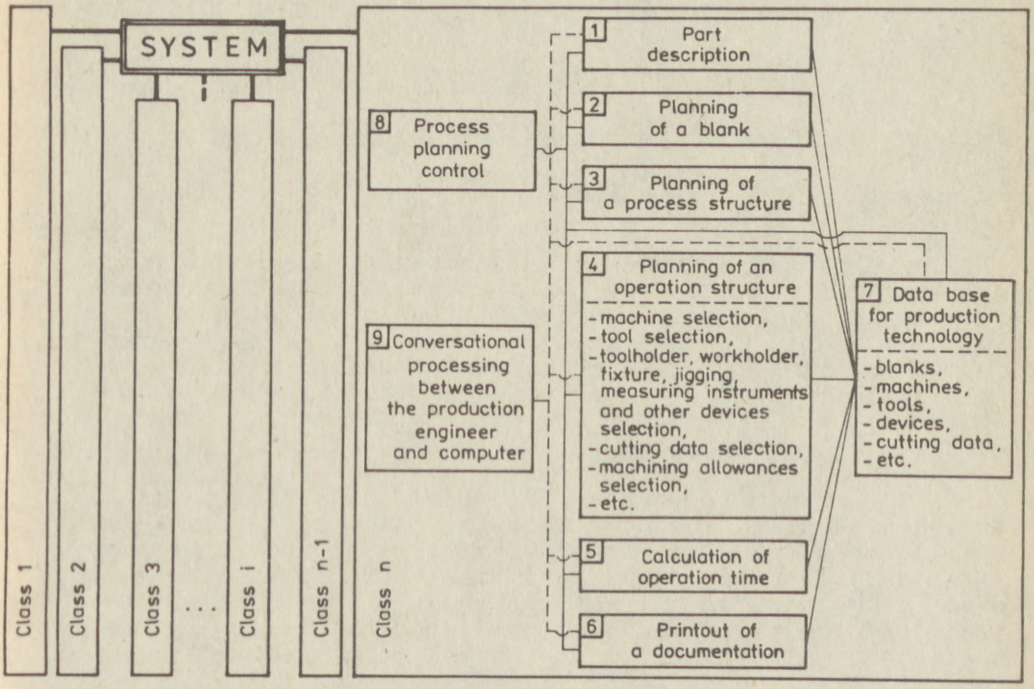


Fig.1. System of computer aided planning of machining processes

During the design of the system many characteristics, resulting from technical, economic and organizing requirements of its structure, practical application and use have been taking into account. They are as follows:

- modular structure,
- possibility of development /among others in the range of other technologies and realized functions/,
- adaptability /e.g. facility to adapt oneself to variable organizing-technical conditions of enterprises and to different hardware/,
- facility of service and maintenance,
- great utilization of typification, unification and standardization /in the range of system structure, e.g. data processing, program modules, codes, designations, process planning control as well as planning of technology on the basis of typical technological processes/.

Technical designes of particular modules foresee the most typical and universal solutions /of a high degree of repeatability in different enterprises/ for which modules of software are elaborated creating jointly the basic version

of the system. During practical application or exploitation the technical designes and basic software can be supplemented by modules realizing specific additional functions, designed according to the wish of the users.

3. STRUCTURE OF CONVERSATIONAL PROCESSING BETWEEN THE PRODUCTION ENGINEER AND COMPUTER

When elaborating the system one has concentrated first of all on man. As a computer has to serve him to obtain data and to help in performing his work. Suitable utilization of the computer by man depends on accessibility of the conversational processing language with the computer and on its intelligibility. The system to be effective, must be designed from outside to inside. Then, man ceases to play a secondary role but will be the one who decides about full utilization of the computer.

In the elaborated system the possibility of communication of the production engineer with the computer is foreseen. Because it seems right to ensure to the production engineer the possibility to interfere in the technological process, even in the case of automatic planning. Due to this, the production engineer can make the decision concerning the application of certain technological methods, used types of tools, division or joining of operations that is in all these cases for which it is difficult to define strictly a priori the principles and criteria of the selection. Thus, the system of planning becomes more elastic as well as can be better adapted to the local production conditions.

In the automatic planning of technology, conversational processing of the production engineer with the computer occurs:

- in particular design stages /steps/ on accepting the solutions generated by the computer,
- at the data input process,
- in initiating activities.

In the mentioned range, the structure of the conversational processing takes into account the following tasks:

- instruction of the production engineer concerning the activities which he should perform when working with the computer,
- presentation of the results of the realized planning by the computer in the form defined by the screen patterns,
- indication of data which the production engineer must introduce into the computer during the realization of the planning,
- indication of errors both of activities and of wrong data input,
- making it possible to select the variant of solution.

The following are included in the activities of the

production engineer at the computer aided planning of machining process:
- initiation of the system,
- coding of the part drawing,
- correction of errors according the indications of the computer,
- change in intermediate solutions,
- selection of solution,
- completion of input data,
- file maintenance.

Figure 2 shows the cycle of activities in the structure of conversational processing. In this processing three levels are distinguished:

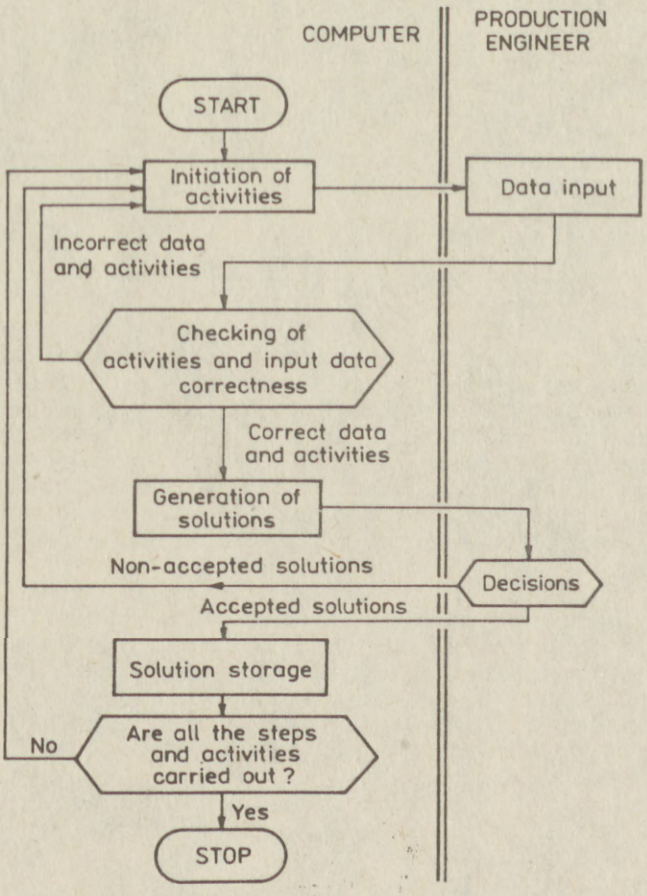


Fig.2. Structure of conversational processing between the production engineer and computer

a/ the first level /internal loop/ includes initiation of activities, data input, checking of correctness of activities and of introduced data realized in this loop;
b/ the second level /middle loop/ includes the generation of solutions realised on the first level as well as the making of the decision by the production engineer about the acceptance of or change in the generated solutions. Non-acceptance of the generated solution causes passage on the first level and the starting of the cycle once again;
c/ the third level /external loop/ includes storage of accepted solutions, checking if the solution of the whole partial task, determined in the given planning step as well as the performance of all the task, has followed. If the partial task for the given step as well as for all the steps in the whole task have been performed, then passage into the first level and starting again of the cycle for the next partial task follows.

The degree and place of the production engineer´s interference in the computer aided planning can be various. The participation of this interference will diminish together with the better and better knowledge of dependences and principles managing the process.

4. METHOD OF PART DESCRIPTION

Until now a uniform universal symbolic language has not been elaborated to describe geometrical-dimensional characteristics of an arbitrary workpiece. Hence a considerable number of different coding systems and languages also occurs and from them only a part has found a practical application in planning of technology. Therefore in the Institute of Mechanical Engineering a new method of part description, utilizing data occurring in the synthetic representative of the given class of workpieces, has been elaborated.

During the planning of the technological process, the workpiece is presented in the form of a constructional drawing and technical conditions written in the form of conventional graphical symbols and alphanumeric signs. The drawing informations can be divided into: drawing identifying data /I/, special instructions /S/, material of the workpiece and its heat treatment /M/ as well as geometrical and physical characteristics /G/.

The drawing shows the technical conditions which the part must fulfil after machining that is if describes the final state of the product. On denoting this state by S_p it can be written in the form:

$$S_p = \{I, S, M, G\}.$$

The following conditions dictate the way of presenting state S_p of the workpiece:

- formalization of geometrical properties of the workpiece in

the language of input data must connect univocally the constructional form of the workpiece with the elements of methods and ways of machining included in the space of technological solutions;
- on the basis of this language, the written construction of an arbitrary workpiece must make the automatic planning of the defined fragments of the technological process possible;
- language should be easy to accept by the production engineer and allow to discern the workpiece and to generate the solutions of the production engineer during the conversation with the computer.

The synthetic representative, expressed by the set of constructional elements CE_i as well as characteristics M and S describing the given class C_j of parts, is the starting point when formulating the procedures of automatic planning of process and operations structures. The constructional elements, describing the synthetic representative, are simultaneously elements of language E_i, serving to code the workpiece construction.

Figure 3 shows a scheme of creation of language describing the synthetic representative. The set C of parts has been divided into classes C_j of parts. For each class C_j on the basis of a classifier of shape elements from set E_i a synthetic representative has been elaborated. Language E_i, describing this representative, contains data shown in Fig.4. Informations expressing separate constructional elements of the synthetic representative has been grouped in data blocks. A data block includes a group of elementary informations, describing a given constructional element, logically connected with each other. In the description of the synthetic representative the following data blocks have been distinguisned /Fig.4/:
- data identifying the class of parts /I_C/,
- data identifying the drawing: type of product /IT/, drawing number /ID/, name /IN/, number of pieces per product /IP/,
- material of workpiece, heat and surface treatment /M/: grade of material /MG/, heat treatment /MH/ characterized by type of treatment /MHT/, location of treatment /MHL/, range of treatment /MHR/, hardness /MHH/, type of blank /MB/ etc.,
- special instruction concerning construction /S/: general conditions /SG/, general roughness /SGR/, product marking /SGM/, worpiece finishing /SGF/, characteristic of special features of workpiece /SF/,
- geometrical features of workpiece /G/ expressed successively for particular shape elements /CE_i/ together with the location in space /XE_i/ as well as the conditions of element run-out /RE_i/, Each element is described by data set identifying the type of surface /CET_j/, its dimensions /CED_j/, dimension tolerance /CEO_j/, shape tolerance /CES_j/, run-out conditions /CEC_j/ and special conditions /CEW_j/.

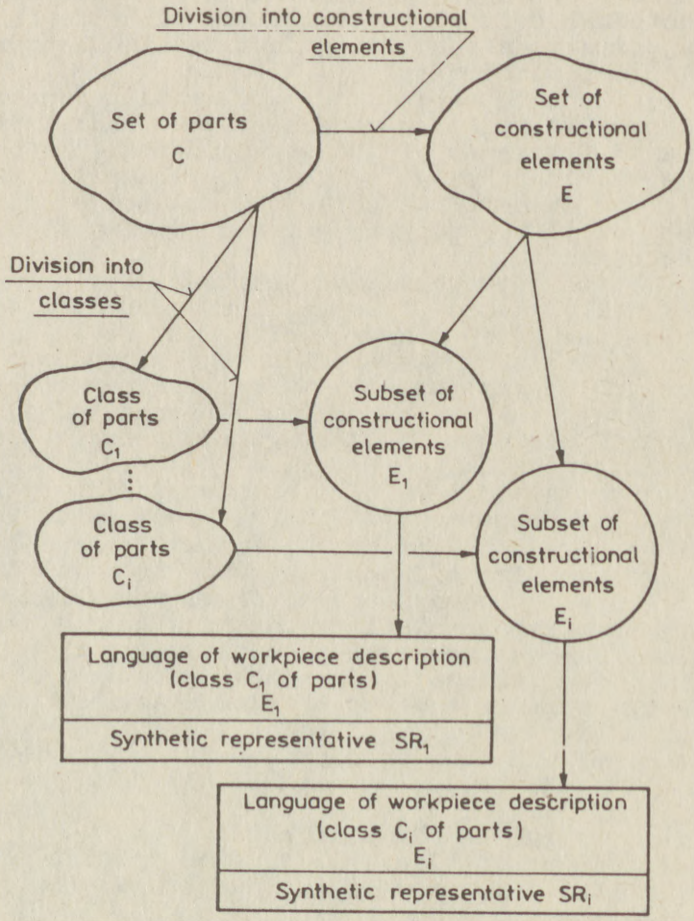


Fig.3. Scheme of creation of workpiece description language

The set of informations, describing elementary constructional characteristics, grouped in blocks, create the language serving to code the workpiece construction in the system of the computer aided planning of machining processes. It serves to describe workpieces belonging to the given class C_i parts and it is also the output in relation to which automatic planning procedures are defined.

On the basis of the presented conception of the language of part description a conversational system of coding workpiece has been elaborated. The conversational processing is initiated by the computer. Data describing state S_p occur successively on the display screen. Data, concerning

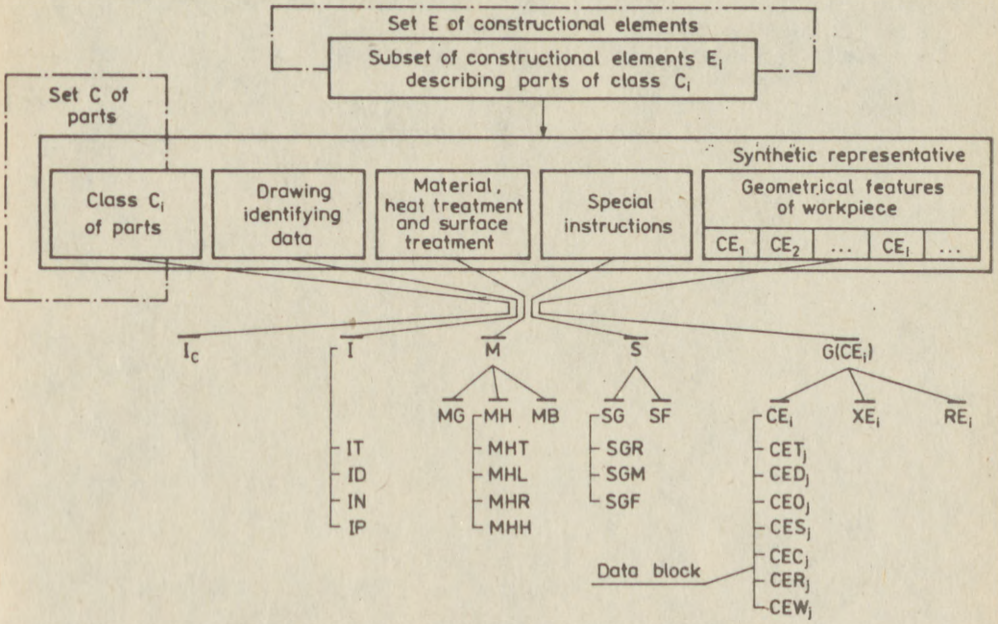


Fig.4. Information content of language E_i describing the class C_i of parts

constructional elements CE_i, are presented in a graphical form together with necessary dimensional data. The production engineer has only introduce informations required by the computer.

5. CONCLUSIONS

Owing to the application of computers to plan machining processes, the way of production engineers work changes completely. The task of the production engineer in a production plant will depend first of all on improvement of technological operations, new solutions of technological instrumentation as well as on enriching the exploited system in new solutions. That is why the activity of the production engineer performed so far is subjected to a change. The work he has been doing up to the present depended on making the same often repeated technological documents and different specifications.

The application of the computers shortens the time of the machining process planning and calculation the operation time as well as it improves the organization of process planning and the quality of technology by:

- possibility of utilizing typical technological processes,
- possibility of an easy and fast creation and selection of a process variant,
- automatic control of input data as well as information on errors,
- storage and improvement of technological knowledge of the enterprise in the sets of the system.

KLEINE FLEXIBLE FERTIGUNGSSYSTEME - TECHNIK, ZUVERLÄSSIGKEIT UND EFFEKTIVITÄT

Prof. Dr. sc. P. ARNDT, Wismar, DDR
Prof. Dr. G. MÜLLER, Wismar, DDR
Prof. Dr. sc. H.-J. RICHTER, Wismar, DDR

0. Einleitung

Die Euphorie zur Entwicklung und zum Bau großer Fertigungssysteme ist in den letzten Jahren spürbar gedämpft worden; als Gründe sind zu nennen:

- jedes Fertigungssystem ist an ein Teilesortiment angepaßt, und andere ähnliche Sortimente sind nicht (ohne weiteres) ebenso bearbeitbar,
- jedes Fertigungssystem ist an das vorhandene Organisationssystem eines Unternehmens angepaßt, und nicht (ohne weiteres) ist die Anpassung an andere Unternehmen vergleichbar,
- Fertigungssysteme sind außerordentlich teuer, sie können nur schrittweise akkumuliert werden und
- Fertigungssysteme sind wegen Überdimensionierung bzw. betriebsorganisatorischer Mängel oft nicht ausgelastet.

Aus den genannten Gründen fällt der Entscheid oft zu Gunsten kleinerer Systeme, zu Fertigungszellen, die bezüglich Werkstück- und Informationsfluß verbunden sind. Dazu sollen auch konkrete Aussagen zu Zuverlässigkeit, Verfügbarkeit und Effektivität gemacht werden.

1. Gestaltungsvarianten

Für ein konkretes Teilesortiment war ein Fertigungssystem zum Drehen zu projektieren mit folgenden Grunddaten bzw. -forderungen

- Stückzahlen zwischen 600 und 5200,
- Stückzeiten zwischen 10 und 31 min,
- Ablängen und Zentrieren sind räumlich einzubeziehen,
- der Teiletransport erfolgt geordnet auf Flachpalette,

- besondere Beachtung von Havariesituationen und
- Nutzung vorhandener Technik.

Für die Gesamtlösung wurden eingesetzt Drehzellen, bestehend aus Drehmaschine 16 K 20 mit CNC-Steuerung und Industrieroboter M 20 P 40 mit Steuerung Kontur 1 und einer Abläng- und Zentriermaschine FZWD 160 x 1000.

1. Variante - Bild 1

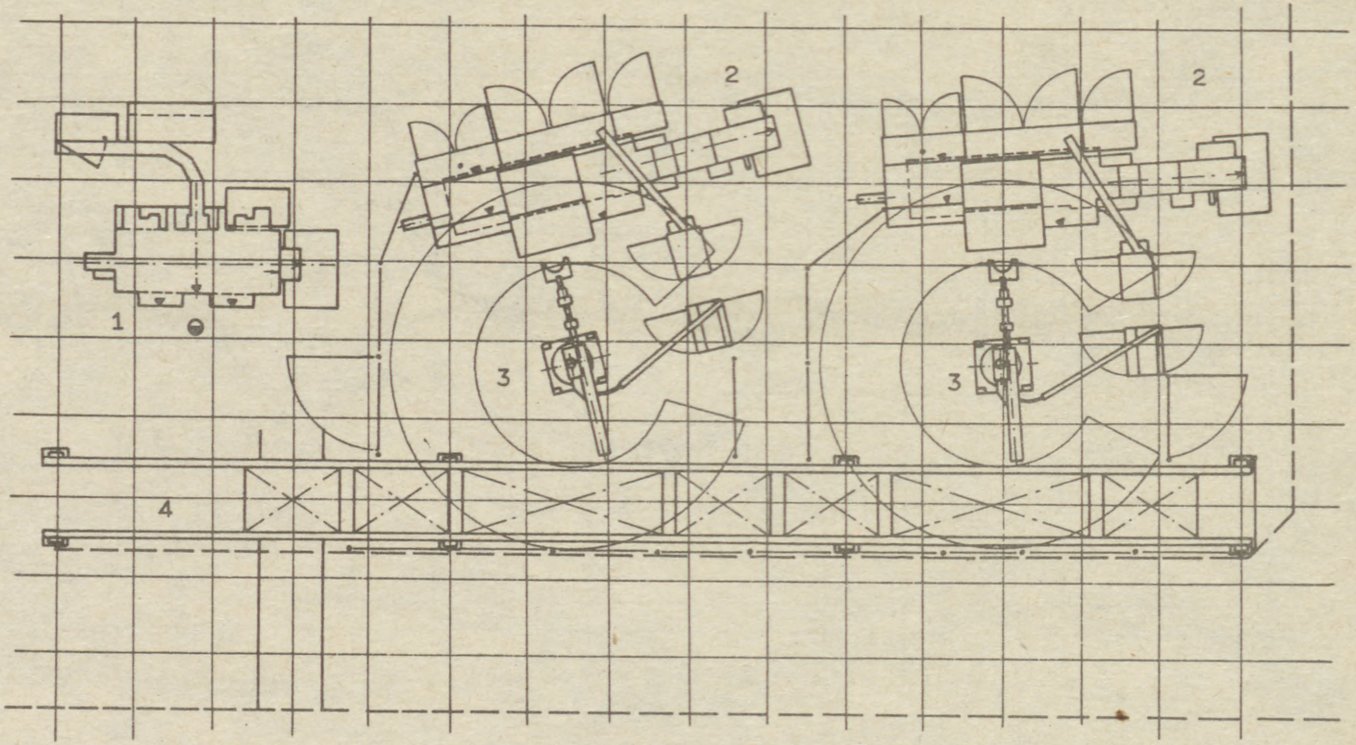
Die Maschinenaufstellung erfolgt in Reihe, wobei insbesondere auf Demontagemöglichkeiten bei den Drehmaschinen geachtet wurde. Die Abläng- und Zentriermaschine bleibt im Gegensatz zu den Drehmaschinen handbedient (Kosten), Dominanz besitzt ein Linienportal zur Verkettung. Die eingesetzten Flachpaletten werden vor den Robotern getaktet. Zufuhr der Teile zum Linienportal und zur Abläng- und Zentriermaschine erfolgt per Gabelstapler. Da das Portal ohnehin nicht ausgelastet ist, kann das Takten der Palette das Portal selbst vornehmen.

2. Variante - Bild 2

Die Maschinen sind annähernd achssenkrecht zum Portal angeordnet, die Roboter entnehmen die Werkstücke wiederum von getakteten Paletten. Eine solche Aufstellung garantiert gute Wartung und Pflege, die Späneentsorgung ist ebenfalls vorteilhaft lösbar. Dagegen ist der Werkstückfluß vom/zum Manipulator per Gabelstapler ungünstiger.

3. Variante - Bild 3

Die Maschinen sind achsparallel zum Portal angeordnet, dabei sind aber die Drehmaschinen zueinander versetzt, weil so der Zugang zum Entsorgen besser gelöst ist. Durch die Achsparallelität sind jedoch bei Versatz die Abstände zum Portal unterschiedlich, das führt im Fall der linken Drehmaschine zur Verlängerung des Roboterarms und bei der rechten Maschine zu geringfügigen Änderungen an der Arbeitsraumtür. Bei engem Transportweg ist - wie bei Variante 1 - ein Gabelstapler mit seitlicher Beschickung notwendig, oder aber die Ein-/Ausgabestation wird schwenkbar gestaltet, so daß eine Front-



1 FZWD 160 x 1000
2 16 K 20
3 M 20 P 40
4 Linearmanipulator

Bild 1: Anordnungsvariante 1

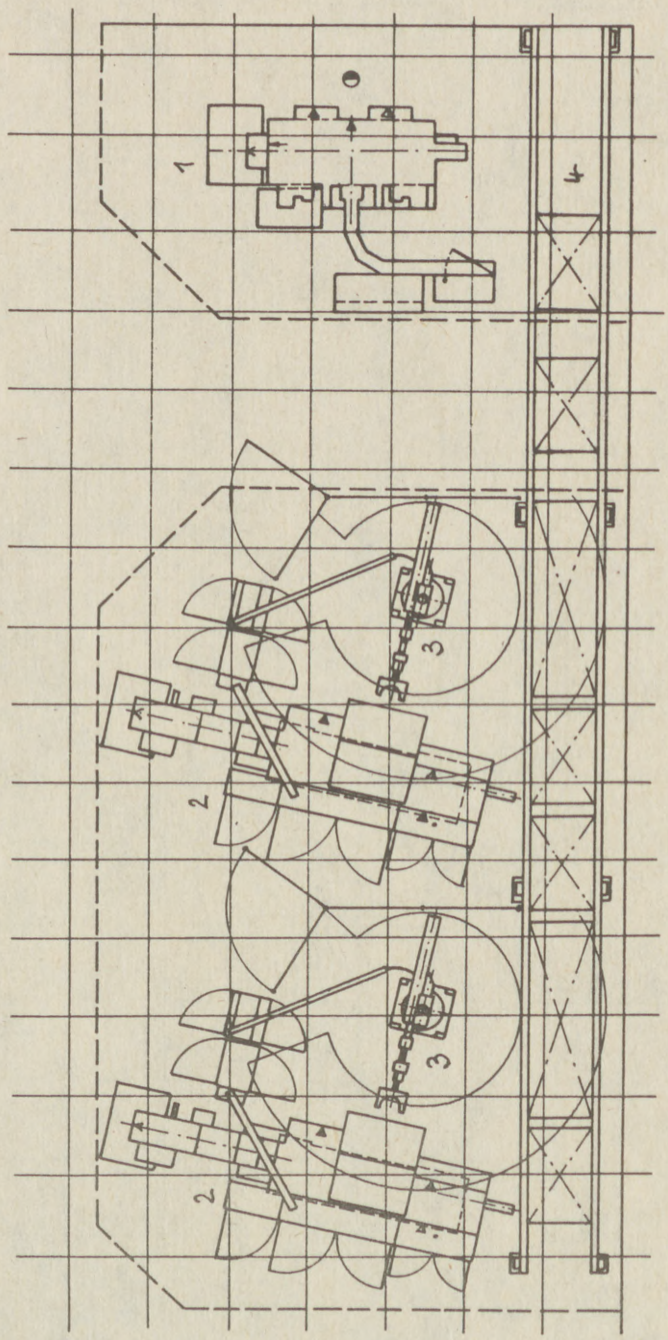


Bild 2: Anordnungsvariante 2

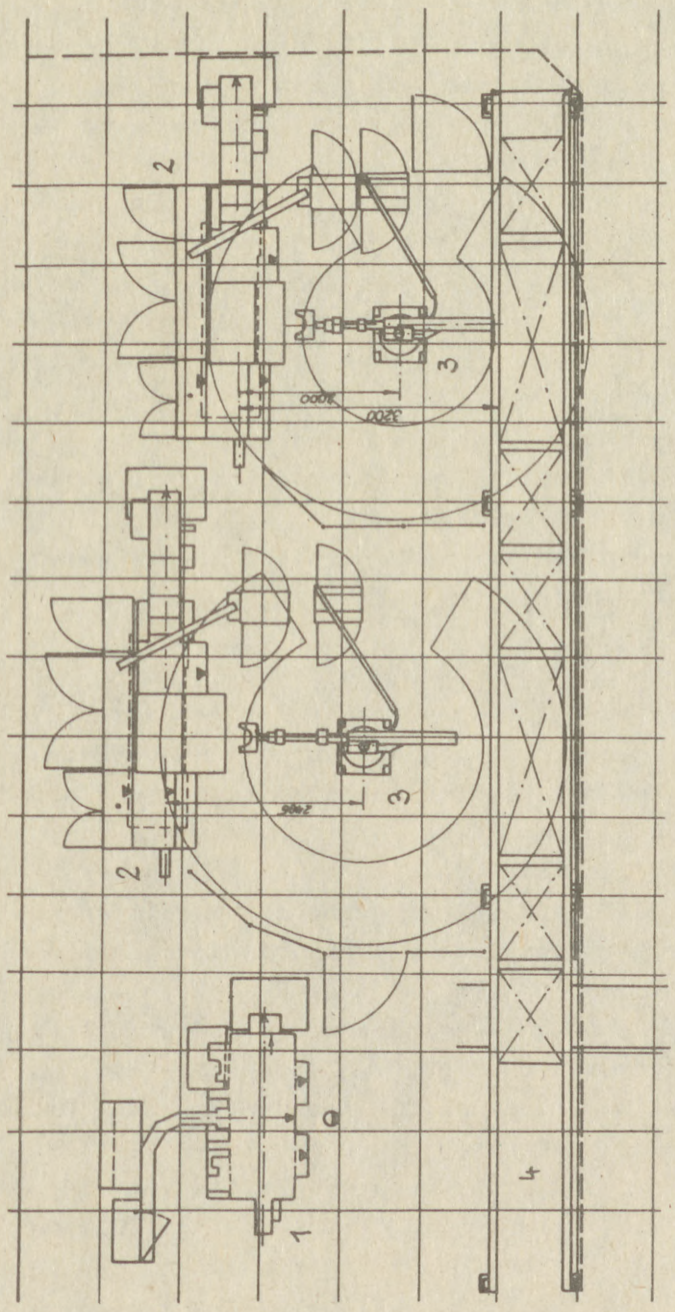


Bild 3: Anordnungsvariante 3

beschickung möglich ist.

Bewertung

Als Optimum wurde Variante 3 ausgewählt - die Gründe können hier nicht im einzelnen angegeben werden. Ein Grund zur Auswahl war die gute Zugänglichkeit des Linienportals. Dieses Portal übernimmt die Verteilung der angelieferten Flachpaletten zu den Drehmaschinen, die Anlieferung erfolgt in stapelbaren Flachpaletten. Das Portal übernimmt ebenfalls das Takten der Flachpaletten vor den beiden Robotern. Die Ablänge- und Zentriermaschine bleibt handbedient, eine Automatisierung ist wegen der nicht ausreichenden Nutzung (27 %) unökonomisch.
Das Linienportal wurde als Eigenbau realisiert, ebenso das System der Flachpaletten. Die konzipierten Werte

- 330 min Arbeitszeitgewinn und
- 60 min bedienfreies Arbeiten (zumindestens)

konnten erreicht werden.

2. Aussagen zur Zuverlässigkeit

Hinter dem Wort Zuverlässigkeit für Produkte (z. B. Werkzeugmaschinen und Fertigungssysteme) und Fertigungsprozesse verbergen sich verschiedene Definitionen und Kennzahlen mit unterschiedlichem Inhalt /1/ . Zuverlässigkeit und Zuverlässigkeitsarbeit sind zu einem entscheidenden Bestandteil der Qualitätsbewertung und der Qualitätsarbeit geworden. Nicht nur der Preis und die erforderlichen Investitionsaufwendungen sind für den Kauf von Produkten wichtig, sondern immer mehr erwartet der Abnehmer bzw. Nutzer Aussagen zur Zuverlässigkeit von Produkten vom Hersteller, sie haben einen hohen Stellenwert im Wettbewerb der Betriebe und Unternehmen. Trotz dieser großen Bedeutung der Zuverlässigkeit kann man feststellen, daß die Zuverlässigkeitsarbeit gegenwärtig noch nicht den ihr gebührenden Platz einnimmt. Bei dem Einsatz von Einzelautomaten, NC-Maschinen usw. in den 70-er Jahren wurde auf dem Gebiet wesentlich mehr getan als bei dem Einsatz von Fertigungssystemen in den 80-er Jahren. Sicherlich

sind solche Aussagen anhand von konkreten Kennzahlen für Fertigungssysteme schwieriger als für Einzelmaschinen, aber von ihrer Wirkung für die Effektivität der Produktion fallen sie wesentlich mehr ins Gewicht. Nicht zuletzt besteht der Mangel von großen Fertigungssystemen darin, daß sie nicht zuverlässig genug sind, daß u. a. ihre Verfügbarkeit zu gering ist.
Der internationale Trend zur Entwicklung und zum Einsatz kleiner flexibler Fertigungssysteme, wie sie unter 1. behandelt sind, bringt auch eine bessere Beherrschung der Zuverlässigkeit mit sich. Kleinere Funktionsketten arbeiten mit einer höheren Zuverlässigkeit, wenn die einzelnen Elemente dementsprechend gestaltet sind. Eine hohe Dauerverfügbarkeit (V_D) der Fertigungssysteme wird durch hohe Zuverlässigkeitswerte der Einzelelemente erreicht. Bekannt ist, daß hierfür bestimmte Systemreserven erforderlich sind (z. B. durch eine entsprechende Dimensionierung), derenwirtschaftliche Grenzen man ermitteln muß. Ansonsten wird die Zuverlässigkeit teuer erkauft bzw. die Effektivität des Systems ist nicht gegeben.
Das Ziel für die Dauerverfügbarkeit von kleinen flexiblen Fertigungssystemen liegt bei 85 bis 90 %, wenn auch teilweise bereits von 95 % gesprochen wird (in der Regel wurden 95 % zu teuer erkauft). Obwohl es zur planmäßig vorbeugenden Instandhaltung (PVI) unterschiedliche Auffassungen gibt, wurde diese Zielstellung am besten bei konsequenter PVI erreicht.
Die Zuverlässigkeitsarbeit erfordert:

- zuverlässigkeitsorientierte Entwicklung und Konstruktion der Fertigungssysteme
- sorgfältige technologische Vorbereitung der Produktion
- hohe Disziplin bei der Organisation der Produktion; Beherrschung der Logistik
- sorgfältig vorbereitete und durchgeführte Prozeß- und Systemanalysen
- ein entsprechendes Qualitätssicherungssystem.

3. Bemerkungen zur Effektivität

Der Automatisierung sind technisch-technologisch kaum Grenzen gesetzt. Ein grundlegendes Problem ist vielmehr die relative Ungewißheit ihrer Ökonomie. Deshalb treten nach einer gewissen Euphorie immer mehr die Fragen der Effektivität der Vorbereitung und des Betriebes in den Mittelpunkt des Interesses. Die hohen Investitionsaufwendungen sind langfristig gesehen nicht mehr mit der Gewinnung von Erfahrungen zu rechtfertigen. Auch hier muß das einfache kaufmännische Prinzip verwirklicht werden, daß die Ausgaben durch die Einnahmen zu decken und ein angemessener Gewinn zu erzielen ist. Die Durchsetzung des Primates der Ökonomie gegenüber der Technik wird zudem mit jeder Ausbaustufe in Richtung rechnerintegrierter Betrieb immer zwingender. Aufwand und Nutzen müssen austariert werden. Das ist stets mit einer komplexen Bewertung verbunden. Die Prozeßwirtschaftlichkeit muß unter Berücksichtigung aller beteiligten Funktionen betrachtet werden.

Die Komplexität von alternativen Fertigungskonzepten der flexiblen Automatisierung erfordert sowohl die monetär erfaßbaren Kriterien als auch die nicht bzw. schwer quantifizierbaren Wirkungen in die Wirtschaftlichkeitsbetrachtungen einzubeziehen. Das ist unbestritten mit den herkömmlichen Bewertungsverfahren nicht möglich. Das mit der Bewertung flexibler Fertigungssysteme im Zusammenhang stehende Bewertungsproblem muß den Kompromiß einschließen, daß das nicht allein auf Berechnungen schlechthin beruhen kann. Selbstverständlich sind Berechnungen erforderlich, und zwar als Hilfsmittel, das dem relativen Vergleich von Alternativen für eine prinzipielle Lösung dient.

Qualitative Analysen, zum Beispiel im Sinne von Wertanalysen, sind notwendig. Systembezogen werden den einzelnen Bewertungskriterien ein entsprechender Erfüllungswert zugeordnet, mit dem jeweiligen Wichtungsfaktor multipliziert und zu einem Systemwert aufsummiert.

Insbesondere für Erzeugnisoptimierungen sind CAD-Lösungen

sowie Simulations- und Dimensionierungsrechnungen von hohem Stellenwert. Mit Hilfe rechnerunterstützter Methoden nach den Grundsätzen der Wertanalyse automatisierungsgerecht gestaltete Werkstücke bedürfen somit eines wesentlich geringeren Material- und Bearbeitungsaufwandes. Die Differenz zwischen konventionell systemgerecht ausgelegten Werkstücken beträgt zum Beispiel bei einem flexiblen Fertigungssystem zur Bearbeitung prismatischer Teile 41 Prozent.
Die ökonomische Ergiebigkeit flexibler Fertigungssysteme hängt vor allem davon ab, wie es gelingt, den personalarmen Betrieb durchzusetzen, die Voraussetzungen für eine loszwangfreie Bearbeitung in den vorgelagerten Prozessen zu schaffen und die Vorteile der loszwangfreien Fertigung in den Systemfolgeprozessen zu nutzen. Es muß erreicht werden, die Gesamtdurchlaufzeit des Finalerzeugnisses von der Auftragserteilung bis zum Absatz zu verkürzen. Die Effektivität muß durch die Erhöhung der Flexibilität der eingesetzten Produktionsmittel gesichert werden. Eine kurze Bearbeitungszeit und Liefertätigkeit sind ein Beweis dafür, daß eine kunden- bzw. anwendergerechte Erzeugnis- und Prozeßanpassung erreicht und in Verkaufsvorteile umgesetzt wurden. Die Erfahrungen besagen, daß etwa vier Fünftel des Effektivitätszuwachses aus dem Gewinn durch Mehrproduktion resultieren.
International ist erkennbar, daß flexible Automatisierungslösungen langfristig eine Kostensenkung um ein Drittel ermöglicht. Gegenwärtig sind davon etwa 50 Prozent realisierbar. Zu beachten ist in diesem Zusammenhang auch, daß der gesamte Realisierungseffekt ebenfalls nur zu zirka 50 Prozent im unmittelbaren Anwendungsbereich der Technologie liegt. Der andere Teil wird erst durch die Automatisierung auf der Grundlage abgrenzbarer autonomer Struktureinheiten, das heißt dem schrittweisen, aufwärtskompatiblen Übergang zur rechnerintegrierten automatisierten Produktion erreicht.

4. Literatur

/1/ Lexikon Technologie (Herausgeber: Müller, G.)
Verlag Europa-Lehrmittel, Haan-Gruiten, 1989

INDUSTRIAL ROBOT - MACHINE TOOL LINKS

(Theoretical and practical results of research at Department of Manufacturing Engineering , Technical University of Budapest)

Dr G. Arz, Dr A. Lipoth, Dr I. Merksz
Dept. of Manuf. Engineering
Technical University of Budapest
H-1502 Budapest, Pf.91
Hungary

Using the industrial robots at machine tools for material handling purposes was a necessary step in flexible automation and triggered a process characterized by the ever increasing role of the industrial robots on one hand, and by the mutual influence of the robot and machine tool design on the other hand. This paper analyses some aspects of this process based on the research at the Dept. of Manuf. Technology and the experience gained developing flexible manufacturing cells. It can be considered as part of an educational material on this subject.

General aspects of the robot - machine tool link.

The most obvious condition of establishing a link between an industrial robot (IR) and a chip making machine tool (MT) is the possibility of placing the MT to the workspace of the IR, so the IR could accomplish its material handling and other tasks with optimal movements, and at the same time the IR-MT unit - let's call it flexible manufacturing cell - could be in contact with its environment, as a part of the material flow of a greater system. (We call it flexible manufacturing system) In this respect there are many different IR-MT layout variations for different IR-s with different workspace (arm system). [1],[2]

If we take a closer look at the different layouts, we can state:

- At the simplest case the workspace of the IR contains the MT (or part of it where the work piece must be placed-MTW) and the work piece storage/transport unit - ST (Fig. 1.a) (or part of it where the work piece can be taken from) (Fig. 1.b) (This case the ST must be able to transport the work piece into the workspace of the IR /active store/).

The Fig. 2 illustrates the fact that a cylindrical type IR

must be able to align its wrist according to the position of the MT within the workspace of the IR.

- The type of solution seen in Fig. 3 is common by gear cutting machines. Here a transfer unit (TU) helps to realize the MT-IR link (see Fig. 3). The TU brings the work piece into the difficult to reach MTW by a single degree of freedom movement.
- The portal type IR is common by lathes. Fig. 4. explains that the whole workspace of the IR can be used practically without loss and the place requirement of the IR is scarcely greater than its workspace. The vertical movement necessary for loading unloading and palletizing (Fig. 5) is the easiest to realize by portal type IR . Simultaneously this solution obstructs the least the free access to the MT (A).

(The link of IR-MT in the control field is mostly defined by standards both in hw and sw and we don't discuss this topic here.)

We should like to point out the achievements of the computer simulation. A lot of work and money can be saved by using the 3D simulation with systems available in Hungary.

The effect of robotized material handling produced on the morphology of machine tools

The design of MT especially the placement of the work piece holding fixtures is even nowadays anthropomorphic. It is based on the assumption that the work piece change is done or controlled by (using crane) the human operator. It is taken granted that the operator makes all the functions related to the work piece handling e.g. opening/closing the chuck, moving the cover and the tailstock etc. This feature is especially conspicuous by lathes. (This is emphasized by the fact that most of the MT-s served by IR are lathes.)

To secure a good link between an IR and lathe the basic requirement is the proper design of the workspace of the lathe, to allow enough space for the rather clumsy - sometimes double - hand of the robot.

The optimal direction of material supply at slant bed lathes is vertical (Fig. 6) therefore the proper material handling device is the portal robot. It is always necessary to increase the distance between the chuck and tailstock /

chuck and slide.

The automatic control of cover and tailstock movement is needed in contrast to the "conventional" CNC lathes.

To increase the security of operation a process monitoring system gives the following information independent of the CNC:

- state of the main spindle (stationary - rotating)
- position of the chuck (open - closed)
- the gripping force of the chuck
- the position of the cover and tailstock and
- the distant position of the slide.

The influence of the robotized material handling to the milling machine and machining center bears a similar character to that of lathes:

- the hand of IR with work piece must have adequate space within the MTW
- a controlled fixture is needed with facilities helping the loading of the work piece
- automatic door on cover

If we consider the tool changer of the machining center or turning center as IR, than it makes the first example of IR-MT integration. The robot - machine connection can be traced in several phases:

- robot mounted on MT (especially in portal style)
- the robotized material handling within the MT (in a double spindle machine the gripper on the revolver head moves the work piece between the spindles)
- machining robots.

<u>The work holding fixture as mechanical interface of the industrial robot - metal cutting machine tool link.</u>

The commonest role of the IR in a flexible manufacturing cell is the work piece handling. This is achieved by the cooperation of the work holding fixture of the MT and the work holding end effector (hand) of the IR. The exactness and reliability of the work piece transfer is very important. It can't be achieved easily especially at horizontal main spindle (lathe) where the force of weight doesn't help. It is not accidental that the vertical spindle can be seen at precision lathes.

We have realized that using a so called pushing device the reliability of the process and the exactness of work position improved considerably. [3]

One of the bottleneck of the system flexibility is the range of chuck/gripper movement. Especially the lack of automatic reliable and exact chucks in the large diameter range causes problem. The various solutions for changing the chuck faces (Berg, Forkhardt etc.) are considered very expensive and complicated.

As far as the flexibility of the IR hand is concerned, it can be secured more easily because of the inherently bigger range, the double hand arrangement and simpler hand/face change.

We can only refer to the control tasks of the transfer process. (sensing the presence of the work piece and the gripping force etc.) [4]

The transfer of work pieces with very high precision constitutes a special task. Analyzing this problem at the design of a ultraprecise turning cell based on the ULTRATURN-UP1 lathe of Csepel Machine Tool Factory (Hungary) we found the following possible solutions [5]:

As usual the work piece can be hold directly and indirectly both in the lathe and IR. (Fig 7)

We consider the following rules very important for choosing the basis surfaces:

- the bases for the lathe and IR mustn't be identical
- avoid using surface with ultraprecise machining as basis for handling if it is possible
- the gripping force of chuck/robot hand mustn't cause greater deformation than the allowed error of form and mustn't deteriorate the surface quality
- prefer the form lock to the force lock by fixing the work piece

The indirect method of holding the work piece can help a lot but we must consider the disadvantages:

- the work holding pallet increases the overhang, the mass and therefore the load of the main spindle
- the indirect member has a detrimental effect on the accuracy

- fixing the work piece to the pallet is a manual operation and can cause deformation
- the pallet is a cost factor

There is an essential difference between manipulating the disks and shafts therefore we discuss them separately.
- By disks the robot hand can be the simplified version of the chuck (Fig. 8)
- Only the shafts not requiring a tailstock support can be machined on this lathe. They can be fixed by a three face pneumatic chuck or a pallet having a base for the vacuum disk on the lathe spindle. (Fig. 9)

Turning the work piece on the pallet is to be solved. The manipulation can be accomplished in proper position (both by hand or by robot) but the second time position of the pallet on the main spindle can not match the accuracy requirements.

The only possible solution seems to be avoiding the change of basis. We must accept that the ultraprecise quality can be secured by work pieces manufactured in one clamping, and this aspect must be observed by designing the key part of any precision device.

The role of auxiliary equipments at the IR - MT link

The properly designed auxiliary equipments - work piece storing or tool storing devices - can influence the type and productivity of IR. The so called active stores when performing the palletizing motions allow the usage of a simpler type IR.

The reliability of positioning the flexibility the modular inexpensive and light structure the easy access to the work piece and the sensing of presence are the most important aspects of the selection process for the optimal solution. [6] It was an interesting experience that a plane having having short vertical rubber studs in short distance (about 5 mm) can hold pieces on it excellently. (It was an ordinary door-mat.)

The disk type pieces must be machined usually on both sides therefore a separate turning device is needed if the IR is unable to perform this task. (Having a push rod for example) The automatic turning devices can work alone or they need some help from the IR. Tradeoffs can be reached considering the advantages of the push rod and the disadvantages of the turning device - place requirement,

price and time loss. There is an interesting solution used mainly in East Germany where the push rod is fixed to the slide of the lathe.

The increasing role of the IR attending the MT

The development of the CNC machine tools, the appearance of new types e.g. turning centers, the high cost of pallets, the increased quantity of tools necessary for automatic operation and the need for system diagnostics open new fields for the IR. [7]

- tool change (in the main spindle, tool magazine and revolver head)
- assembly and setting of the flexible fixtures
- chip disposal, cleaning of the workpiece
- moving and operating the measuring devices
- moving the sensor equipment for system diagnostics (CCD camera, vibration sensor, microphone)

It is evident that the robot can cope with these new tasks only if they are formulated taking into account the constraints of a robot. It must be able to grasp the objects to move e.g. work piece, tool, measuring equipment, etc. and last but not least the machine tool is designed for the robot. (workspace, cover opening, control etc.)

This changing role has its effect on the robot itself:
It is characterized by multi-degree of freedom arm system, automatic gripper change, quick nonlinear positioning servo control combined with highly reliable sensory, control and self-diagnostic system and easy programmability.
"If we want a machine tool to be self-supporting, self-configuring it must have a very dexterous manipulator." [8]

Problems and plans of the Department of Manufacturing Engineering Budapest Technical University

At the present moment we are working on the realization of two flexible manufacturing cells. The one is the ultraprecision turning cell mentioned earlier, sponsored by the Agency for Technical Development, and the other is the machining cell forming a part of the CIM pilot system of BTU sponsored by the Ministry for Industry.

We end this paper giving short information on these cells.

- Solving the robotics material handling for the ULTRATURN lathe we mentioned earlier is an unknown problem even abroad. To select the proper robot and to analyze the machine - robot link, animated system models were used, made by the CAD software KTR developed in the Institute of Machine Structures at our University. The phase pictures of the computer animation help to create the phase diagram by determining the characteristic positions in space, securing the collision free movements and combining the elements of the robot movement in proper order. The components of the system are in the laboratory and the system integration has started.

- The material transfer system of the machining cell (Fig. 10) within our CIM pilot system has special features. The cell consists of a CNC lathe (a) and a horizontal spindle machining center. (b) The different tasks of manipulating shafts on one hand and disks and prismatic pieces on the other hand are divided between two robots (c d). (Fig. 11) The portal robot transports the shafts to the lathe. Material gets from the lathe to the machining center trough: portal robot (c) storage (e) robocar (f) buffer (g) cylindrical robot (d) machining center (b).

The cylindrical robot (d) transports the disks to the lathe. Then the way of the material: system store, robocar (f) buffer (g) robot (d) lathe (a) robot (d) storage (g) or directly the machining center (b).

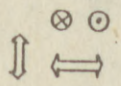
Machining the prismatic pieces the material reaches the machining center through: system store, robocar (f) buffer (g) robot (d) machining center (b).

There is a just question: why does two robots do the tasks? The answer: we had all the machines except the portal robot prior to the development. With two robots we made three cells: one for turning shafts, the second for turning disks and the third for machining prismatic parts. At the same time solving the communication problem between one lathe and two robots, manipulating prismatic parts without pallet, developing a robot hand capable of holding disk shaft and prismatic parts are new results which can be exploited in the industry.

The CIM pilot system is under construction.

F I G U R E S

Abbreviations used on the figures
ST : storage/transport unit
IR : industrial robot
MTW : machine tool workspace
TU : transfer unit
TTU : transfer and turning unit
O : operator



movements of the IR within the MTW



movements of the ST

References :

[1] Hartley,I : FMS at work
IFS Ltd. North Holland (Amsterdam), 1984
[2] Zachav,H; Buschbek,H; Helm,W : Einsatz von Industrieroboter
VEB VIg.Technik, Berlin 1986.
[3] Arz,G; Merksz,I; Alpek,F; Kocsis,I; Lipóth,A :
A robotalkalmazás tapasztalatai a BME-MTA SzTAKI közös kísérleti üzemében.
III. Ipari Robot Szeminárium, Győr, 1984, OMIKK pp.231-238
[4] Merksz,I : Esztergákat kiszolgáló ipari robotok munkadarabmegfogó szerkezetei
Műszaki doktori értekezés, 1984 BME
[5] Lipóth,A; Arz,G; Merksz,I : Ultraprecíziós eszterga ipari robottal történő kiszolgálása
Mechatroinfo'88, Eger.
[6] Schiele,G; Schmidt,I : Handhabung in einem flexiblen verketteten Fertigungssystem für Rotationsteile
VDI Zeitschrift 122(1980) Nr.8. pp.316-322
[7] Arz,G : A rugalmas gyártócellákban dolgozó ipari robotok bővülő feladatköre
III. Célgép Szeminárium, Győr, 1986. GTE pp.98-106
[8] Wright,P.K; Greenfield,I; Hansen,F.B : Self-sustaining open-system machine tools
17th Annual NAMRC, Colombus (OH), May 24-26, 1989.

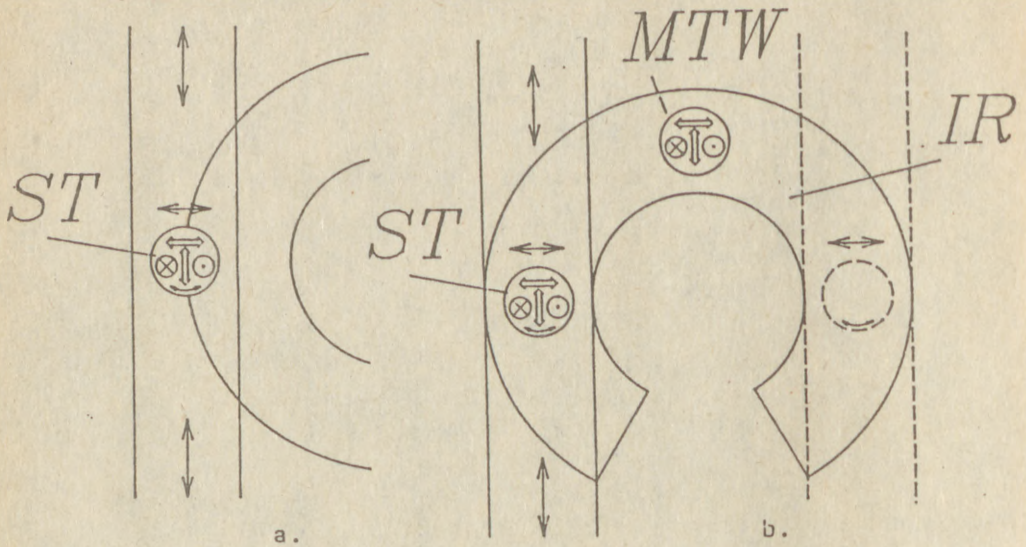


Fig. 1.

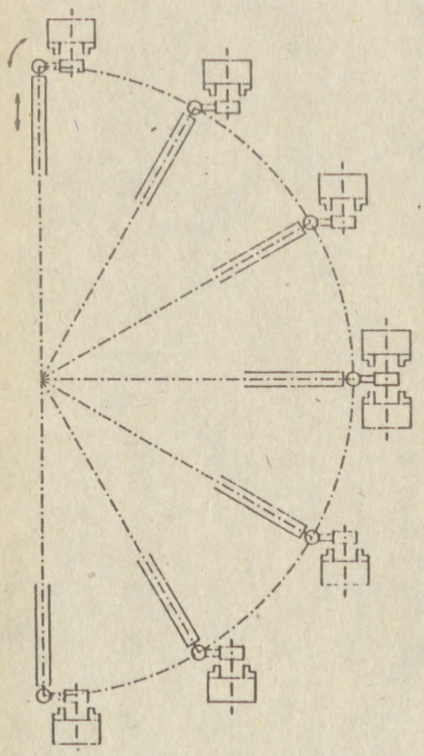


Fig. 2.

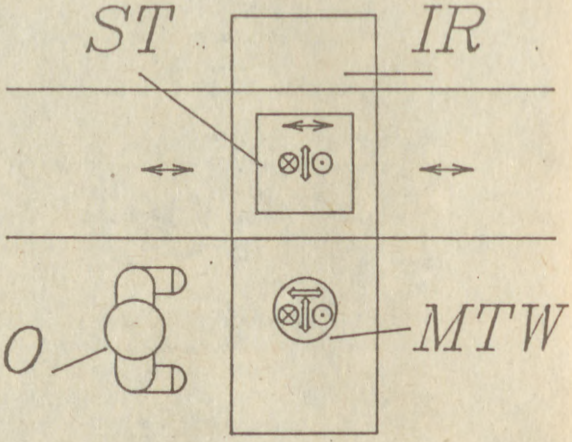


Fig. 4.

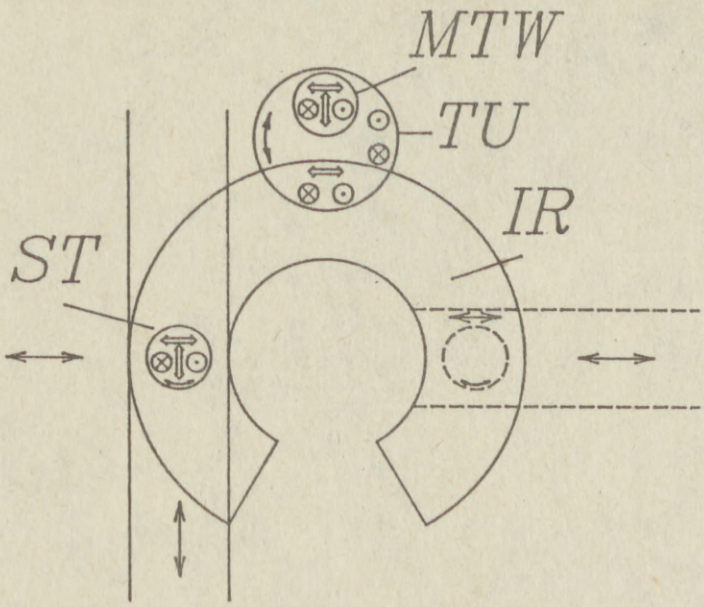


Fig. 3.

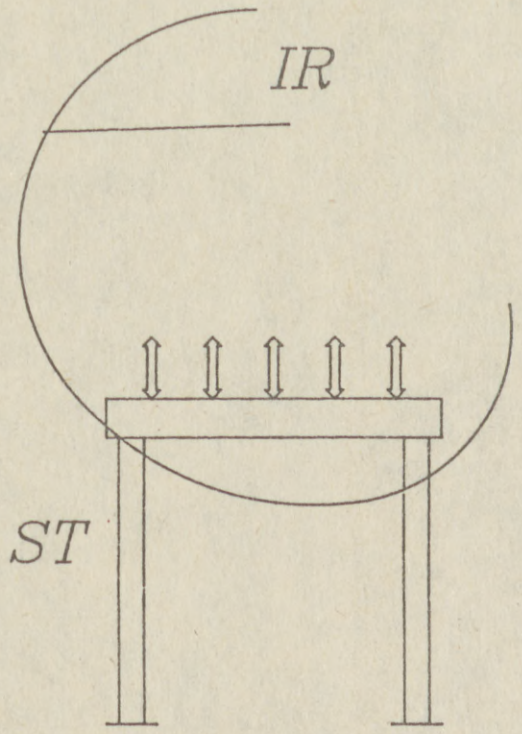


Fig. 5.

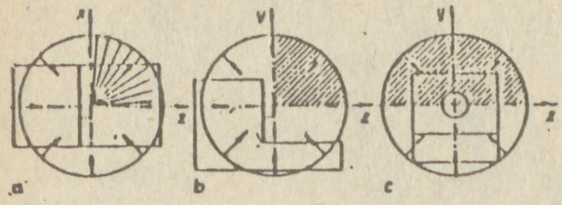


Fig.6.

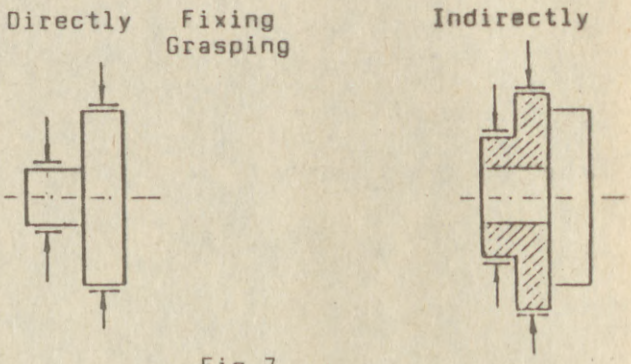


Fig.7.

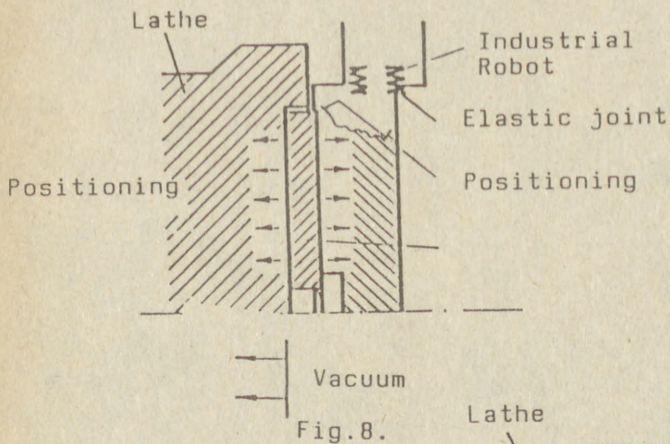


Fig.8.

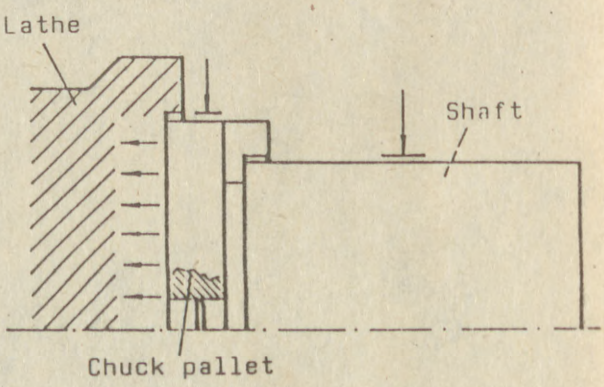


Fig.9.

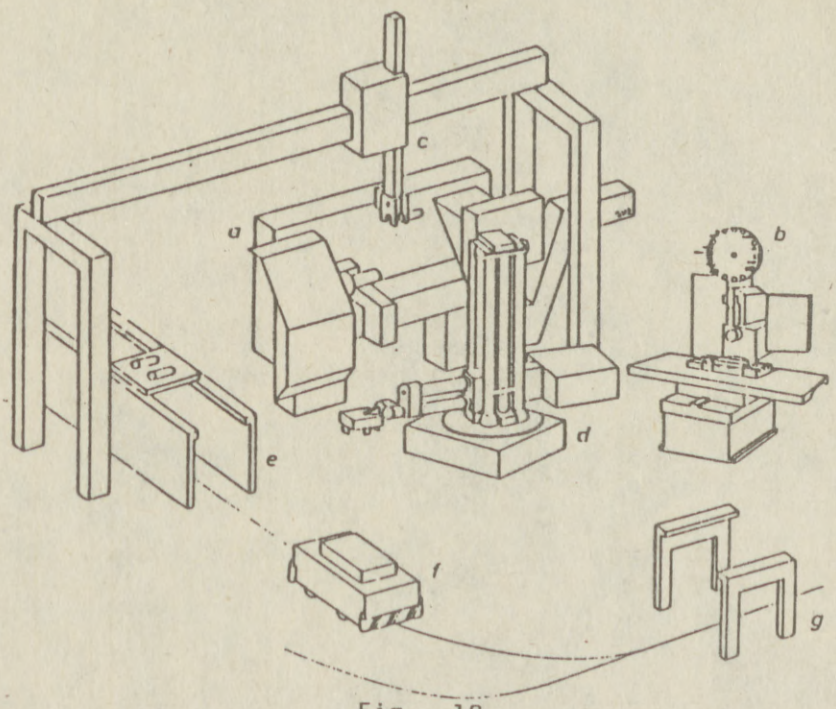


Fig. 10.

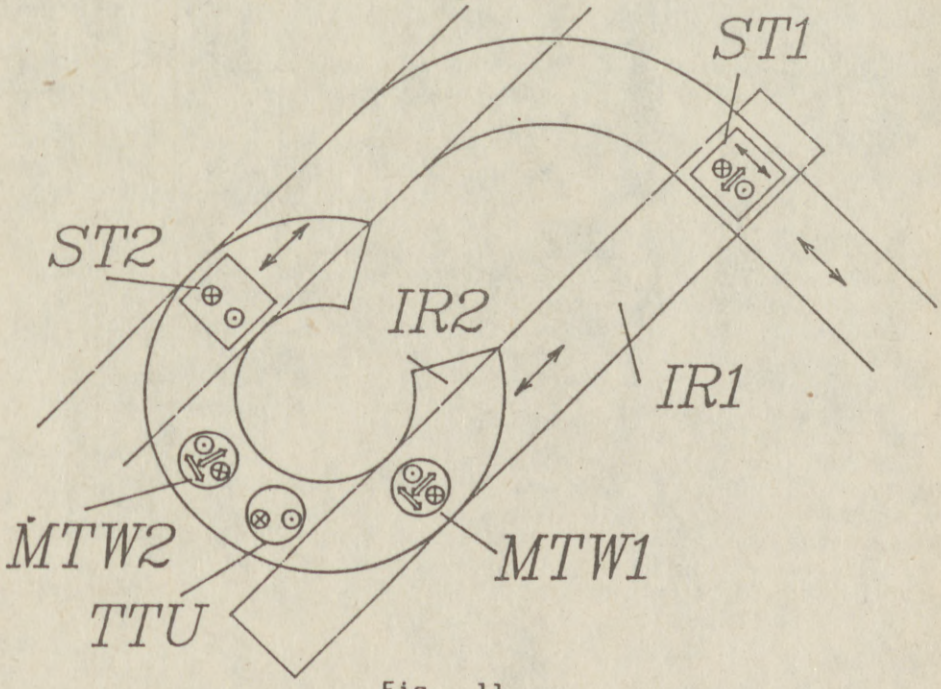


Fig. 11.

CAD/CAM SOFTWARES IN PRACTICE

János Basa - INNOVA-CAD Office Műszertechnika - Hungary

Introducing, spreading of CAD/CAM techniques needs a wide-ranging activity. The knowledge of certain companies, cooperatives and professional circles, and their willingness to accept this technique, show a varied aspect.

For the successfull adaptation of CAD/CAM methods, the Office INNOVA-CAD, established in the farme of Műszertechnika Kisszövetkezet and specialized in planting of CAD/CAM systems, determined its tasks, namely

- the choice and putting into circulation if leading, high performance (home and foreign) CAD/CAM softwares for mechanical engineering, elektronics, general engineering activity, etc.
- configuration of individual or increased performance systems for special tasks, areas
- establishing of sample systems, representing the functions, advantages and operation of CAD/CAM technology, designer supply
- assembly and installation of complete CAD/CAM workstation.

Criteria of choice of CAD/CAM software

Today on the international market of informatics, there is an enormous supply of the CAD/CAM systems, running on personal computers. For lack of thorough knowledge of the field, without continuous informations, it is nearly impossible for the user to select the most appropriate system.

The Office INNOVA-CAD, on the base of previous study of market demands and estimation of Hungarian technical requirements with regard to softwares selected for circulation in Hungary, stated the following demands

- the most advanced system in CAD/CAM techniques
- high technical level, wide-ranging function supply
- possibility of adaptation and application in Hunagry
- continuous software development (updates of software)
- internal program language (macrowriting, parameters)
- large reference background
- communication with other CAD/CAM programs and customised softwares.

In consequence of the consistent trade policy for more than two years - thanks to the dealers agreements - we can offer to our users the best known CAD system on the world among the softwares running on PC, the favourit three dimensional CAD system leading in mechanical applications, and the most advanced West-German CAD system which is especially appropriate to home applications.

TAR

Mechanical and general CAD program packages

The mechanical designing, drawing and dimensioning offers countless opportunities for use CAD programs. In practice they are applicated mostly for product planning, design of part and assembly drawings, marking arrangement plans.

However the continuous development of software and hardware gives an ever enlarging area to the spreading of the computer aided designing system. With the appearance of the three dimensional CAD systems, that is the geometric modelling, there is a chance to help the constructional planning with computers on higher level. The CAD techniques conquest newer and newer fields. Today it comes natural that construction of tools and appliances as well as pattern-making is helped by computer aided designing system. The picture of prototypes appears on the computer display for the first time, the ideas of the industry designer are realized by the aid of CAD software.

On the created solid modells one can accomplish operating and technological analyses, examinations of the physical effects on the object as well as simulation tests.

The data processing, the execution of required modifications lead to the confirmation of material, technological and functional features of components, constructional units or complet products.

The Office INNOVA-CAD puts into circulation CAD softwares, offering these designing, design, modelling functions and takes part in their industrial propagation.

The outstanding features of the CAD programs, getting introduced are the following

AutoCAD 10-11 (A CAD system for PC the general on the world.)
- three dimensional database
- surface given by 3D boundary curves
- simultaneous display of four views
- automatical removal of hidden lines
- 3D surface of revolution, displacement
- assistance in networking
- connecting of programs written in external graphical language

AutoSolid
- common employment of combination of standard solid shapes (CSG) and boundary surface modelling
- programming interface (connection to C language)
- solid modelling on the base of Boole operations
- display with wireframe and shading
- material-like colour-ordering
- automatical computing of material properties
- two-way DXF and IGES connection
- output to the finit elements program packages

CADKEY 3.55 - 386

The CADKEY software package - with its dinamic development background and unic solutions - takes a leading place among the personal computer aided designing systems, in the field of three dimensional drawing and design. Though it is in general use in mechanical planning, designing of tools and steel-structures as well as industrial design, also the cartography, the pipe-line drawing and the electronics make use of it.
They introduced for the first time the solid modelling, the facility of Boolean algebraic operations, automatic generation of the mechanical properties.

They built up, also among the firsts, in the designing system the surface modelling methods. Their latest development is the so called Render-man modul, which makes possible the generation of realistic, quality of photo image of the designed component or object. It helps the prototype making and design in an unbelivable manner.

An additional force of CADKEY is the CADL internal graphical program languauge. By its use one can produce user-specific macros, employer programs. The third-party developers generally adopt the CADL to write customised programs and in the connections with CADKEY. The choice of theese is wide-ranging in the Hungarian applications and are more and more frekvently looked for.

The CADKEY software packages, installed by the Office INNOVA-CAD are used, beside training, to design plastic tools, drawing of electro-mechanical components, making mine-mapping plans, to applications in ergonomy, etc.

CAM program package

The professional personal computers play a more and more important role in the production too. In the field of preparation of production, the resource planning, the product following, the handling of stocks, the quality control, etc. there are many occasions to run customised programs, to automate the production process.

Among the CAM systems the so called NC/CNC part programming systems, making the programs of the numerically controlled machinetools, are used above all.

The Office INNOVA-CAD knowing the Hungarian NC/CNC technology, the machine-park and the choice of components, decided to put into circulation the PEPS2 NC/CNC programming system. This program package is very popular in West-Europe and - among others - disposes the following features

- independent programming station or CAM system with the ability of connection to the known CAD softwares
- suitable for 2D and 3D manufacturing, to the later it has a surface modelling modul
- ability to real time graphical simulation of machining and tool-path generation

- beside the interactive designing, one can use a quick, easy to menage program language
- calculates the manufacturing time, hardcopy output
- ability to make postprocessors integrating the specific set of instructions of the control - facility of varied data transmission for the connection between the computer software and the control or peripherical equipments.

The base system diposes different manufacturing moduls
geometric design - milling - turning - punching - wiring - burning - wood industry manufacturing - three dimensional display

CAD/CAM - system

Automation of the manufacturing process from design to the end-product needs the integration of the applied CAD/CAM softwares. That means, for example, that after construction of the component with the aid of CAD program, the graphical data, in the form of coded electronical signals get by cable into the component programming CAM system, where the running of technological planning, machnining and simulation takes place. The so formed program, by means of a new electronic tasks transmission, gets directly into the CNC machine s control unit and the automatical manufacturing can be started from here.

The simplification of the process to such a great extent makes clear anyway, that the direct communication between the applied CAD and CAM techniques, the identical graphical database is absolutly necessary.

Naturally, the CAD/CAM system means a large integration, it contains the whole circle of computer aided designing a manufacturing areas.

Of course the CAD/CAM technology may influence even the organisation structure of the company or its sections. If theese only want to increase the productivity of part drawing, the structural change is not reasonable, but where the aim is manysided exploitation of the central database, to build up a low of information, there it is necessary above all to make closer the connection between functional section, to determine the communication processes in an unambiguos manner.

Industrial CAD/CAM reference system

In cooperation with the experts of the Aluminium Processing Company of Ajka, in 1989, we began to install and put into operation a computer aided designing and manufacturing system, working in professional personal computer environment.

The main requirements of the system are summarized in the followings

To build up an integrated CAD/CAM network, comprising

- the technical design in the area of planned previous maintenanche and tool workshop

- preparation of product documentation (part drawings, processiong plans, tool drawings) in the central machine-production and tool-making shop

- preparation of manufacturing technologies of parts and assemblies elaboration of effective manufacturing programs, excution of manufacture, in the central machineproduction and tool-making shop

Realization of the system happens in more steps. The targets, set and accomplished by the second half of the year 1989 and the first quarter of the year 1990 are

- to estabilish a CAD and CAM workstation in the central machine production section
- data transmission between the two workstations
- 2D/3D part designing, provision of technical drawings in more views
- register of drawings, made by computer, hardcopy output
- change of data connection with other CAD softwares
- using the base of data of the component designed in CAD for CAM workstation
- installation of inteactive NC/CNC programming system to make the control program of the components - ability to test CNC manufacturing programs, independently of the machine
- ability to process the manufacturing programs for the CNC manufacturing machines of the factory
- to build up direct and indirect input in machine of the generated and processed programs.

Composition of the manufacturing machine-park served by the CAD/CAM system

1., Type MC 1250-01 machining center - 1 pc
Control FANUC System 6M - Model 8
2., EEN 630-04 universal CNC lath - 2 pc
Control Hunor PNC 721

Structure and functional units of the realised system

1., CAD workstation in the central machine-production section Workstation of base MAT 286 + VGA monitor + graphical peripherals
AutoCAD release 10. CAD software
transfer of drawing files happens in the form of IGES to the CAM.

2., CAM workstation
Workstation of base MAT 286 with 20" VGA graphical + Hercules alphanumerical monitor + printer, plotter
PEPS2 - version 2.3 CNC partprogramming system
Milling + turning modul + 3D visualisation + communication modul.
To the program PEPS we prepared the HUNOR 712 and FANUC 6MB postprocessors which use the cycles and instructions of the controls and make the program sentences in non explicit form.

3., Workstation to NC program archivation + NC machine service Base machine type MAT 286 with monochrom, 14" monitor

4., System connection by Novell network
with MAT 386 server and file transfer between the NC machine serving workstation

5., Connection between the NC machines and server computer by cable connection built up through RS 232C interface. The choice of individual NC machines from the communication software is realized with direct adressing.
To the connection the four channel interface card of Műszertechnika was built in.

6., The data transmission between the CAM workstation (PEPS software) and CNC controls can be realized also by PSION Organiser II portable pocket computer what can give the technologist a possibility for direct connection.

The phases of development planned and being under realization for year 1990

- change of training CAD program package of tools-workshop for 3D high performace CAD program packages, able to design sophisticated pressed castings,
- development of the tool and appliance element library parameterized to 3D CAD software, by the aid of auxiliary programs and the built in program language,
- manufacture of parts, designed by the CAD software on the three dimensional CNC milling machine which will be installed in the tool workshop by the aid of a control program, made on the CAM workstation,
- to estabilish the facility of data transmission between the 3D measuring machine and the CAD program package,
- to enlarge the earlier CAD designing system for four workstations,
- to built in the tool workshop s CAD/CAM system into the Novell network.

To the casting design we are going to use the 386 version of CADKEY software package, supplemented by the surface modelling modul.

The drawing file - data transmission between the CAD and CAM programs happens by the Novell network, in the form IGES.
Between the CAM workstation and the CNC machine the connection is kept by cable built through the RS 232 interface.

Summary

The prsented CAD/CAM reference system is one of realized solutions of the INNOVA-CAD Office. Our installed CAD/CAM configurations and software packages work efficiently on different areas of the industry.

During our activity we got really favourable experiences concerning the interest in the CAD/CAM techniques.

We are convinced that today the computer aided design and manufacture are the most efficient resources of the technical development.

Some aspects of flexible automatisation of welding technology

Béla PALOTÁS[x] and László BECKER[x] and Attila FARKAS[xx]

Abstract

Arc-welding robots are being increasingly applied in industry, a process furthering demand for off-line programming. An essential item in off-line programming - in addition to the simulation of robot arm motion - is reliable computation of welding parameters.
A possible method of welding parameter computation, based on so-called machine calibration, will be presented.
The calibration method defines relations between welding parameters underlying parameter computation of welding for both filling and melting welding. It is suitable for any GMAW method, hence also for arc-welding robots.

1. Introduction

A large part of all industrial robots are arc-welding robots [1] . Programming of robots for a given task is generally done in teach-in mode, imposing a significant time demand; if the robot is applied in continuous operation, a considerable working time loss has to be reckoned with. Therefore it is important to be able to develop robot programs independent of the robot. Plenty of relevant software has been developed to this end ([1,2,4,5,7,8,10,11,12] without aiming at completeness). An essential part of off-line programming serves to compute welding parameters.
There are a great many publications on the computation of welding parameters ([1,2,3,6,9,10,11,12] again, without aiming at completeness).

---

x Ass. Professor, Department of Mechanical Technology, Technical University of Budapest, Hungary
xx Research worker, Department of Mechanical Technology, Technical University of Budapest, Hungary

A possibility for computing welding parameters for GMAW will be presented below, relying on the so-called machine calibration method, suitable also for arc-welding robots.

2. Calibration GMAW equipment

The scheme of calibrating of GMAW equipment is seen in Fig. 1. Adjusting various machine characteristics on the welding machine and varying the wire feed rate yields various working points. Statically and dynamically analyzing welding parameters at the working points, the weld shape - outer and inner form factors - permints us to determine successful related welding parameters resulting in proper welds. Also relations between wire feed rate and current intensity may be determined. In the knowledge of the domain sutting for welding, so-called adjustment line(s) may be assumed (Fig. 2). Based on calibration may also underly determination of adjustment data for switches, potentiometers for every parameter.

3. Welding parameter relationships

Calibration permits us to determine welding parameter relationships (Fig. 3). Wire feed rate and welding speed are related by the weld cross-section for a given wire diameter, the so-called continuity relationship:

$$A_w \cdot v_{weld} = \frac{d_e^2 \cdot \pi}{4} \cdot v_w \cdot 1000 \cdot \eta \qquad (1)$$

where:

A_w - weld row cross section, sq.mm
v_{weld} - welding speed, mm/min
d_e - wire diameter (equivalent metal diameter), mm
v_w - wire feed rate, m/min
η - efficieny, taking the splashing loss typical of the procedure into consideration.

Other relationships:

$$I = C_1 \cdot v_w^{C_2} + C_3 \qquad (2)$$

$$U = C_4 \cdot I + C_5 \qquad (3)$$

where:

I - current intensity, A

U - arc voltage, V

C_i - machine-dependent constants determined by measurements ($i = 1,2,3,4,5$).

Relationships have been plotted in Fig. 3, showing at the same time the action of wire outlet (free wire length). Plotting adjustment lines typical of calibration improves parameter reliability.

Constants in the relationships above vary for each procedure, constants taken from statistic analyses - taking linear regression into consideration for different procedures - are given in [9].

4. Computation of welding parameters

In GMAW from the aspect of welding work, two major groups are distinguished [9]:

- filling welding,
- melt welding.

Weld types typical for these groups are seen in Fig. 4.

Filling welding parameters may be computed from the algorithm according to Fig. 5.

Melting welding parameters can be determined on the basis of Rykalin's thermal process theory - resulting from physical considerations. Relationship between characteristics of the intrinsic weld hape factors and the fused weld cross section based on statistic analysis is seen in Fig. 6, that is:

$$A_m = 0.6 \cdot H \cdot B \qquad (4)$$

where:

A_m - fused weld cross section, sq.mm

H - fusion depth, mm

B - weld width, mm

(interpreted according to Fig. 4).

According to the theory of thermal process:

$$A_m = \frac{1}{\varrho \cdot S_s} \cdot \eta_t \cdot (q/v_{weld}) \cdot 1000 \qquad (5)$$

$$X = \frac{q.v_{weld}}{a^2 \cdot S_s \cdot \varrho \cdot 600} \qquad (6)$$

$$\eta_t = 0.09206 \cdot X^{0.28306} \qquad (7)$$

where, in addition to symbols already defined:

ϱ - weld metal density (for steel: 7.85 g/cu.cm)

S_s - heat content of metal at its melting point (for steel: 1356.5 J/g)

η_t - so-called thermal efficiency

X - dimensionless number

$q = U.I.\eta_p$ electric heat output in J/s (8)

$-\eta_p$ - efficiency of the procedure

a - temperature conductivity coefficient (0.08 sq.cm/s).

The suitability (applicability) of these relationships will be illustrated on the frequency histogram characteristic of their exactness (Fig. 7). According to this figure, application of this relationship causes a deviation on the safety side. The algorithm calculated on the basis of these relationships seen in Fig. 8. The relationship (7) valid for the thermal efficiency remain to be checked for different procedures. There exists favourable practical experience with the use of the presented algorithms.

5. Application of the theory for arc-welding robots

An application of the measurement method presented for arc-welding robots type Limat Rt 280-6 made by IGM has been described in [8], publishing exact measurement results, underlying Fig. 9, effect of programmable parameters on welding parameters. The range suitable for welding is seen in Fig. 10. The relationships between parameters adjustable on the robot are seen in Fig. 11. The voltage correction value K_u is to be

chosen as a function of the welding cable length. In the knowledge of the welding speed v_{weld}, wire feed rate v_w for a given weld row cross section is obtained from (1). Welding output K_A can be obtained from the wire feed rate for a given characteristic K_v, to be chosen as a function of arc voltage - taking into consideration the weld part to be made.
With a view to the above algorithms presented both for filling and melting welds may be applied to robots.

6. Conclusions

Determination of welding parameters by computation permits the realisation of several technical-economic advantages. Functional relationships between welding parameters may be determined by measurements. Functions set up by measurements yield in fact adjustable parameters; even machine adjustment data alloving for a given parameter may be indicated.
In programming arc welding robots, in connection with functions set up from measurements, data needed for given welding operations may be determined either for filling or for melting welds. Being able to compute robot adjustment data is indispensable for off-line programming, itself of increasing interest.
A possible method for computing welding parameters has been presented.

References

[1] F. Eichhorn:
Aspects of the Mechanisation, Automation and Utilisation of Robots in Welding
= Automation and Robotisation in Welding and Allied Process. IIW. 1985. Strasbourg. Pergamon Press. p.: 3-53

[2] D.K. Feder:
Computers in Welding Technology - A look at applications and Potentials
= Weld Quality, The role of computers; p.: XVII.-XXXV. IIW. 1988. Pergamon Press. Vienna, Ausztria

[3] W. Lucas, A.D. Brightmore:
The Welding Institute Approach to Writing Information Software for Welding Engineers.
= Weld Quality, The role of Computers, p.: 141-157.

[4] A.H. Kuhne, H.B. Cary, F.B. Prinz:
Expert System Improves the Robotic Welding Procedure
= Weld Quality, The role of Computers, p.: 175-180.

[5] M.G. Milanova, P.I. Ruseva, I. Ivanov:
Programming welding robots using CAD/CAM systems
=2nd International Conference on Computer Technology in Welding
Cambridge, UK. 1988. p.: P30-1...P30-3.

[6] B. Palotás, L. Becker:
Designing the manufacture of welded constructions
= 2nd International Conference on Computer Technology in Welding
Cambridge, UK. 1988. p.: P5-1...P5-13.

[7] G.S. Bolmsjö:
Robotic Arc-Welding-State of the art
= Proc. of the International Conference on the joining of Materials
JOM4. 1989. Helsingor, Denmark. p.: 77-82.

[8] L. Becker, A. Farkas, T. Konkoly, F. Nagy:
Investigations on Parameter-Control for Arc-Welding Robots
IIW DOC. XII.-1114-89.
=Comm. XII. Pergamon Press.
Helsinki 1989. p.: 243-257.

[9] B. Palotás, T. Konkoly:
Computerized Design of Welding Technologies
IIW DOC. XII.-1115-89.
= Comm. XII. Pergamon Press.
Helsinki 1989. p.: 258-285.

[10] A. Brenner:
Expert System for the fabrication of welded structures*
Gép. XLI. évf. Budapest, 1989. 8. sz. p.: 314-316.

[11] T. Konkoly, F. Bauer , L. Becker, K. Bödök, A. Farkas, B. Palotás:
Research work in the field of welding technology*
Gép. XLI. évf. Budapest, 1989. 10.sz. p.: 390-397.

[12] A. Brenner, B. Palotás red.:
= Computer Aided Welding*
BME MTI Budapest, 1989. (5289) p.: 456.

* In Hungarian

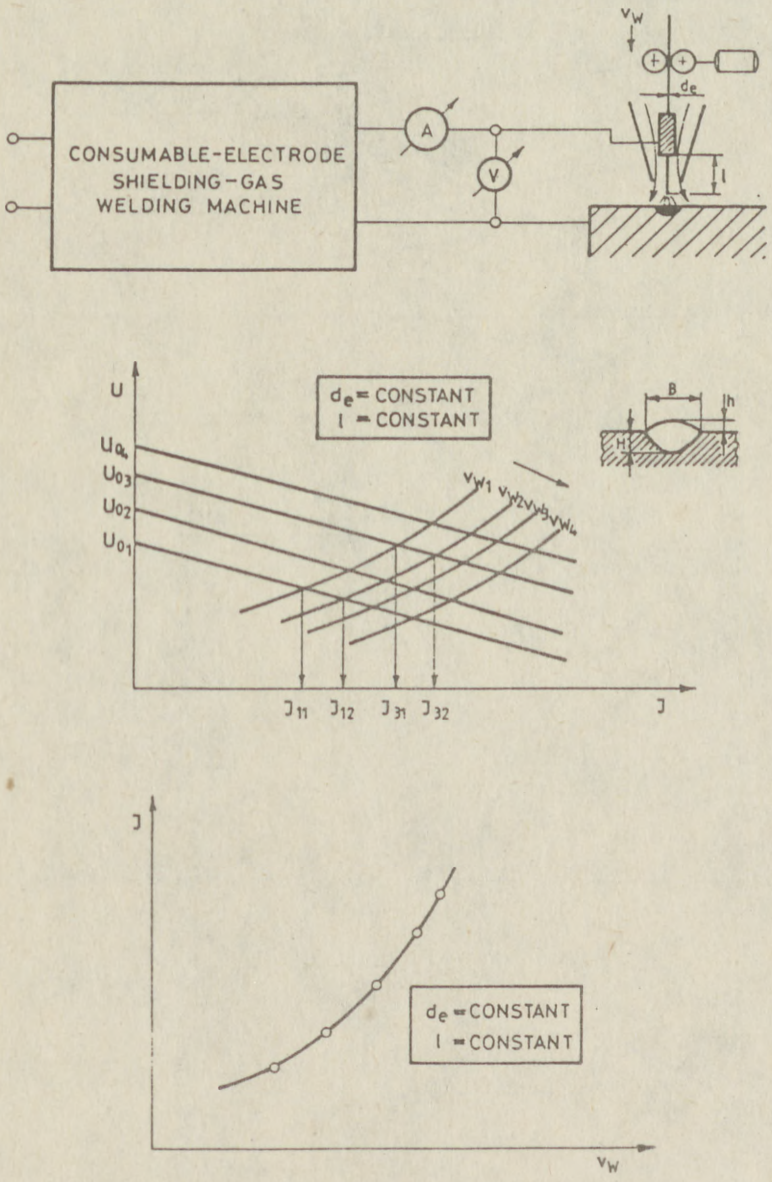


FIG. 1.

PRINCIPLE FOR CALIBRATING CONSUMABLE ELECTRODE SHIELDING-GAS WELDING MACHINES

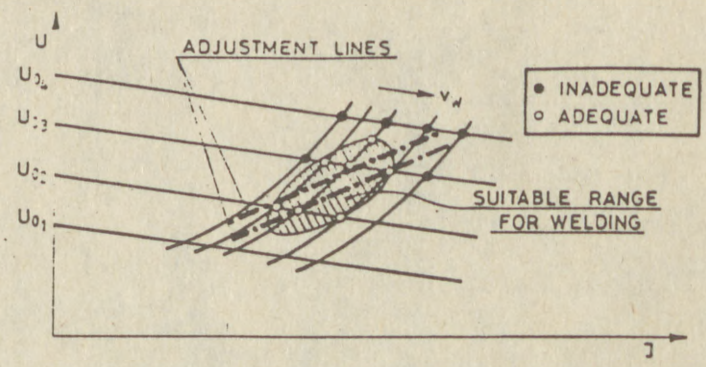


FIG. 2.

DEFINITION OF THE SUITABLE WELDING RANGE

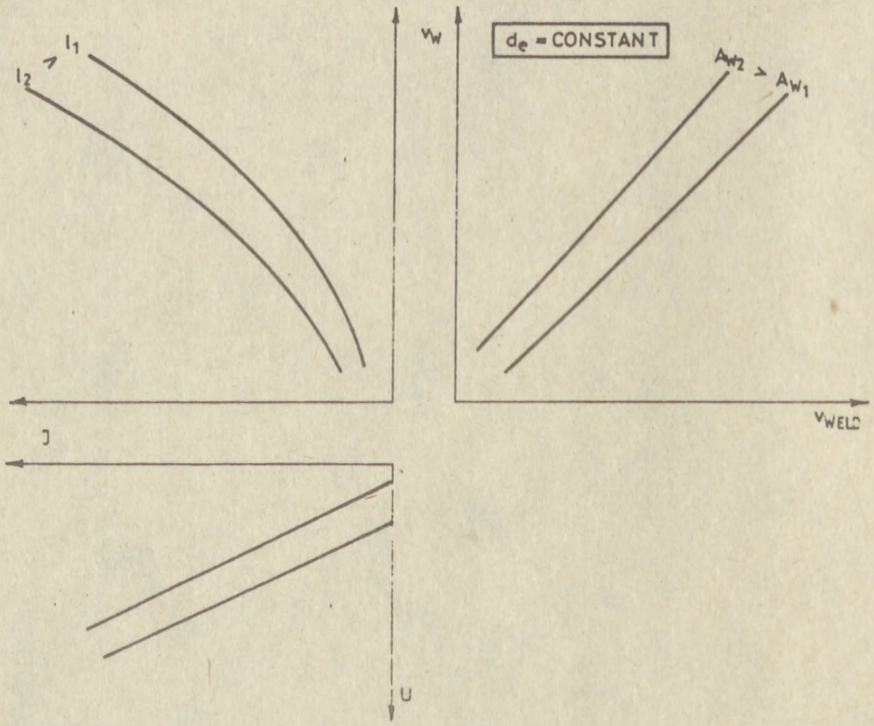
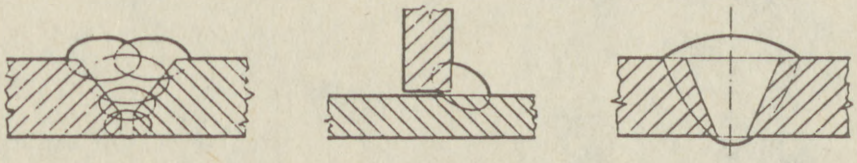


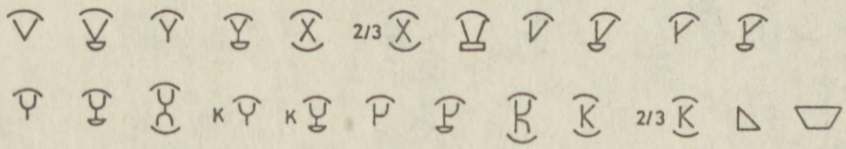
FIG. 3.

RELATIONSHIP BETWEEN WELDING PARAMETERS

FILLING



TYPES OF WELDS:



MELTING



TYPES OF WELDS:

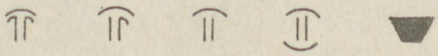


FIG. 4.
GROUPING THE WELDING TASKS
ACCORDING TO THE WELDING PARAMETERS

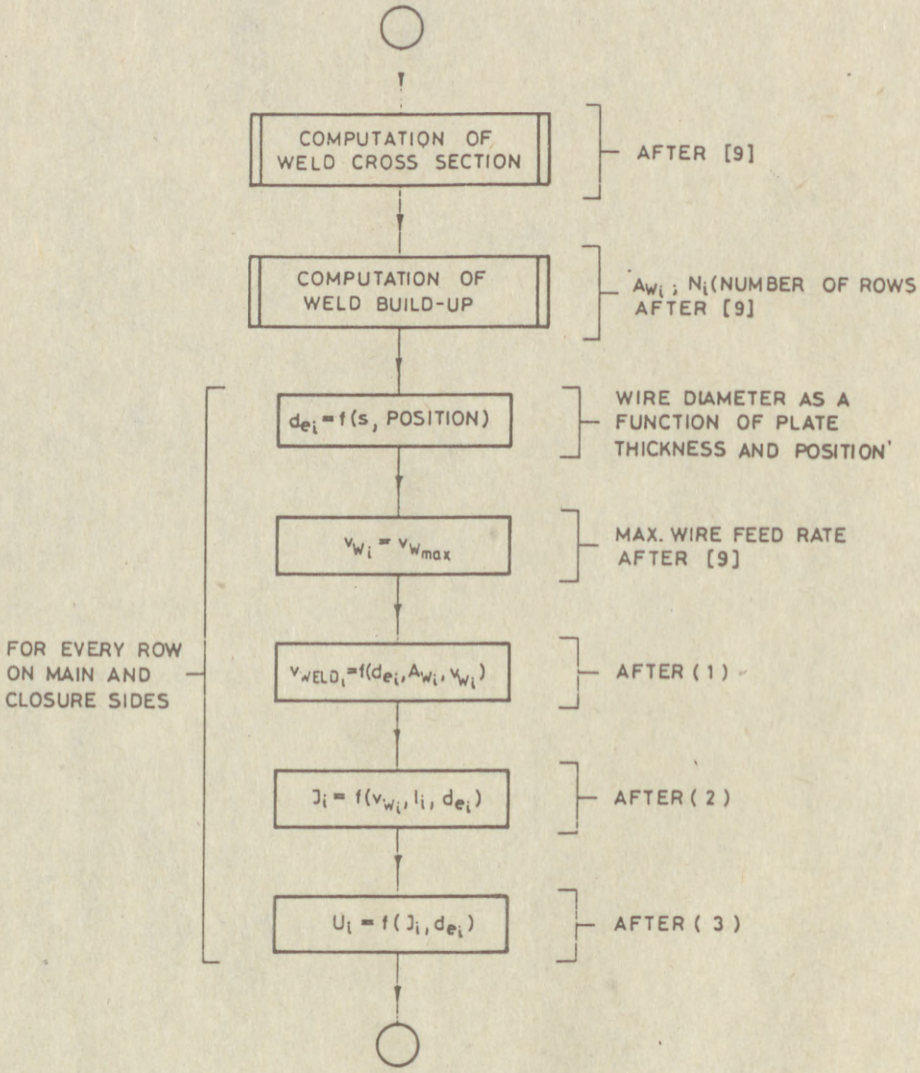


FIG. 5.

COMPUTATION OF FILLING WELDING PARAMETERS

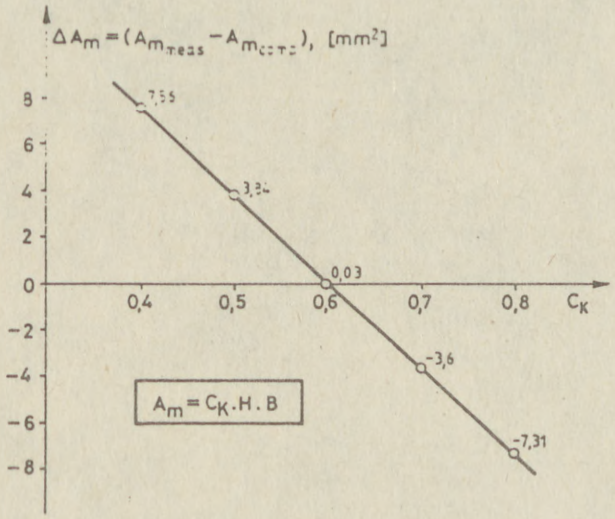


FIG. 6.

RELATION BETWEEN INNER FORM FACTORS OF THE WELD

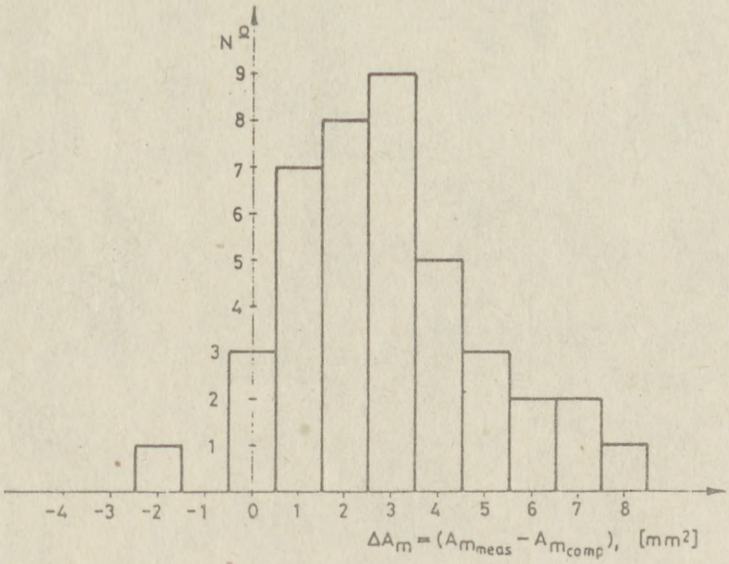


FIG. 7.

FREQUENCY HISTOGRAM OF DIFFERENCE BETWEEN WELD CROSS SECTIONS MEASURED AND COMPUTED FROM THE RYKALIN HEAT THEORY

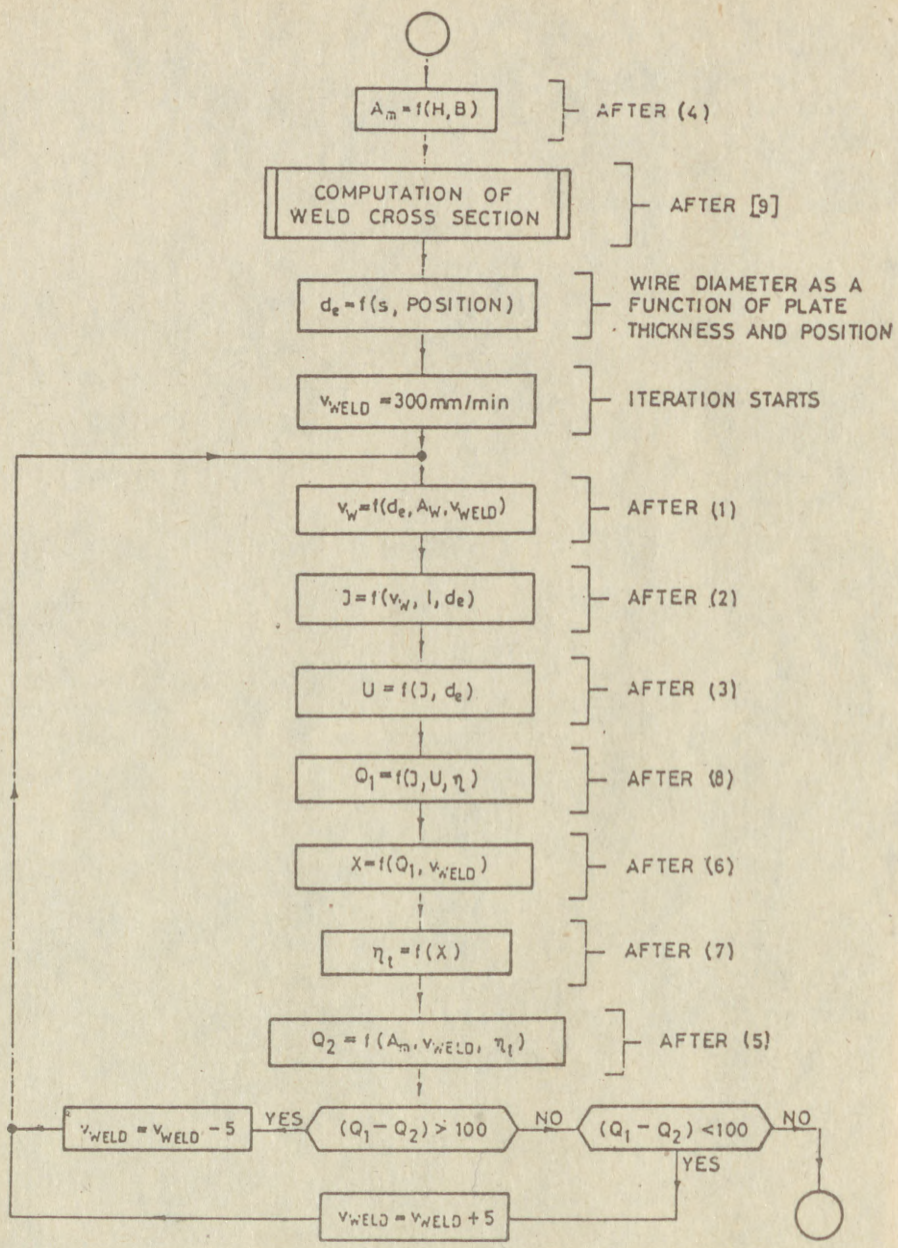
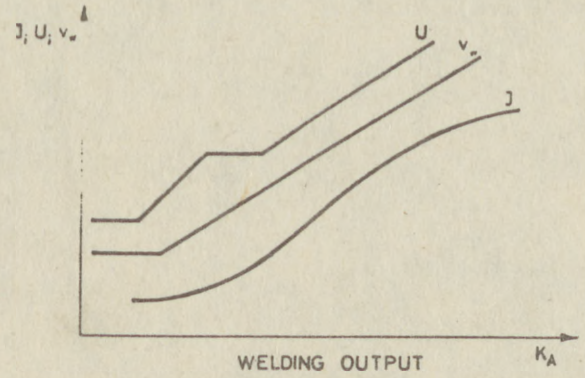
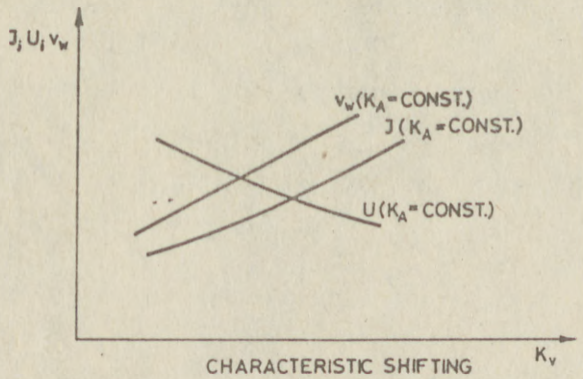


FIG. 8.

COMPUTATION OF MELTING WELDING PARAMETERS





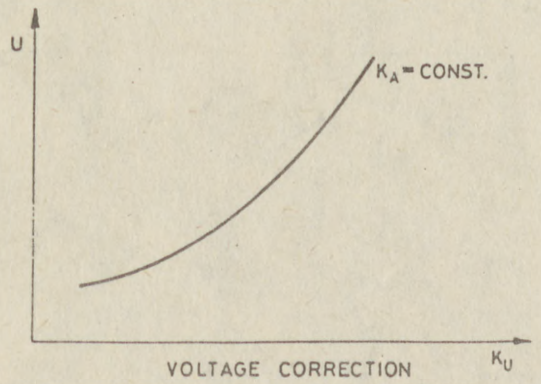


FIG. 9.

CALIBRATION CURVES OF ARC WELDING ROBOT TYPE LIMAT RI 280-6 (SCHEMES) (d_e = CONSTANT)

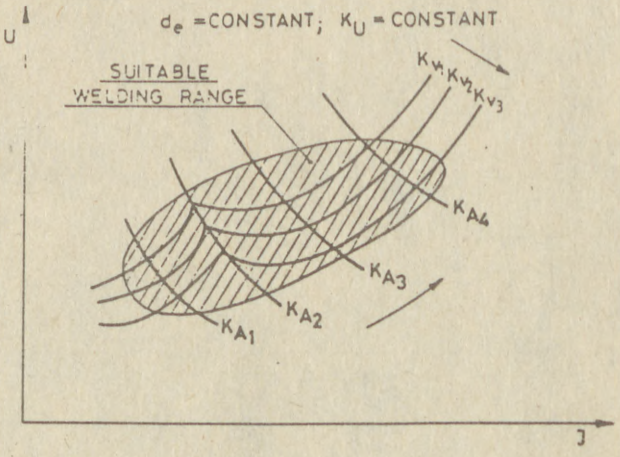


FIG. 10.

ADJUSTMENT DIAGRAM FOR ARC WELDING ROBOT
LIMAT Rt. 280-6 (SCHEME)

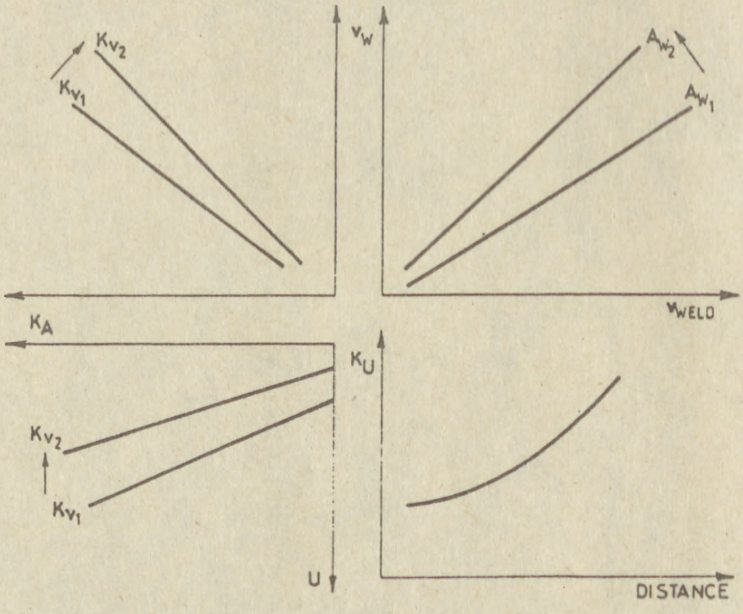


FIG. 11.

RELATIONSHIP BETWEEN PARAMETERS OF ARC WELDING
ROBOT LIMAT Rt 280-6 (SCHEME) (d_e = CONSTANT)

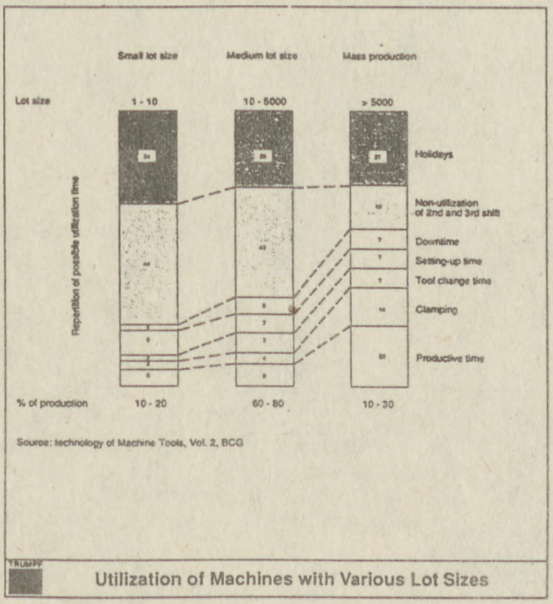
FLEXIBLE AUTOMATED MANUFACTURING OF FLAT SHEET METAL COMPONENTS IN LOW QUANTITIES

Dipl.-Betriebswirt Hans-Jochen Beilke, Senior Marketing Manager,
TRUMPF GmbH + Co., 7257 Ditzingen, West Germany

The demands towards industrial manufacturing processes have been changing in general during the last few years. The increasing call for smaller batch sizes due to a larger number of product variations coupled with a shorter life span confront the manufacturers more and more with frequent changes in their production. At the same time, to be competitive, the capital intensive manufacturing equipment has to run with a better utilization as ever before. For this reason one can therefore feel today a strong inclination not only towards better quality and higher productivity but as well with a tendency towards extended flexibility with a high degree of automation.

Flexible Production in Sheet Metal

As for some time in metal cutting, there is a trend to flexible automated manufacturing as well in the sheet metal field.



Utilization of Machines with Various Lot Sizes

In view of aforesaid it should be recognized that in most machine tool units even nowadays an average of just about 15 per cent of total time available is utilized for the actual cutting process. The remaining rest is consumed by non productive "Idling Times".

This potential of time available besides the actual machining times deserves closer attention. In most cases a somewhat slower procession time will be acceptable if the "Idling Times" available are utilized for the requirements of unattended machine operations.

The goal is the same being the realisation of advanced automated manufacturing of small batches with simultaneous adaptation possibilities to changing manufacturing needs. Despite the concept analogy when compared with metal cutting, for the realisation of flexible systems for sheet metal, different conditions have to be observed to start with.

Sheet metal production differs to metal cutting in substantial details, so for instance cycle times are normally extremely short. Automating small batches creates a problem especially with regard to change overs on the tooling side, as a far larger number of tools are necessary.

An important difference can as well be seen from the fact that on sheet metal fabrication centres components are loaded into the machine and unloaded from the machine without the aid of any fixturing. In combination with the large scale variation with regard to component size and geometry common in the sheet metal production the problems concerning loading and unloading are rather more difficult. An obstacle for automation is furthermore the fact that sheet metal components are often large and therefore require a far higher expenditure concerning storage, transport and handling. An important difference is that in most of the cases the raw material comes in standardized sheet formats with sizes which are geometrically not related in any way to the finished component. This confronts one in sheet metal with the additional task to utilize the available material as far as possible and to minimize the waste.

Automatic Loading and Unloading of Sheet Metal Centres

If one considers the means which under such conditions prove suitable to serve as modules for the flexible automated punching and contour machining of sheet metal components in small quantities so are these at first hand the automatic loading devices. They are capable to pick up sheets of various sizes, quality and thicknesses from a material stack without the necessity of change over, and position them accurately in the machine.

The technical development for separating, picking up and transferring the sheet as well as double sheet detection renders such equipment suitable to be standardized and used in various applications and combinations with punching/nibbling machines as well as punching/laser and punching/plasma cutting machines. Of course the same flexibility is necessary on the unloading side of the machine to take finished components away. An universal unit has proved successful being equipped with a large number of vacuum suction cups. These suction cups can be individually programmed to take care of the component's geometry. This enables the unloading of small or large components without the necessity for any change over, whereby it is immaterial whether the component has a complex external or internal contour and independent of the fact whether it is positioned within the skeleton or lying separated on the machine table.

For various applications, especially when the majority of components are small, a special unloading system for these parts might be used to advantage. This could be a flap or chute integrated into the machine.

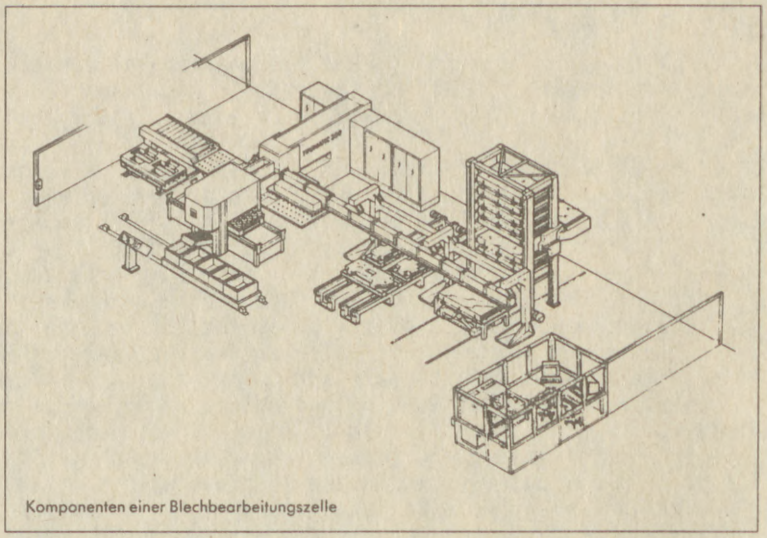
By a combination of movement whereby the flap first drops vertically down and then inclines, the component is ejected onto a conveyor belt which will take it away from the machine.This belt can be linked with an additional sorter "TRUMASORT" for identified part disposal into up to four different containers. A further unloading concept which is mainly employed for extremely small components uses so called "Micro Joints" whereby smallest connections retain the components in the sheet respectively in the skeleton. For the common unloading of these parts, the skeleton is taken out of the machine by means of grippers and positioned onto a level controlled table. Such types of loading and unloading equipment form the general basis for flexible material handling in the automatic production of sheet metal parts in limited quantities. However, an operator independent utilization of such a machine will only be possible when the loading and unloading devices are equipped with large enough material buffers.

Storage and Retrieval System for Sheet Metal and Sheet Components

The pallet pool now commonly used on machining centres in the metal cutting area corresponds with the pallet store in the sheet metal shop. The sheet metal store provides access to various materials, thicknesses or sheet formats and gives buffer capacity for either semi-finished or finished components.

The latest storage technology can offer concepts which are easily adaptable to the capacity requirements reaching from compact stores with a few pallet spaces and a simple pallet picker unit to a highly sophisticated multiple store with three-axes pallet picker crane and the link-up to a number of machines. Normally the material is supplied to the machine in form of sheet stacks positioned on pallets. The same applies to semi-finished or finished components, they are loaded to pallets and returned to the store for further storage. As in sheet metal identical material is used for a number of various components, it is essential that an automatic system offers the feasibility of continous material administration. For this the necessary data are supplied by scales weighing both the material input and the consumption on the machines. To interlink the storage with the machines, mainly electric carts on rails or wire guided vehicles are employed. Whilst the former is the more economical version wire guided vehicles offer immense flexibility. They not only allow the optimal material flow with regard to the workshop and floor conditions but as well offer the possibility to being able to serve a multiple of machines.

An extremely compact material supply situation is formed by coupling the machine direct to the store.

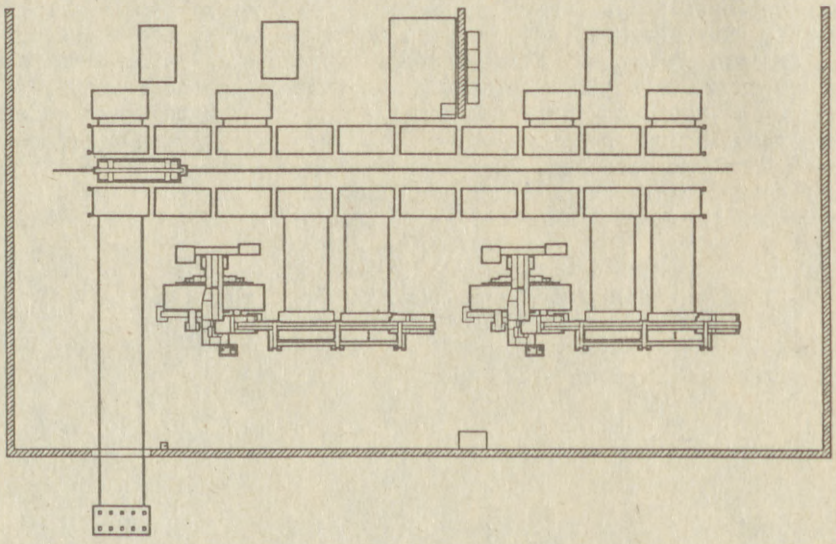


Komponenten einer Blechbearbeitungszelle

With such a system the pallets are taken from the store by the pallet picker and directly positioned under the loading unit for the machine. Thus shortest material preparation cycles are achieved.

Integrated Manufacturing Systems for Sheet Metal Components

The use of the store not only for raw material but additionally to receive machined components offers an advantageous work flow. At the same time the store can be used to interlink the punching/contouring operations with a pre or successive machining station. An example employing one guillotine shear, two punching and nibbling machines and two press brakes combined to form an integrated manufacturing system for sheet metal parts is shown on below illustration.



The machines are arranged on either side of the twin row store configuration. The material flow inbetween store, punching and nibbling machine on one side and the guillotine shear and the press brakes on the other side is controlled in the sequence of the orders to be processed by a computer.
This system is employed in multi shift operation at a switch gear manufacturer. A substantial productivity increase in the sheet metal department has been achieved by means of the flexible automated material flow using the shortest possible ways within the system. Furthermore a noticeable drop in order lead times and less inventory might be interesting to report.

High Tool Flexibility and Availability

The adaptable raw material and finished component handling is important enough for an automated manufacturing of sheet metal parts in small numbers but to achieve a high degree of utilization it is important that the machines have access to tools without the necessity of frequent change-overs. The availability of large numbers of tool sets is in sheet metal important for the automatic operation for two reasons:

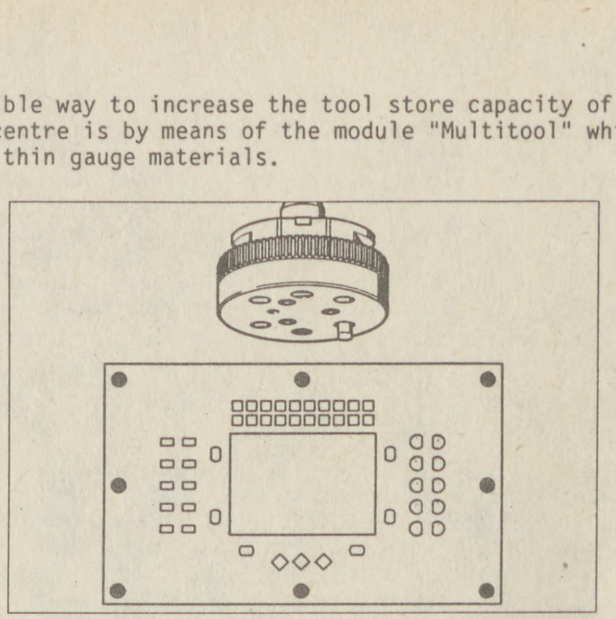
First the cycle times and therefore the use of the individual tool is relatively speaking small, they are definitely smaller than in metal cutting. This would mean that with a fast order succession the machine with a limited tool capacity could run only for a short period of time without being attended.

Secondly when punching various material thicknesses it is necessary to have various tool sets even with the same geometry as the die clearance, which is the clearance between punch and die, depends on material thickness. Alone this requires a large number of tool sets if frequent change-overs are not wanted.

Modern sheet metal fabricating centres today offer a large range of features to take care of the tool requirements for an automatic operation. So, for instance, a substantial extention of the tool availability has been successfully accomplished by means of the combination punching and laser cutting, whereby the thermical tool "Laser Beam" can be used universally. The same applies with only a few restrictions for the combination with plasma cutting.

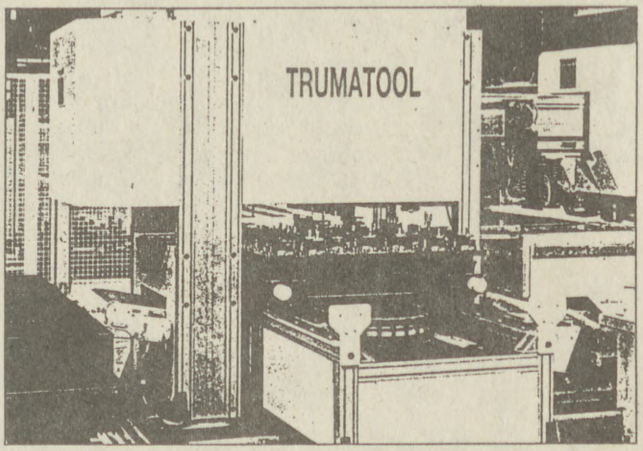
But as well on the punching side there are solutions available. Both, flexibility of tool usage and numbers of available tools take care of the requirements for automation to a large extent. The first noticeable item in this context is formed by the module "Rotary Ram". By the introduction of a third axis to control a rotary movement of the tool adapter it has become possible that shaped tools can be applied under any angular position by means of the programme. This guarantees a multiple useability of one and the same tool with the advantage that the necessary number of tools can either be reduced or with the same store capacity it becomes possible to employ a larger number of tools with various shapes.

Another possible way to increase the tool store capacity of a sheet metal fabricating centre is by means of the module "Multitool" which can be employed for thin gauge materials.



With this additional module for punching machines one basic tool body incorporates a multiple of small individual tools which can be called off independently by the programme. Thus any tool store position can hold up to six various tools extending the total available tool capacity by the multiplier six.

Access to still more tools can be obtained by employing a tool handling system to carry out the tool changing.



With this concept the tool system will feed the sheet metal centre with tools taken from an extensive tool store magazin with a capacity of up to 196 tools. If necessary, the tool changing system pallets may be set up while the machine is running. A comprehensive tool administration appoints the individual tool to the pallet place.

Furthermore the hit rate for each tool and, when required, tool lenght offset values can be recorded. By these measures sheet metal centres can be operated for long periods of time without any interferance regarding the availability of tools. The flexible automated sheet metal machining in small batches requires furthermore a direct transfer of control data into the machine's CNC control. In the simplest case this can be carried out by means of a call of terminal whereby a number of programmes are called off from an external memory and transferred into the CNC memory on the machine.

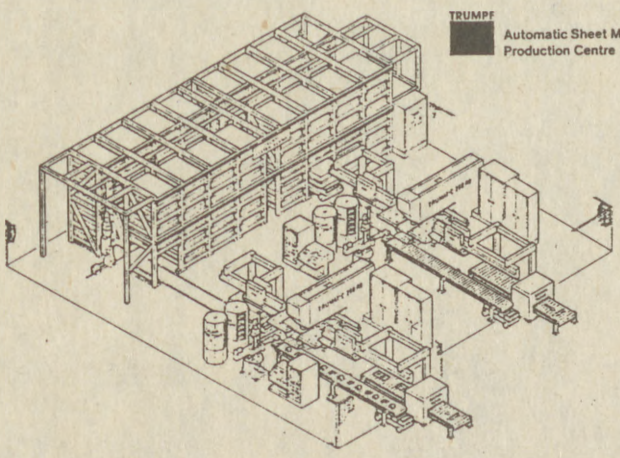
Host Computer Controlled Sheet Metal Manufacturing Systems

For an independent full DNC system the services of a host computer are required which would feed the machines with NC-data and at the same time control all the peripheral components such as storage and retrieval system or material transport. Thus the whole system is supervised.

By means of the elements
* free and direct access to material store
* change-over-free raw material and component handling
* extended tool store capacity and
* computer guided process control and monitoring

combined with an efficient CNC sheet metal fabricating centre to a total system the aim is reached to produce sheet metal components in small numbers by means of flexible automation.

An example of a system capable to fulfill this task is shown on below illustration.



Such a system was installed during the course of last year at a company situated in Germany, manufacturers of computers and laboratory equipment. The components are produced in their majority from aluminium and stainless steel materials and the material thickness is ranging from .7 to 5 mm. The comparatively small parts are made from sheet formats with max. dimensions of 1.000 x 1.250 mm. In a pattern repeating system a number of identical components are produced from one sheet.

The main components of this system are two highly efficient punching/nibbling centres, one storage and retrieval system, loading and unloading equipment for the machines and a host computer. The storage system retains all the various materials used in the company's sheet metal department. There is a capacity of 88 pallets each with an usable area of 1.000 x 1.250 mm and a load capability of 1 ton. The max. sheet stacking height is 200 mm. The pallet location in the store is at random and monitored by the host computer which as well takes care of the material administration keeping track of sheet per pallet togehter with type of material and gauge size. The machines are connected to the store by means of rail type carts. They are computer controlled and carry out the transport of order related material to the machines and return unused raw material to the store when a material change is called for. By means of the loading equipment individual sheets are separated from the stack and accurately fed into the machine. For the punching/nibbling and separating operations a total of 200 tools are at one machine's disposal. They are administered by the host computer which as well takes care of the actual tool lenght offset values, accumulated hit rates and the tool store pocket location.
Two different means can be used to unload finished components. Smallish parts leave the machine via a programmable chute, larger ones by the aid of the suction cup equipped unloading unit. Both devices will pass the parts onto conveyor belts which will take them out of the system and transfer them to deburring and degreasing machines. Material remnants and clamp strips will not have to be taken care of as they will be totally chopped off and sent through the die into the chip bin. All the equipment related to machining and handling of raw material and components is designed in a way that the extremely high surface quality is retained, this means that a far advanced scratch free operation will be possible. Besides the material and tool administration the host computer will in correlation with production engineering and process control under consideration of material and tool availability supply the individual orders to the machines. The NC programmes are normally rather substanial and in order to avoid any break, a data accumulator proceeds the CNC control. This is acting as a buffer memory which receives the data at a high rate and simultaniously passes them on in a blockwise manner to the machine's control. A smooth operation of the whole system is guaranteed through the intensive data communication between the programmable controllers of the individual modules and the host computer. At the same time the host computer takes care of comprehensive operating data recording.

Manufacturing of Sheet Metal Components in Small Batches by Means of Nesting

Whilst batch sizes on the aforementioned system allow a pattern repeat whereby identical components are spread out on one standard sheet, will this not be practicable when very small numbers of components or even individual parts are concerned as waste would become excessive. On the other hand using sheet sizes which are related to each individual component would render the size of the material store and complexity of the handling equipment unacceptable. For this reason today in a number of cases various components are combined and spread out on a common standard size sheet.

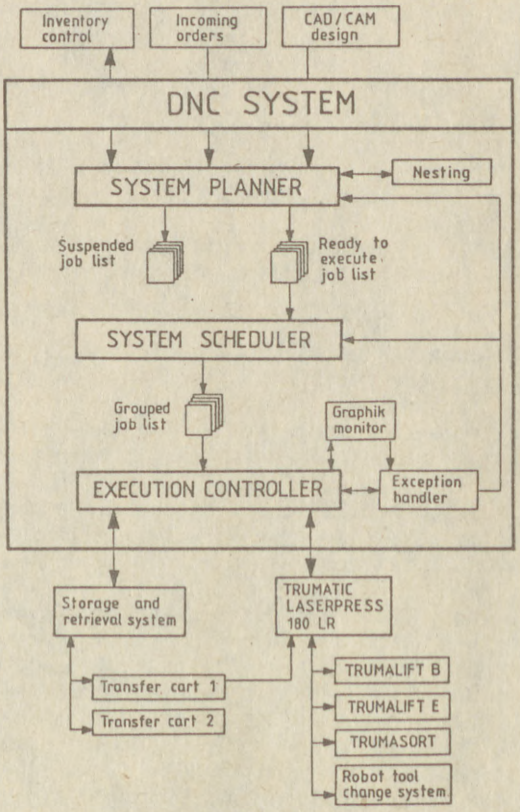
This is mainly the case where order orientated manufacturing with a short lead time towards assembly results in extremely low quantities. By means of this technique which is called "Nesting" both handling and material waste will be minimized. Of course to use nesting economically a number of substantial features are demanded from the equipment. A comprehensive hard- and software system for generating and transmitting of NC programmes for the total sheet spread is not sufficient.

Machine specific requirements must be met as well with regard to

* machining of components which are laid out on the sheet in various positions
* a large number of available tools and
* an efficient equipment to separate the individual components from the sheet.

These basic requirements can be accomplished easily by the already mentioned three axis controlled punching machine fitted with a robot tool changer.
A manufacturing system with computer control and based on the aforementioned machine and nesting principle is being commissioned at a German manufacturer of medium and low voltage switch gear just at this very moment. Although based on modules their products are custom made and repeat orders are practically zero. The installation aims towards an automated manufacturing of sheet metal components with a lead time reduced to a few days only.
The requirement of individual components which are in process during the same nesting period and which are made from the same material are compiled to form a common order. The computer will nest the parts into a number of standardized sheets under consideration of waste material. From the individual component programmes the computer will generate NC-sheet-programmes and pass these on to the controls on the machines. First all the punching operations over the whole material area will be performed and successively with the material still in the same clamping position the parts will be separated.
A similar set-up is realized at an American manufacturer to produce emergency power equipment. For their component range incorporating some difficult contour lines a punching/laser cutting combination is best suitable. The material supply to the machine is carried out from a store via interlinked transport equipment. As well here an industrial robot takes care of tool changing. Punching and laser cutting operations will produce the parts which are nested in standard sheet sizes. By laser cutting of the external contour the individual component will be separated from the skeleton and can then be removed by the automatic unloading equipment. For the assorted stacking of different components being produced simultaniously a number of positions are available on either a sorting table or on two shuttle carts. A gripper arrangement will be used for the removal of the skeleton itself which is then placed onto a special table for disposal. The total functional sequence within the system is controlled by means of a computer again coupled to a material management computer and a CAD/CAM system providing data on requirements, inventory and components.

The principle of the control system is shown on below illustration.



It is divided into three logical function blocks: The "System Planner" is used for the administration of individual orders together with the appropriate part programmes. It decomposes the individual orders into a succession of waste-minimizing nesting layouts which according to material and tool availability are inserted into an order queue or a waiting list. The order queue which is generated on a first-in/first-out basis is revised by the "System Scheduler" in a way to obtain an optimal utilization of the system. The "Execution Controller" is responsible for the actual order processing. It initiates the material supply from the store and transfers the total sheet NC-programmes to the punching and laser cutting machine. At the same time it monitors the manufacturing process and the status of the most important system mudules.

Manufacturing automated in such a way solves the problem to produce flat sheet metal components economically even when continously changing orders necessitate the production of parts in very small numbers. This guarantees the flexibility which today is so important in sheet metal fabrication with our rapidly changing markets and products.

INTEGRATED CUTTING TECHNOLOGY PLANNING SYSTEM

L. Bolla, ITC-AMT Ltd., Hungary
I. Cser, ITC-AMT Ltd., Hungary

Technological planning is a part of technical preparation of manufacture. its tasks are as follows: planning the manufacturing processes and producing the technological documentation required for the manufacture (process charts, operation sheets, NC controlling program tapes etc.). Profoundness of tech - nological planning, as well as types and detalling of documentation to be printed out must be in accordance with organization of manufacture and automation level of the manufacturing system given (or: factory, workshop, manufacturing cell, etc.) including its equipments, devices, facilities. The higher requirements are set against technolgy planning by CIMs carrying out integrated material - and data processing.

The CIM concept assumes informatical connection between the machining process planning and other subsystems of the preperation of the production. The main elements of the machining process planning system and their connections with other elements of the CIM system can be found in [1]. We have developed on integrated machining process planning system within the scope of the hungarian OKKFT G/6 research and development project. This system has features for the connection with other elements of a CIM system and has been developed in cooperation with Technical University of Budapest (BME), University of Miskolc (NME) and Computer and Automation Institute of Hungarion Academy of Sciences (MTA SZTAKI).

The planning tasks which can be performed include all features of the computer aided machining process planning:

- rough process planning (analising of the machining requirements of the workpiece, choosing the machine tools, clamping metohods and devices, determining the operations and generating their sequence, elaborating process plan variants, editing process plan sheets);
- Fine process planning (generating the operation elements and their sequences , choosing the cutting tools and planning their arrangement);
- Planning of operation elements (planning the tool paths, determination the cutting conditions, computation of time data);
- Postprocessing (final modification of the process plan according to the manufacturing environment, the machine tool and its control system, elaborating the NC tapes and the environment-specific documentation).

The majority of the recently publicated CAD/CAM systems support only the last two groups of planning tasks. These have not intelligent features for the rough and fine process planning tasks.

The subsystems and outer connections of our integrated process planning system can be shown in the fig. 2. The subsystems, all of which can be used as self-contained program product are:

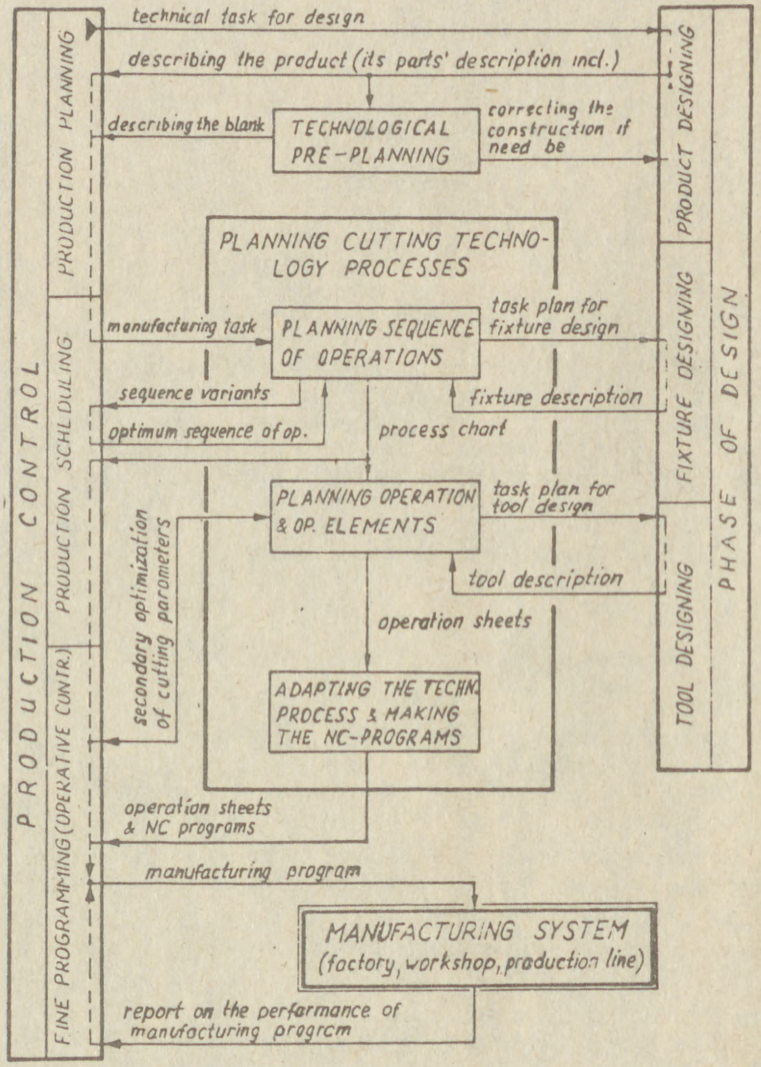


Fig.1. Interconnections between the technical preparation and control system of manufacture

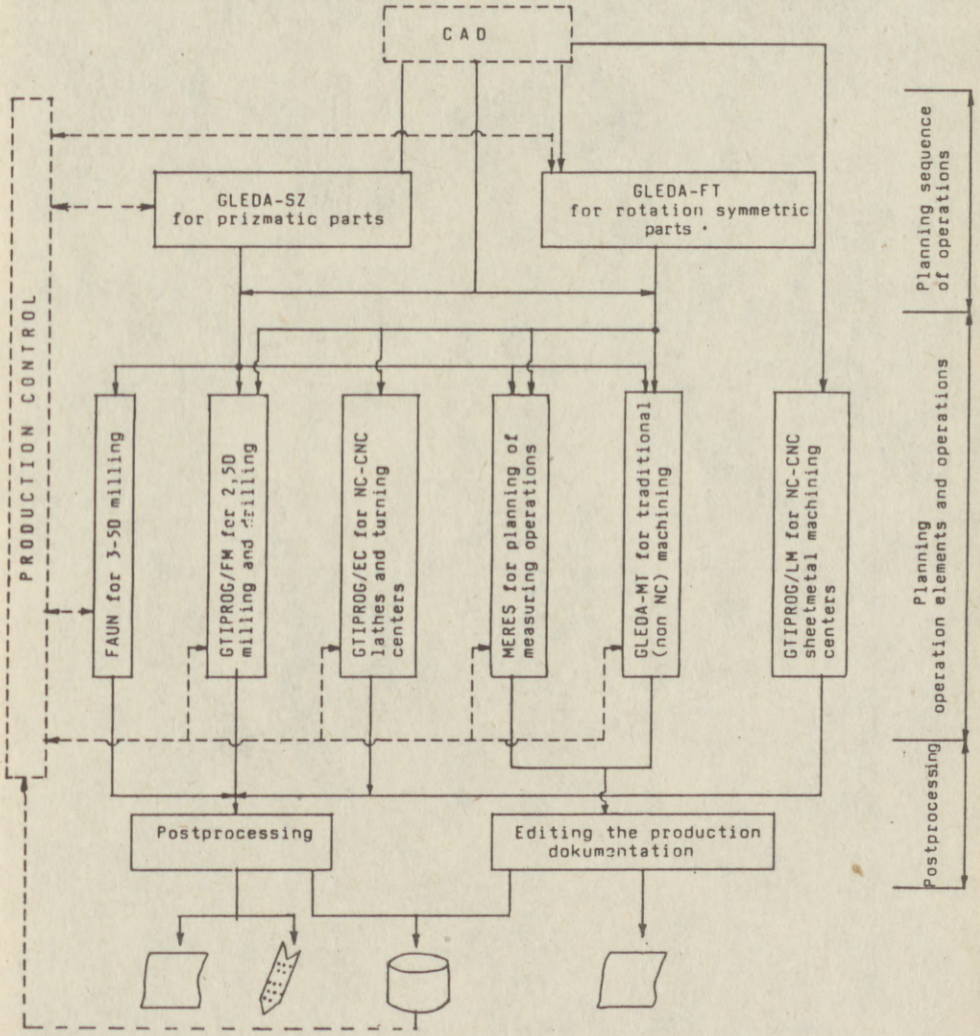


Fig.2. The main structure and subsystems of
Integrated cutting Technology Plannning System

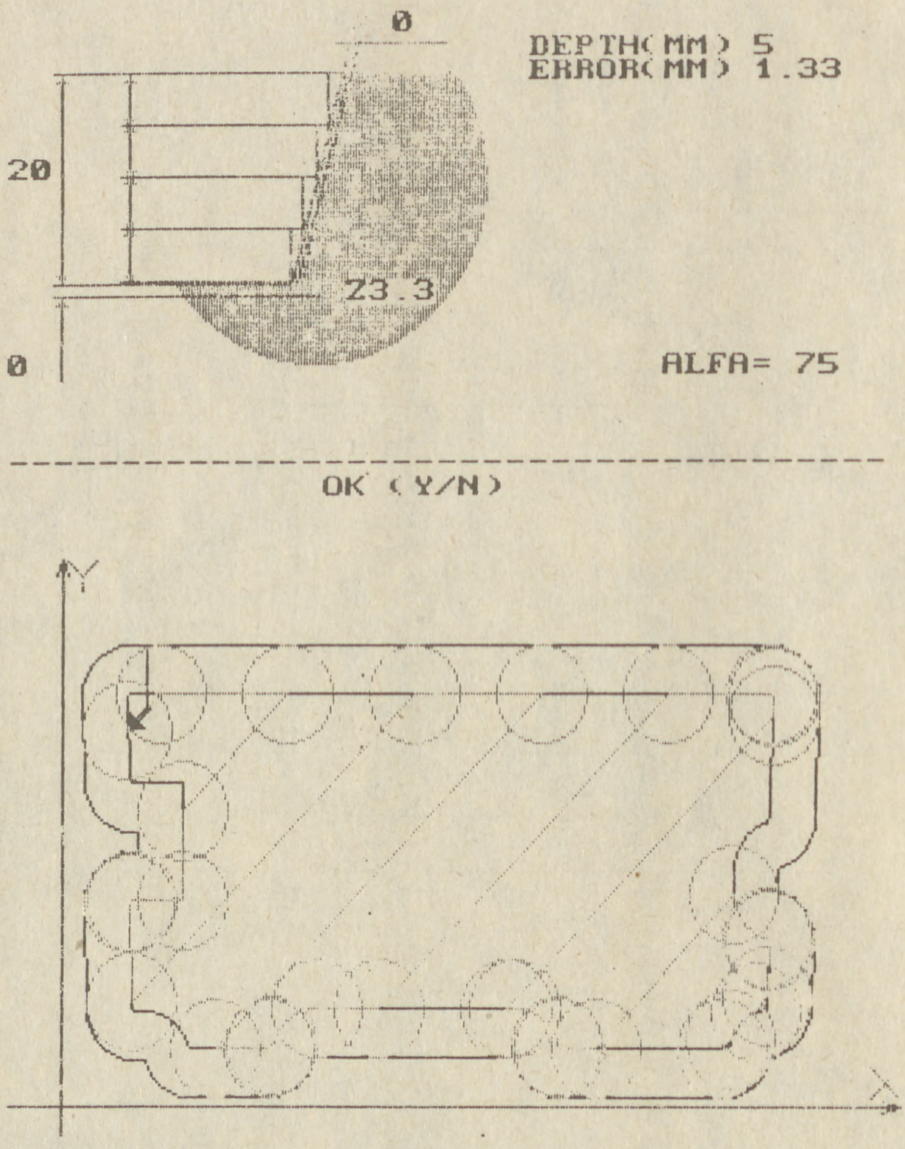


Fig. 3. Planning of pocket milling by GTIPROG/FM

- GLEDA-SZ	rough process planning system for prismatic and cubic parts;
- GLEDA-FT	rough process planning system for rotation-symmetric parts;
- GLEDA-MT	fine process planning system for conventional and special purpose machine tools
- FAUN	fine process planning and NC programming system for 3-5 axis machinings (developed by the BME);
- GTIPROG/FM	fine process planning and NC programming system for 2.5D milling and boring;
- GTIPROG/EC	fine process planning and NC programming system for lathes and turning centres;
- GTIPROG/LM	fine process planning and NC programming system for sheet metal parts
- MERES	Planning system for inspection operations

More information for the GLEDA-FT, -SZ and -MT as well as the GTIPROG/EC systems can be found in our contributions for the printed matter [2], [3].

Our process planning systems can be used for conventional and NC/CNC machine tools as well as conventional machine shops and FMS'too. All of the subsystems have full modularity which supports the develoment of custom-tailored software. The subsystems have basic features and options for the sake of versatile applications. For example the main elements of the GTIPROG/FM system are:

- GTIPROG/FM basic version for 2.5D milling and boring,
- TECH option for selection of cutting tools and determining of cutting conditions,
- ZSEB option for regular pockets,
- ZSAK option for non-regular pockets without and with islands (Fig.3),
- SIKGORBE option for handling of splines.

From the subystems and their options we can integrate the most suitabla system for the given application field and user requirements. For example, the fig 4. and the fig 5. show tipical systems for rotation-symmetric and prismatic parts accordingly.

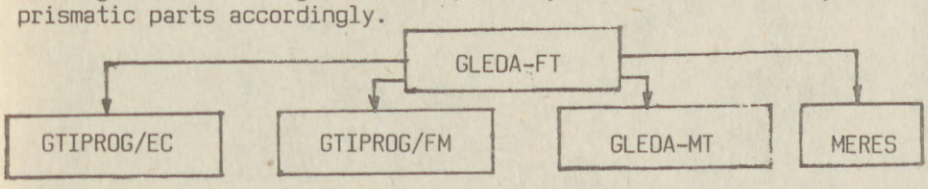


Fig.4.: Subsystems for rotation parts

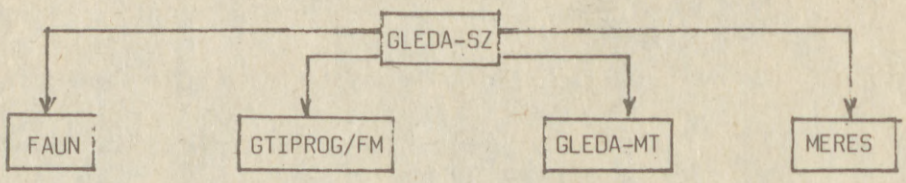


Fig.5.: Subsystems for prismatic parts.

The connection of our integrated system with the production control and scheduling system can be as folluws:

a) the production control system can prohibit temporarily or permanently the application of a given machine tool, cutting tool at the level of raugh process planning,

b) the process planning system can offer process plan variants, time and cost data for the production control.

As for the connections with the CAD systems, the process planning can use CAD workpiece data. We have developed this connection with AutoCAD system. Data exchange can be realized with tool and fixture design. The AutoCAD and similar systems use drawing representation instead of worhprece-modell. This causes difficulties at the using there data for process planning purposes. The process planner can intervene interactively at the interpretation.

At the realisation of the connection our system with the AutoCAD we used two methods anording to the task:

a) The process planner completes the informations of the drawings with data, instructions and nominations on a technological purpose layer which have to be freezed. The process planning system make use of this information.

b) We gain the required geometrical information from the CAD system by the help of CAD+ modules written in AutoLISP language and can be run under the AutoCAD.

in the Fig.6. the "b" variant can be shown [4]

The implementation of our integrated machnining process planning system for the environment of the user is assisted by the modular structure, the user-specific data and knowledge base and the processor- postprocessor pinciple.

The process planning system as a part of a CIM is tested now at the BME and NME experimental CIM systems.

References

1. I.Cser, T. Tóth, Computer-Aided Technological process Planning, Methods, Systems and Application Experiences, in: Modelling and Design of Flexible Manufacturing Systems, edited by Andrew Kusick, Elsevier Science publishers B.V., Amsterdam, 1986. p: 249-285.

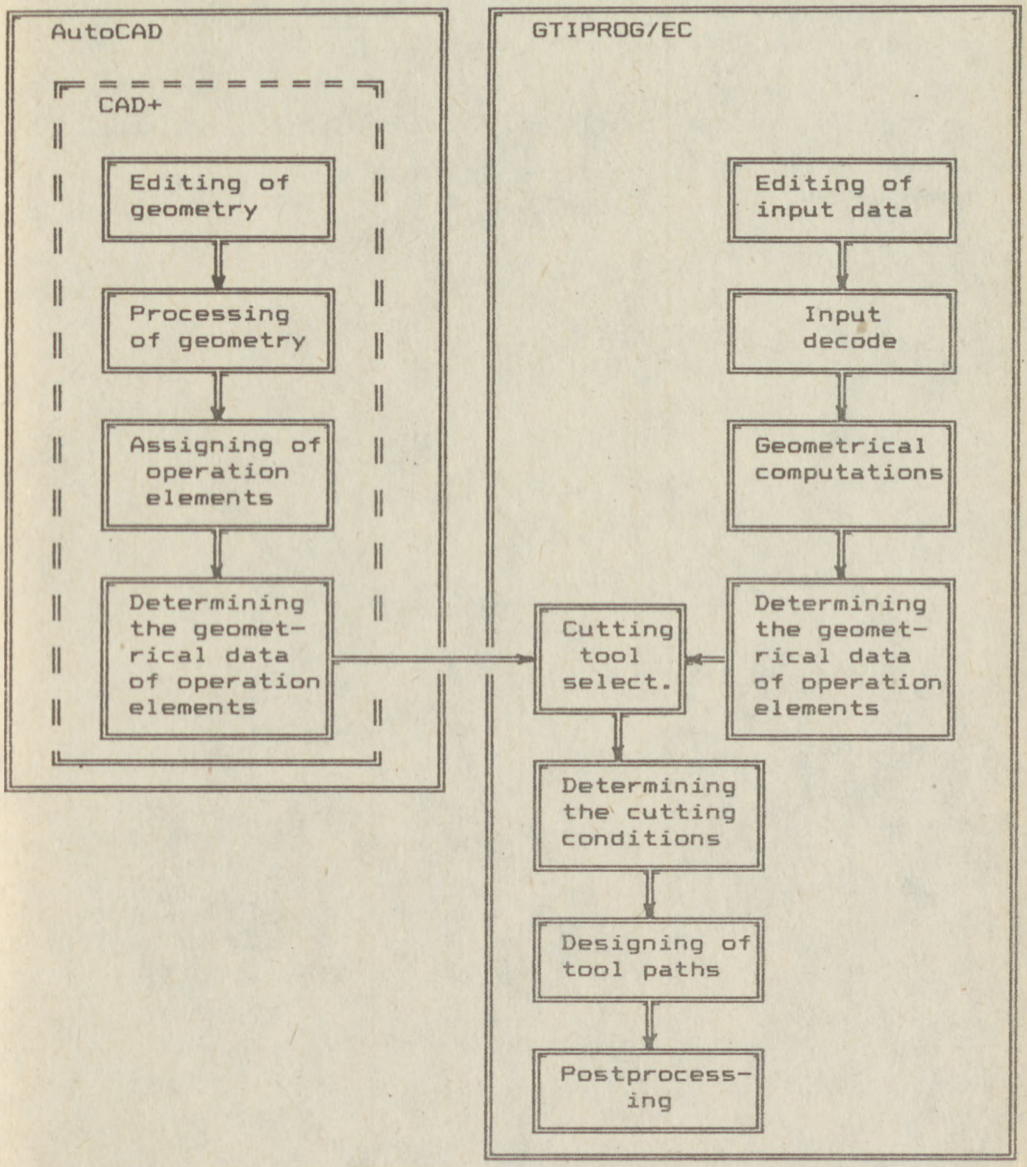


Fig. 6 Integrated AutoCAD - GTIPROG/EC system

2. Dr. László Horváth, The GLEDA Computer-Aided Manufacturing Process planning System, in: preprints of the INTERTECHNO'90, Budapest, 1990.

3. Dr. M.Berta, Dr.I.Cser, M.Juhász, Turning Centers Programming by GTIPROG/EC System, in: preprints of the INTERTECHNO'90, Budapest, 1990.

4. Voloncs György, CAD/CAPP-rendszer fejlesztése NC esztergálási műveletek tervezéséhez, in: Ipari Technológiai Tájékoztató 1988/2., p:141-146.

BAKÜER MODULAR SYSTEM

Mauro Cioci
BAKÜER S.r.l
via Stagnacci - 50010 BADIA A SETTIMO, Firenze, Italy

Machine tools had in the recent past remarkable developments and improvements and the new exigencies compelled their manufacturers to find solutions having as a main objective the achievement of the maximum flexibility of use.
The new machines, thanks also to the evolution of the numeric controls, are now able to very easily shift from one to another machining operation. To better take advantage of the potentiality of said machines, also the toolholders had to be adequated to the new needs. Actually, as a matter of fact, integral toolholders proved to be uneconomical for the owners of many CNC machines and machining centres. There was an enormous growth in the number of toolholders due to the fact that each machine has its own particular attachment and has to be equipped with its own toolholder stock.
Even the flexibility of machines was thus jeopardized because it was practically impossible to transfer a machining cycle from one machine to another one without more and more increasing the stock of toolholders, already very important.
The investment of capital was, therefore, very heavy.
To try and solve these problems, Baküer designed and manufactured a system of modular toolholders compound from modular elements. Baküer Modular System is based on two main principles.
The first one is to disassemble the toolholder into its main parts: attachment to the machine and front part, so as to allow to mount on any machine attachment any array of toolholders.
The second principle is that of decomposing on its turn the front part, still using modular elements, in order to allow for the realization of the most suitable toolholder for each machining process, by using intermediate elements consisting of extensions and reductions,which can be inserted to obtain various lenghts of the toolholders and the various diameters which are to be obtained starting from the greatest diameter up to the smallest diameter adequate to the diameter which is to be machined and achieve thus the maximum rigidity of the toolholder as necessary for the desired machining process.
Up to now the majority of integral boring bars were available only in special execution because the toolholder had to be tailor made for the specific process for which it was designed. Delivery times were consequently very long and it was necessary to have a boring bar for each machining operation. The Modular System eliminates this problem. In fact, on one side the existence in the inventory of composable elements allows for the assembling in place of a boring bar having the desired structure and on the other side the same boring bar can be disassembled and re-assembled from other elements to obtain a new boring bar ready to be used in another process.It is to be underlined that the technological performances of the modular toolholders

are equal to the performances of the corresponding integrals. The results are even better regarding resonance and vibration due to the fact that the joints act as damping elements. Under the economical point of view, the modular toolholders have proved to be far more economical as compared with the integral toolholders. If the cost of a single boring bar or toolholder is examined, one can have the impression that the modular toolholder is more expensive, but if one takes into account that the various elements can be used to compose several toolholders or boring bar structures, it can be easily noted that the initial cost divided by the number of obtainable structures by using the same elements is by far less than the cost of one integral boring bar.

BORING HEADS.

Particular attention is to be given to the boring system modular type, which allows through the use of insert-holding bars triangular, square and finishing heads, to bring about machining operations from a minimum of 8mm diameter up to 340mm diameter. By this system it is also possible to achieve bigger diameters up to 666mm (whilst usually special boring bars are necessary) by using the proper extension arms being part of this system.

MODULAR ELEMENTS WITH POSITIVE DRIVE.

Since when machining large diameters the couple which develops overcomes the locking couple applied when assembling the various elements, thus going into an overlocking phase, which may determine a condition of unscrewing irreversibility, a system of positive transmission of the forces has been studied. This system provides a front tag which by engaging the elements joined together, prevents the overlocking. This system is available starting from 63mm diameter.

F.M.S TOOLING LINE.

The evolution of toolholders for flexible production lines is not limited to the proper Modular System but has greatly grown by the development of special devices which allow for an extensive automatization of the machines and reduction of their costs of use. Baküer " F.M.S TOOLING LINE" is an answer to these exigencies. This line can be used both on NC and CNC machines as well as on traditional machines. In this line are comprised the following devices:

1. Speed Increaser.

To reach a high revolution number of the machine spindle in order to work in optimal conditions even with small diameter cutters has always been a problem for the users of machines. In order to solve this problem Baküer produces a speed increaser which allows to increase the revolution number from 1 to 4 and from 1 to 7 times with a limit of 12.000 revs. Besides preventing any slipping effect, these gear devices allow for a remarkable transmission of power.

2. Angle Heads.

Not all machine tools can bear angular boards. Consequently, it was necessary to use in the production line a particular type of milling heads. These heads allow to modify the orientation

of the tool with regard to the original axis of the machine spindle.They are available in two versions: right angle heads and adjustable angle heads. The movement is carried out in a continous way over 360°. By having two rotation movements, one at 90° and the other one at 45°, the adjustable heads permit the tool to be oriented on any point over a semi-spherical area. When used on CNC machining centers, these heads can be provided with coolant feed through the index arm.

3.Oil Feed Holders.

These devices are specifically conceived to feed the coolant inside all tools designed to this purpose. In case of traditional machines, the coolant is fed to the body through a simple threaded shank and a bar will prevent it from rotation. The oil feed holders for CNC machines are provided with an index arm which besides connecting the feeding of the coolant also prevents the holders from rotating. The index arm can be oriented over 360° (it has not a steady position,as usual) to be placed in any position on the circumference. These devices are supplied in two versions: standard type which can reach 3,000 revs.ca. and special type which can reach 7,000 revs.ca.

3.Blower Device.

During the machining function of machining centers without operator, it can frequently happen the necessity of having to take off residuate chips from the interior of holes prepared to undergo a further finishing process, such as tapping, boring or other. The Blower Device has the basic functioning concept of blowing exactly onto the point a strong jet of compressed air. The nozzle moves perimetrically around the hole or recess to be cleaned with perfect cleaning results. The Blower Device has a taper engaging with the machine spindle with which engages a body inside of which resides the collector for the air passage. A side pin has the double purpose of establishing the position between the drive guides of the taper and the position of the air inlet block. The pin has a valve lifter which automatically opens the air adduction valve. When the device is removed from the automatic arm the valve closes automatically. The inlet air valve is located into a threeway block which combines in a single monoblock the inlet for the coolant and the seat of the pins for milling heads, besides said valve.

5.Lubricant Oil and Grease Dosing and Distributing Device.

This device is particularly useful on machining centers when it is necessary to bring about a lubrication specific for particular machining operations such as tapping. Since it is not possible to use for tapping the lubricant used in the cooling equipment of the machining center, not sufficiently viscous for tapping and since the hand lubrication is expensive, Baküer studied a device, particularly apt for use on machining centers without operator, which works as a dosing-distributing device of lubricant oil and grease. The use of grease is particularly apt in tapping blind holes. The device has a taper attachment MT 3 and is apt to be mounted on any reduction with any taper type, what makes it flexible and apt to be transferred from one to another type of machine. It has a tank of transparent acrilic resin allowing to control by sight the quantity

of lubricant inside said tank. The device can operate both in vertical and horizontal position and a series of interchangeable nozzles with threaded joint is provided.

6. Taper Cleaner Device - P = R - O,oo.

The cleaning of the machine spindle is a main condition to warrant concentricity and repeatability of tool changers. The machining centers provided with tool cribs of great capacity, have sometimes due to long machining cycles to keep on stock tools for a rather long time so that dust particles, grease and the like deposit onto the same as are present in every workshop. For machines which do not have their own cleaning apparatus for cleaning the machine spindle, Baküer offers a device which takes away from the taper seat of the machine spindle the above said impurities. This device, called P = R-O,oo, can be included in the programm like any other tool and can be programmed for cleaning at the beginning or at the end of the cycle. The total cleaning operation is very short: 3/4 seconds plus the time for changing a tool, i.e. ca. 16 seconds. During the cleaning operation the machine spindle must have a minimum rotation, however not less than 100 revs. The device is provided with felt holder bells for cleaning, which are replaceable, so that once they are worn out, only the felt parts are to be replaced.

7. Combined stop block

This device is apt to allow the feeding of coolant and compressed air. NC machines and machining centers have an increasing need to mount on the machine nose special devices of this FMS line. Each device must have its own stop block, even with the same interaxis, so that it is necessary to mount one stop-block for each device. This causes difficulties since the space is rather limited. This drawback can now be overcome thanks to Baküer combined stop-block. By mounting this single stop-block on the machine nose, it is possible to mount 5 and more devices, different, but with the same interaxis, to which both coolant and compressed air can be fed. This device has the structure of a prismatic block with tapered and prismatic seats.

8. Oil Feeder Tapper.

To reach optimization in the machining of threaded holes on mechanical workpieces on automatic machining centers, Baküer offers a tapping device apt to yieldingly support the tap and to bring to the same the coolant taken up from a source positioned on the machine nose, but exterior to the machine spindle. This device merges the features of both the Oil Feed Holder and the Tapping Device. It consists of a shank having at its end a taper apt to fit on the machine nose. On this taper is located the tapping device with elastic tension and compression long stroke support. This tapping device has a distribution box allowing for the passage of the coolant through it to reach a special tap chuck with inner grooves for the coolant, which from them goes directly onto the tap.

9. B.F.B.

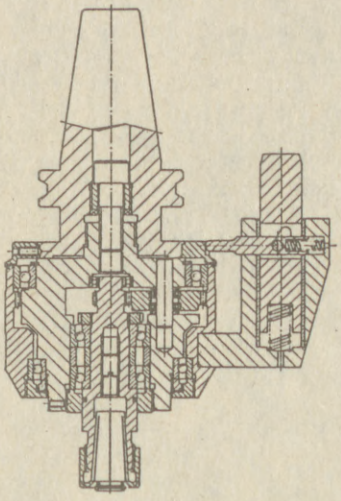
The BAKUER BORING BAR SYSTEM is a system of automatic adjustment "in process" of the tool of boring bars for automatic machines without operator. This system is very rigid, although the bar is

Mauro Cioci
compound from various elements, since these are rigidly joined by means of positive couplings and there is no moving element such as slides, eccentrics or the like. Adjustment occurs by a mechanism directly on the tool of the boring bar. The device consists in a body attached to the machine spindle through traditional systems of attachment. It can be handled like a common toolholder and controlled by the programm. Due to its average encumbrance there are not problems of space in the crib . A housing bell located on the side of the machine rotates outside the box of the speed decreaser with a high gear ratio: 1:500 or 1: 1,000 according to the model. At the other end is mounted a micrometric head, type ONE/TWO MICRON/BFB,which according to the type of the device can bore holes from dia. 0.5 up to dia. 124. On this head is located the insert-holder provided with an extra brake so as to stay rigid during the machining process. This tool is controlled by a mechanism inside the boring bar, which transfers the adjustment rotary motion from the reduction gear directly to the tool.The housing of the reduction gear can have a revolutions counter ring which transfers information to the CNC of the machine by means of a touch probe. The tool is adjusted by locking the outer bell with the help of a hydraulic or pneumatic device and by rotating the spindle by a number of revolutions as are necessary for the correction.
The operations necessary to correct the bore diameter "in process" by means of the B.F.B are as follows:

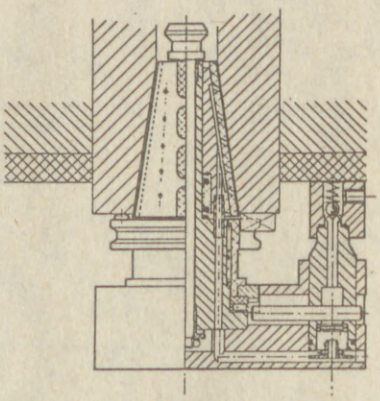
1. Boring
2. Checking by means of a touch probe which transmits the data to the CNC of the machine which latter changes the linear measures into number of revolutions following instructions received
3. Second boring if the diameter is smaller
4. If the hole diameter is larger, than the programm calls from the tool crib another device, namely a stamping device, which marks the piece with the legend " oversized"

The device guarantees the maximum accuracy as determined by the precision of the size reader.
The BFB can carry out corrections up to 0,002mm on the diameter.

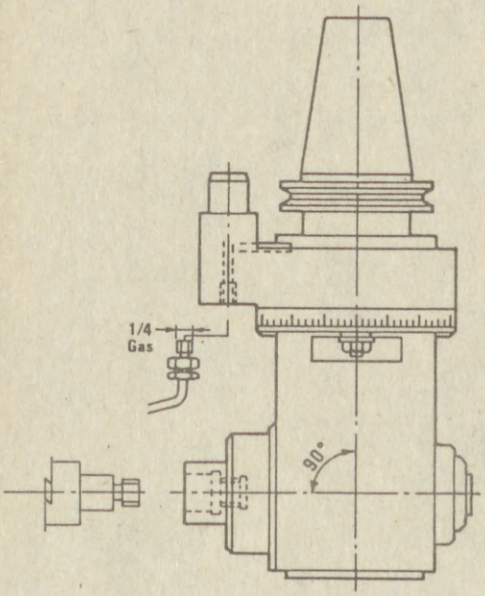
SPEED INCREASER



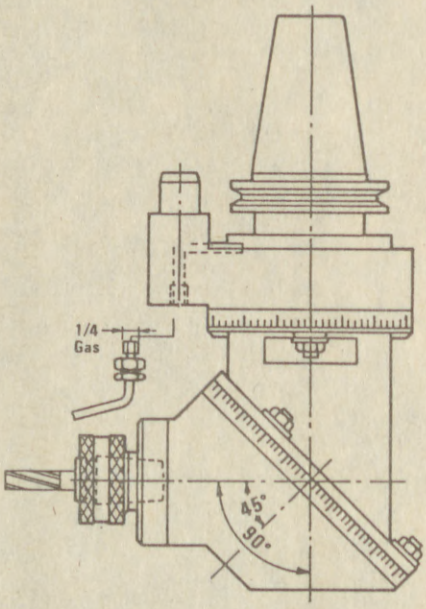
TAPER CLEANER DEVICE P=R-0,00

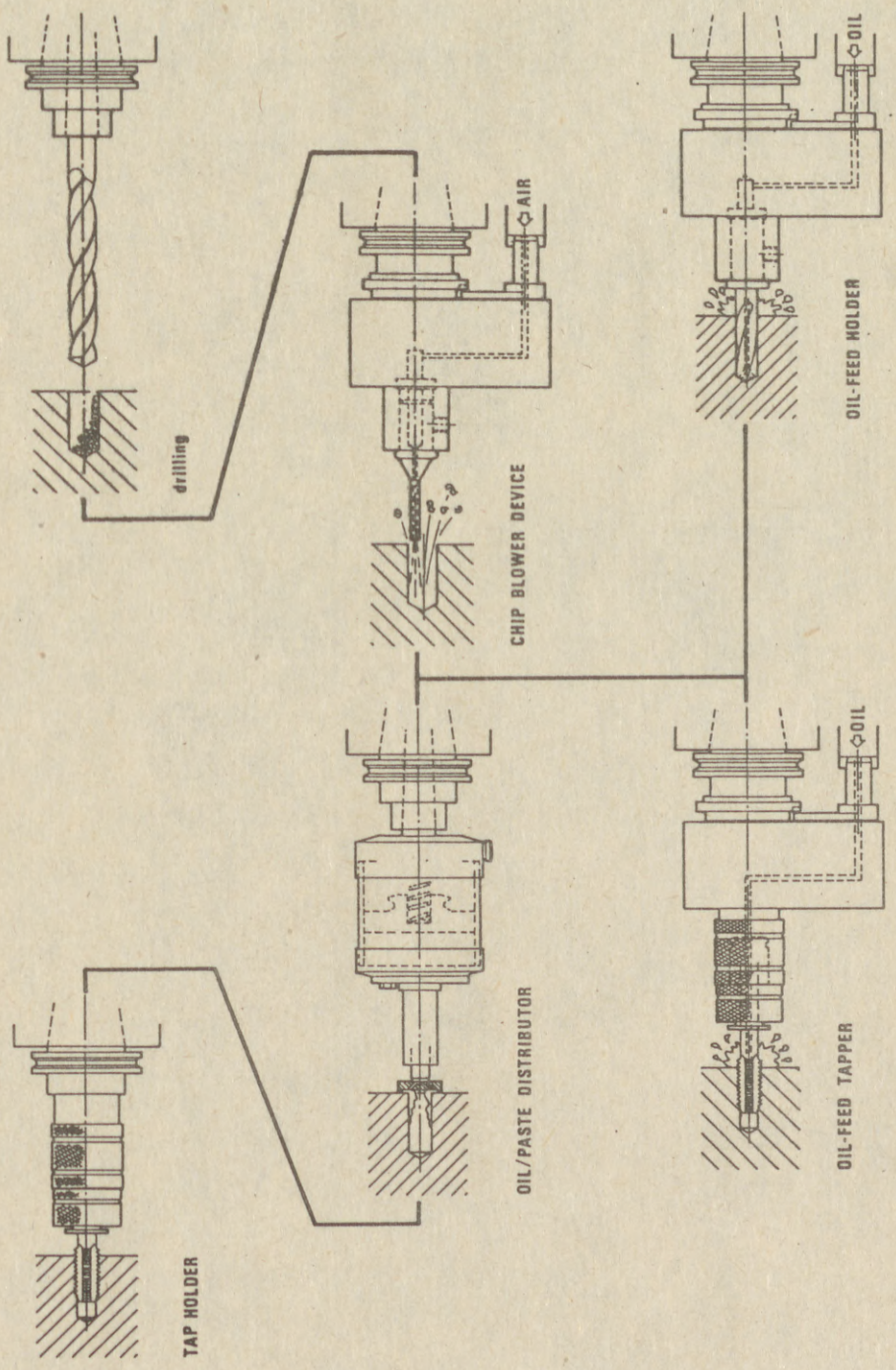


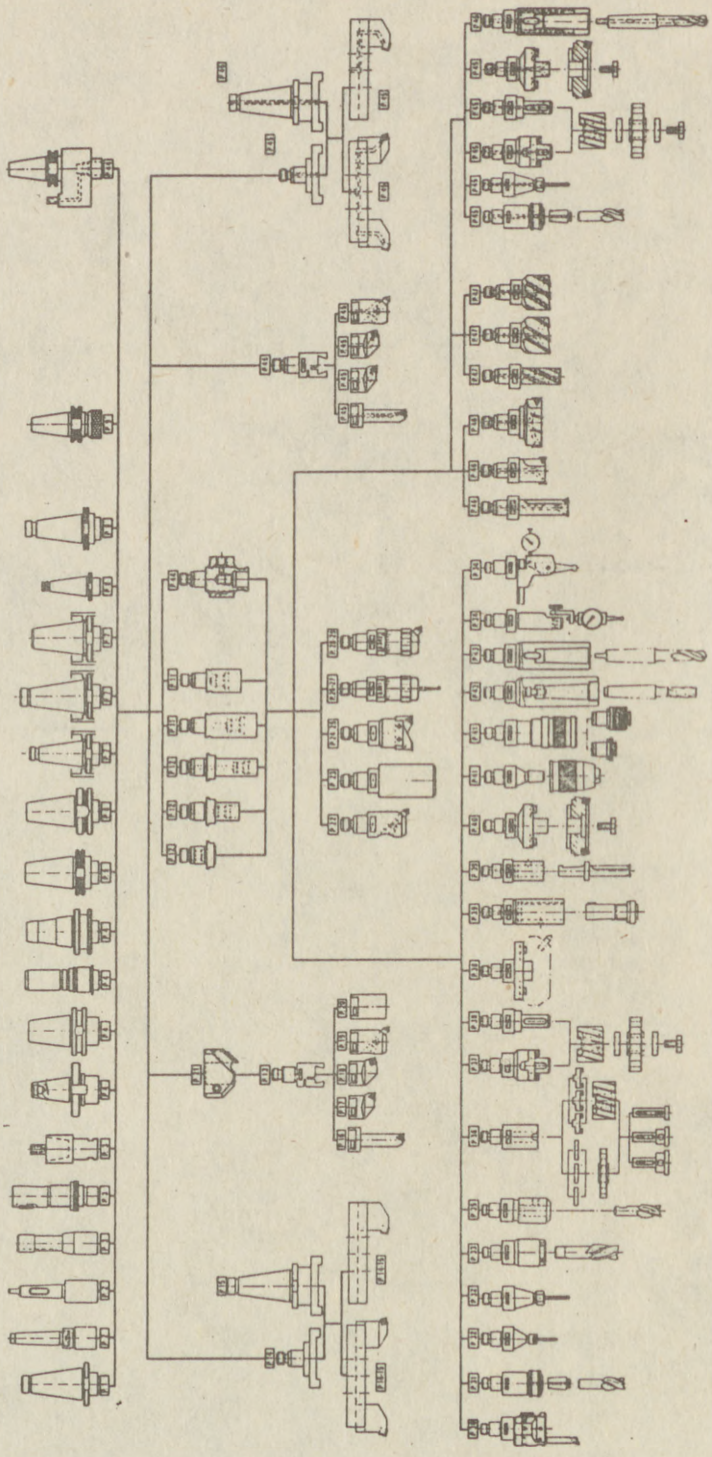
RIGHT-ANGLE HEAD



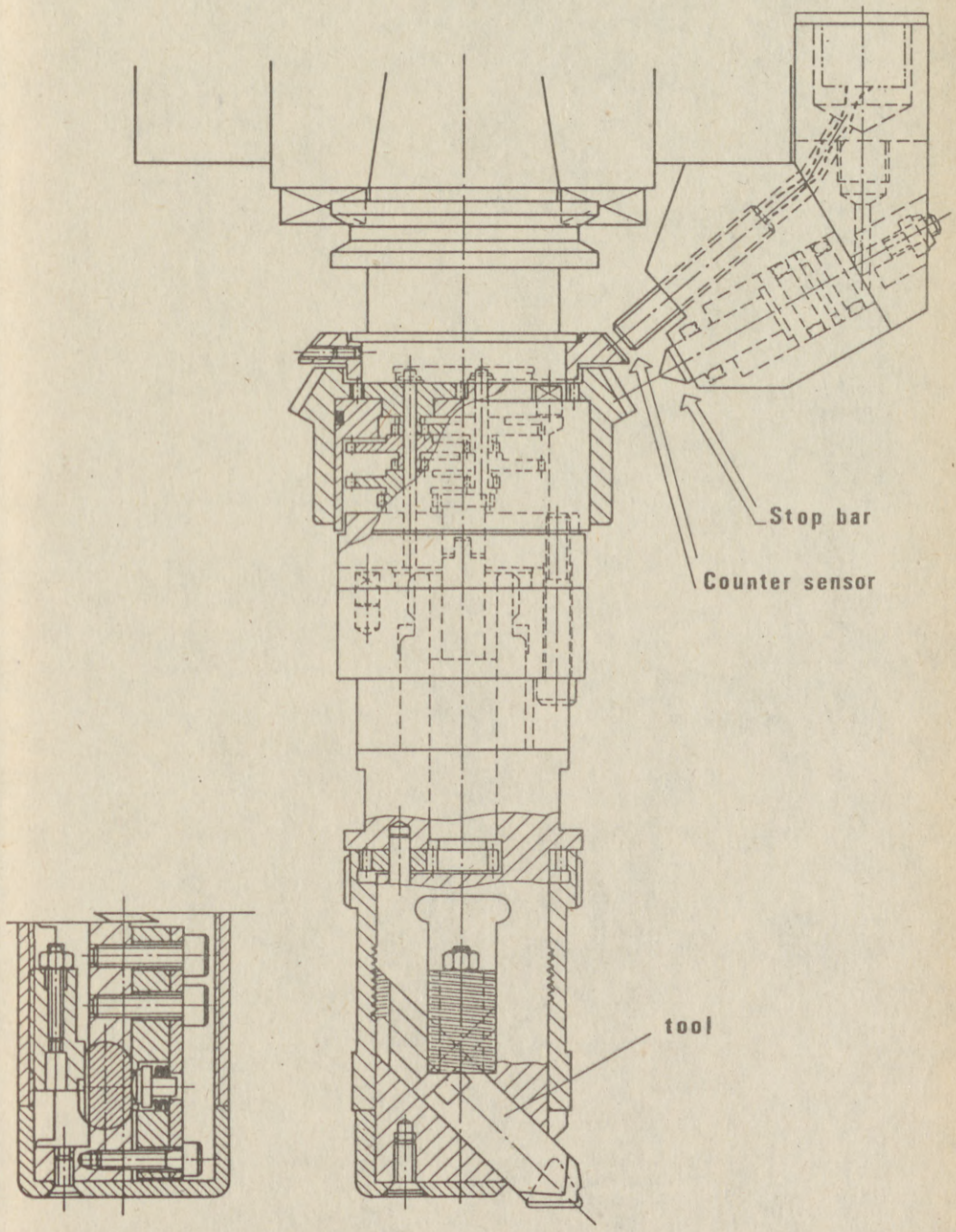
UNIVERSAL HEAD

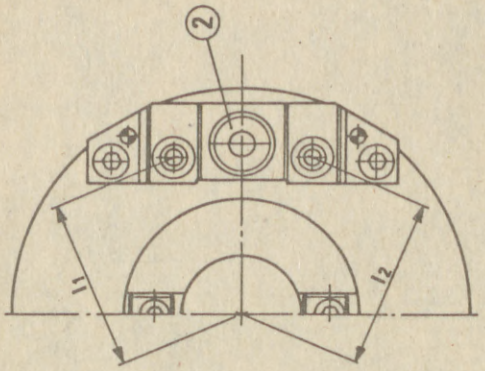


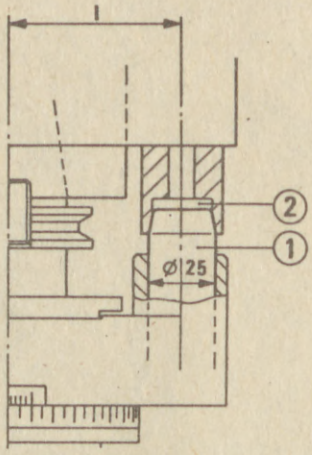

drilling
AIR
CHIP BLOWER DEVICE
OIL
OIL-FEED HOLDER
TAP HOLDER
OIL/PASTE DISTRIBUTOR
OIL
OIL-FEED TAPPER

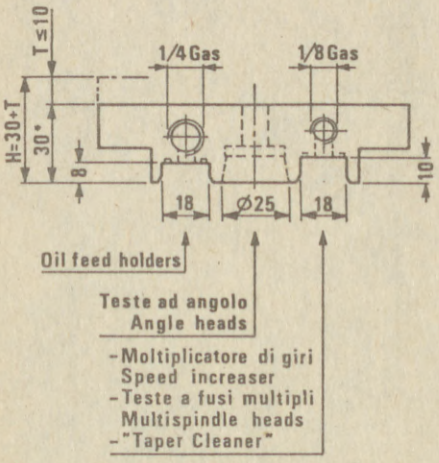


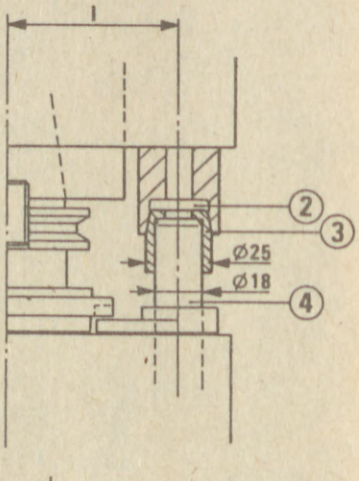
B.F.B.

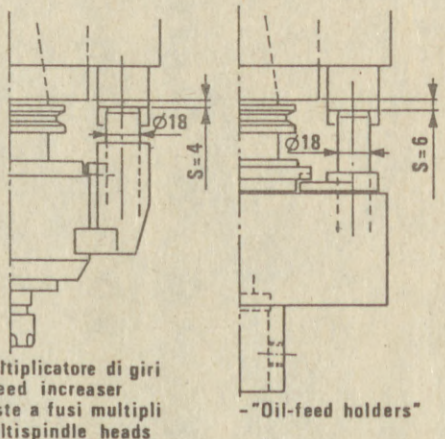



2
l1
l2


l
2
1
Ø25


T≤10
1/4Gas
1/8Gas
H=30+T
30°
8
10
18
Ø25
18
Oil feed holders
Teste ad angolo
Angle heads
-Moltiplicatore di giri
Speed increaser
-Teste a fusi multipli
Multispindle heads
-"Taper Cleaner"


l
2
3
Ø25
Ø18
4


Ø18
S=4
Ø18
S=6
-Moltiplicatore di giri
Speed increaser
-Teste a fusi multipli
Multispindle heads
-"Taper Cleaner"
-"Oil-feed holders"

CONTRIBUTION TO THE DEVELOPMENT OF CRITERIA FOR SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY

Dr Ilija Ćosić, associated professor
Mr Dragan Šešlija, assistant
Zoltán Tót, dipl.ing.
University of Novi Sad, Faculty of Technical Sciences
Institute of Industrial Systems Engineering, 21 000 Novi Sad,
V. Vlahovića 3, YUGOSLAVIA

Abstract

In many branches of industry, assembly costs are more then 50 % of all manufacturing costs and assembly involves in some cases even more then 40 % of workers. One of the reasons for such a situation is that, in past, a lot of attention was paid for improving machining technology not concerning assembly technology. Introducing of industrial robots in assembly without taking in account this fact, will be wrong way to improve productivity. In order to use industrial robots in assembly in proper way we have to know which product is suitable for such assembly, or in design phase, we can design products according to the criteria for the suitability of products for robotic assembly.
This paper deals with suitability of products for robotic assembly and presents it in a numerical way. Overall suitability for robotic assembly has three aspects: a) suitability of parts concerning grasping possibilities, tolerances etc. b) dimensional suitability, c) suitability for automatic handling. They are all quantified in special tables and final result is sum of those numbers. It can be used, also, as a help in choosing proper industrial robot for specified product range.

1. INTRODUCTION

Industrial robots are, due to their repeatability and ability to work in the hardest environment, present in production processes in a significant number. Application of robots is bringing increase in productivity and quality of work, successfully replaces workers at dangerous or monotonous jobs, cuts loses in material (no waste) and energy (no rework).
In the near past robots have been used mainly for spot welding and paint spraying but now days we can see increase in the number of robots applied in assembly. In that sense, assembly is predetermined to become one of the main fields of robotic applications. Basis for such an opinion are results of investigations that shows that more then 50% of production cost in some parts of industry are assembly costs and also, assembly involves about 40% of workers.
Design of products that have to be assembled is of essential importance for robotic assembly. Evaluation of product design in terms of suitability for robotic assembly should be very

useful for decision which technology procedure should be applied and also for possible changes in product design.
Design is suitable for assembly if assembly requires the least possible amount of time, assembly devices, space and personnel.

2. DEVELOPMENT OF CRITERIA FOR SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY

Many factors are of influence to the suitability of product to be assembled by robot. We have tried to encompass the most important and to systematize them in a clear and easy way. In our opinion overall suitability consists of:

- suitability of parts for grasping
- dimensional suitability
- suitability for automatic handling

Particular suitabilities are discussed in separate chapters and dimensional suitability is discussed separately for geometric dimensions and separately for mass.

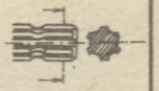
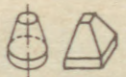
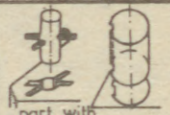
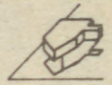
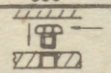
2.1 SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY CONCERNING SUITABILITY OF PARTS

This method consider characteristics of:

- product, subassemblies and parts design
- material
- assembly method concerning possibilities for robotic assembly

Suitability of products for robotic assembly (R) is reached through six steps using Table 1. Each step discusses a certain characteristic of the part or assembly operation and quantifies it. The more complex operation is the higher code number it gets.
STEP 1 - GRASPING: Most suitable parts for robotic grasping are parts that have parallel surfaces for grasping as well as rotational parts. Therefore, those parts have least code number. Highest number is reserved for cone-like or pyramid-like objects that have to be grasped so that basis is below the gripper.
STEP 2 - POSITIONING: Considers possibility of easy reaching accurate insertion position. Presence of cones and big chamfers on mating parts facilitates robotic assembly. Chamfers with beveled edge less then 2 mm does not contribute much to facilitating of robotic assembly. Any wedge or groove as well as complex geometrical shapes make difficulties in robotic assembly.
STEP 3 - TOLERANCES: In design phase, mating of two parts can be planned with clearance, uncertain clearance and lap. Desirable case for robotic assembly is clearance therefore other two cases have higher code numbers.
STEP 4 - FIXTURING AND SECURING: Most suitable case is simple insertion, while all other cases like pressing, welding, glueing, riveting requires some additional devices like welding guns, screw drivers, presses etc., as well as more synchronization of movements and in many cases sensory information is necessary.

TABLE 1

step 1 GRASPING	 parallel surfaces	 rotational surfaces	 not parallel surfaces	 surfaces with grooves or teeths	 cone-like surfaces	small dimensions $d < 5$ mm	 cone-like surfaces with base down
	100 000	200 000	300 000	400 000	500 000	600 000	700 000
step 2 POSITIONING	 cone for centering	 chamfer bigger then 2 / 30	 chamfer bigger then 2 / 45	 part with groove or bulge	 part with holes without self centering	 rotational part without chamfers	 complex silhouette without chamfers
	10 000	20 000	30 000	40 000	50 000	60 000	70 000
step 3 TOLERANCES	min. clearance > 1 mm	min. clearance $> 0{,}5$ mm	min. clearance $> 0{,}2$ mm	min. clearance $> 0{,}05$ mm	min. clearance $> 0{,}05$ mm	possible clearance and possible lap	lap
	1 000	2 000	3 000	4 000	5 000	6 000	7 000
step 4 FIXTURING AND SECURING	simple insertion	press fit	spot welding	riveting	screws	wedge	glueing or arc welding
	100	200	300	400	500	600	700
step 5 ACCESSIBILITY TO PLACE OF INSERTION	 accessible vertically down	 accessible vertically up	 accessible horizontally	 not easy accessible		 not easy accessible need rotation also	not easy accessible and change of direction during insertion
	10	20	30	40	50	60	70
step 6 OTHER PART FEATURES	not deformable		possible damage of surface		deformable (seals, rubber parts)		changeable shape (o-rings, long thin parts....)
	1	2	3	4	5	6	7

STEP 5 - ACCESSIBILITY TO INSERTION POSITION AND DIRECTION OF PARTS PRESENTATION: Direction of parts presentation from vertically above seems to be most suitable for robotic assembly. On the other side, inserting screws in the presence of obstacles is not favorable for robots.
STEP 6 - OTHER PART FEATURES: Considers preserving achieved quality of parts from previous processes like polishing, coloring, chroming etc., deformability of parts and changeability of shape during insertion. If parts are made of rubber, soft plastic or something similar like O-rings and seals they need specific care and often special devices for inserting.
The procedure for calculating suitability of parts for robotic assembly is following:
- Obtain code numbers from Table 1 through steps 1 to 6
- Add code numbers to obtain mark
- Add digits in mark to obtain final mark (r_i) for suitability of parts for robotic assembly
- Depending on r_i by using Table 2 obtain degree of complexity of parts for robotic assembly (R_i)

In Table 2 all parts are ranked in four degrees of complexity for robotic assembly.

r_i	R_i
up to 9	1
10 to 14	2
15 to 25	3
over 25	4

Table 2

Suitability of products for robotic assembly is then calculated as:

$$R = \frac{\sum_{i=1}^{m} n_i R_i}{q} \qquad (1)$$

where:

R_i = degree of complexity of i-th part (derived from Table 2 on the basis of r_i where r_i is complexity of i-th part derived from Table 1)
n_i = number of i-th identical part
m = number of different parts in product
q = total number of parts in product

2.2 SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY CONCERNING DIMENSIONAL PART FEATURES

Depending on the diversity in dimensions of parts that have to be assembled by robot, different number of grippers is required. Assuming that gripper can handle parts in various ranges according to Fig.1 depending on the part dimensions we have defined eight dimensional groups shown in Table 3. Essential measure for using Table 3 is part dimension on the position of grasping. When the parts are grouped, a comparison is made between number of groups that is used and possible number of group (eight):

$$d = \frac{H_d}{H_{d_{max}}} \qquad (2)$$

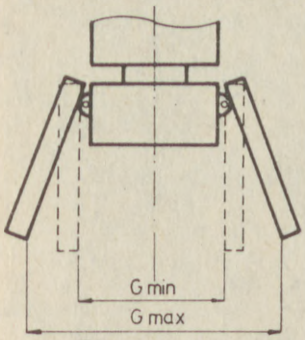


Figure 1

grasping dimension of part	group
5 ± 5	1
15 ± 5	2
25 ± 5	3
40 ± 10	4
60 ± 10	5
80 ± 10	6
100 ± 10	7
over 110	8

Table 3

where:

d = comparative characteristics of grasping dimensions

H_d = number of groups in which parts are classified

$H_{d_{max}}$ = maximal number of groups (eight)

According to the value of d, we define D in Table 4 as a degree of suitability of products concerning dimensional part features.

(d)	(D)
L < 0,3	1
0,3 < L < 0,6	2
0,6 < L < 0,8	3
0,8 < L < 1,0	4

Table 4.

Of course, values for grippers range could vary from one manufacturer of grippers to the other so this classification in eight groups is just our proposal.

2.3 SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY CONCERNING MASS OF PARTS

With a increase in weight-carrying capacity usually goes a decrease of repeatability and accuracy. Therefore, it would be very convenient if parts does not vary too much in sense of mass, because appropriate robot with wright balance of weight-carrying capacity, repeatability and price can be chosen. We have defined seven groups shown in Table 5 in which parts can be classified according to the mass. Ranges of mass are obtained considering common weight-carrying capacity (payload) of commercially available industrial robots.

When the parts are grouped, a comparison is made between number of groups that is used and possible number of groups (seven):

mass (kg)	group
up to 0,1	1
up to 0,5	2
up to 1,0	3
up to 3,0	4
up to 6,0	5
up to 10,0	6
over 10,0	7

Table 5

$$m = \frac{H_m}{H_{m_{max}}} \qquad (3)$$

where:

m = comparative characteristic of mass

H_m = number of groups in which parts are classified
$H_{m_{max}}$ = maximal number of groups (seven)

According to the value of m we define M in Table 6 as degree of suitability of parts concerning mass part features.

m	M
m < 0,3	1
0,3 < m < 0,6	2
0,6 < m < 0,8	3
0,8 < m > 1.0	4

Table 6

Naturally, robot with payload of 6 kg can handle part that has a mass of 0,1 kg but in that case, robot utilization is not the best. On the other side, if all parts in assembly are with mass less than 0,5 kg except one which is 5 kg that means that we have to buy a robot with payload more than ten times higher than that is needed for overwhelming majority of the parts. That was the reason for introducing this criteria in suitability for robotic assembly.

2.4. SUITABILITY OF PARTS FOR AUTOMATIC HANDLING

In many cases of robotic assembly it is needed for parts to be handled automatically in order to achieve robots working space in wright position and orientation. This is almost the same situation as with locating of parts in automatic assembly and many systems have been developed for describing suitability of parts for automatic handling (1, 2, 3, 4). For the proposed system we are using method developed at FTN-IIS* and described in (4) so here we will not explain it in details. Suitability for automatic handling is calculated as:

$$A = \frac{\sum_{i=1}^{m} n_i A_i}{q} \qquad (4)$$

where:

n_i = number of i-th identical parts
m = number of different parts in product
q = total number of parts in product
A_i = degree of complexity of i-th part (derived from Table 7 based upon the value of a_i
a_i = complexity of i-th part (derived from Table 8 through steps from one to seven)

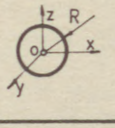
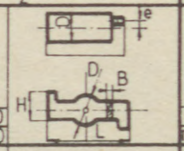
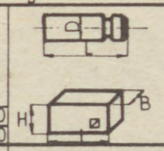
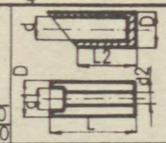
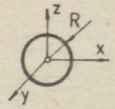
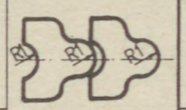
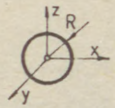
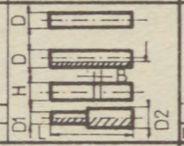
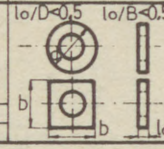
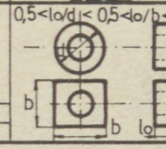
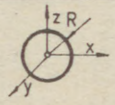
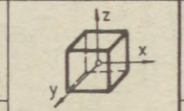
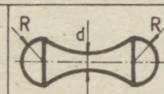
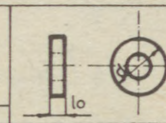
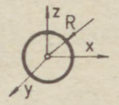
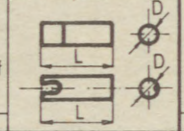
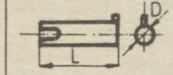
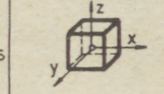
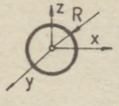
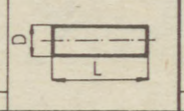
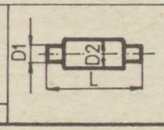
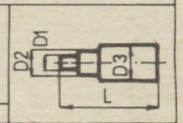
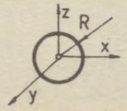
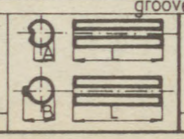
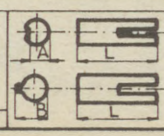
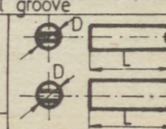
Procedure for obtaining suitability of parts for automatic handling is same as in chapter 2.1.

a_i	A_i
up to 10	1
10 to 20	2
20 to 25	3
over 25	4

Table 7

With the development and application of "intelligent" robots that will be capable to recognize and grasp parts randomly oriented on undefined positions, necessity for this component of suitability for robotic assembly will disappear. However, this is still not actual due to high price of "intelligent" robots.

* - Faculty of Technical Sciences, Institute of Industrial Systems Engineering, V. Vlahovića 3, 21000 Novi Sad, YU

BASIC FEATURES		CHARACTERISTICS								TABLE 8
	name	1		2		3		4		
I	ORIENTATION IN SPACE	no need for orientation metal 0000000 non met. 1000000		asymmetry of outer shape metal 1000000 nonmet 2000000		asymmetry of COG metal 2000000 nonmet 3000000		asymmetry of inner surfaces metal 4000000 nonmet 5000000		
II	TRANSPORTATION THROUGH DEVICES	no joining 000000		joined 500000		joined mechanically 600000		casts 700000		
III	SHAPE	not important 00000		rod-like ferom 10000 neferom 20000		sheet-like ferom 20000 neferom 30000		sheet-like ferom 40000 neferom 50000		
IV	SHAPE	ball 0000		cuboid 1000		curved 1000		flat 2000		
V	SYMMETRY	few axis of rotation 000		one axis of rotation one plane of symmetry 100		one axis of rotation 200		three and more planes of symmetry 400		
VI	OUTER SHAPE AND CENTRAL HOLE	ball 00		no central hole smooth 10		step-like with symm.ends 30		step-like with no symm.ends 60		
VII	AUXILIARY SURFACES	no auxiliary surfaces 0		groove whole 1		partly 3		central groove whole 2		

3. OVERALL SUITABILITY OF PRODUCTS FOR ROBOTIC ASSEMBLY

As we have shown in previous chapters, four separate marks are obtained, each describing some particular product features. In order to present an integral estimation of suitability of products for robotic assembly all separate marks have to be observed together. In that way we can obtain an complex estimation of suitability K_{sr}:

$$K_{sr} = \frac{R + D + M + A}{4} \qquad (5)$$

where:

R = suitability of products for robotic assembly concerning suitability of parts (equation 1)
D = degree of suitability of products concerning dimensional part features (Table 4)
M = degree of suitability of products concerning mass part features (Table 6)
A = suitability for automatic handling (Table 7)

Expression (5) represents simple arithmetic mean of particular factors. It is possible that some of the factors have greater or smaller influence in some cases that should be taken in account but that will be part of our further investigation. According to the value of K_{sr} we evaluate suitability of products for robotic assembly in Table 9.

K_{sr}	degree of complexity	characteristics
1÷1,5	1	Assembly operations robot can handle easy and product is very suitabile for robotic assembly
1,5÷2	2	Robotic assembly of medium complexity. Some assembly operations are difficult so it would be convenient to redesign parts that makes assembly difficult
2÷3	3	Robotic assembly of high complexity. Detailed analyse and redesign is needed. Additional devices are required.
> 3	4	Due to high complexity of assembly and unsuitable part/product design robotic assembly is hardly possible

Table 9

Application of the proposed system for estimating suitability of products for robotic assembly will be shown on an example.

4. EXAMPLE

As an example we are showing analyze of suitability for robotic assembly of wheel for chairs. This product consists of six different parts that are shown in Table 10. For each part in Table 10, all necessary data for calculating suitability for robotic assembly is given so we can calculate R, D, M and A:

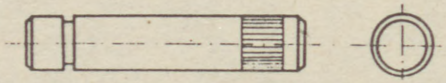
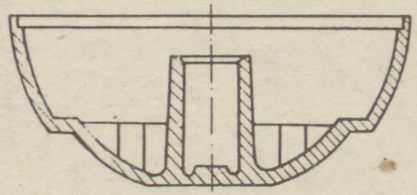
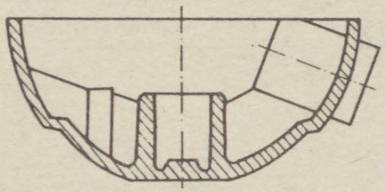
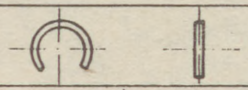
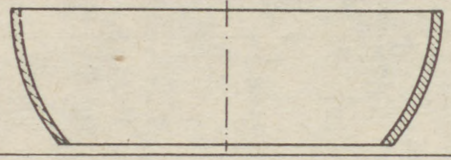
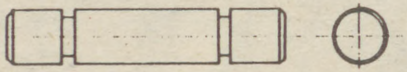
No	Drawing	Qty	Code from Table 1	r_i	R_i	Group from Table 3	Group from Table 5	Code from Table 8	a_i	A_i
1		1	267211	19	3	1	1	1012261	13	2
2		1	723111	15	3	5	1	1024794	27	4
3		1	541111	13	2	5	1	2025998	35	4
4		3	247215	21	3	1	1	1824621	24	3
5		1	717215	23	3	5	1	2534120	17	2
6		1	263411	17	3	1	1	1012230	9	1

Table 10

$$- R = \frac{\Sigma n_i \cdot R_i}{q} = \frac{1 \cdot 3 + 1 \cdot 3 + 1 \cdot 2 + 3 \cdot 3 + 1 \cdot 3 + 1 \cdot 3}{8} = 2.875$$

– for calculating D we need number of used groups. That is two (parts are classified only in groups 1 and 5), therefore:

$$d = \frac{H_d}{H_{dmax}} = \frac{2}{8} = 0.25$$

For the value of d = 0.25 it follows D = 1 according to Table 4

– for calculating M we need number of used groups. That is one because parts are classified only in one group.

$$m = \frac{H_m}{H_{mmax}} = \frac{1}{7} = 0.142$$

For the value of m = 0.14 it follows M = 1 according to Table 6

$$- A = \frac{\Sigma n_i \cdot A_i}{q} = \frac{1 \cdot 2 + 1 \cdot 4 + 1 \cdot 4 + 3 \cdot 3 + 1 \cdot 2 + 1 \cdot 1}{8} = 2.750$$

Finally, we can calculate K_{sr}:

$$K_{sr} = \frac{R + D + M + A}{4} = \frac{2.875 + 1 + 1 + 2.75}{4} = 1.906$$

For that value of K_{sr} we can see in Table 9 that this product is of medium complexity for robotic assembly so it would be convenient to redesign parts that makes assembly difficult if we intend to assemble it using robots.

4. CONCLUSIONS

This paper presents an approach to estimating suitability of products for robotic assembly. During the design phase of designing technological procedure for particular product, various procedures are estimating in order to obtain most suitable one. Presented method gives a numerical estimation which can help in comparing various styles of the same product or for choosing part of product range for robotic assembly. It can also serve as a measure of design efficiency and help product designers to obtain designs more suitable for robotic assembly. As we have noted in chapter 2.4 it is possible that same numbers can be slightly changed due to development in industrial robotics.

5. REFERENCES

1. Boothroyd, G., Poli, C. and Murch, L.E., Automatic Assembly, Marcel Dekker, New York, 1982.

2. Boothroyd, G., and Dewhurst, P., Design for Assembly, Department of Mechanical Engineering, University of Massachusetts, 1983.

3. Redford, A. H. and Lo E., Robots in Assembly, Open University Press, Milton Keynes, 1986.

4. Ćosić, I., Milić, D. and Šešlija, D., Contribution to the development and application of criteria for estimating suitability of product design for automated assembly, PROMJER'87, Mostar, Yugoslavia, 1987. (in serbocroatian)

DATABSE FOR EXTRUSION PROCESS DESIGN

SURESH DALELA
Mechanical & Industrial Engg. Deptt.
University of Roorkee
Roorkee-247 667 INDIA

ABSTRACT

Extrusion process is very well established in the present technological environment due to achievement of good mechanical properties and dimensional accuracy in the finished product. If any industry is to survive in today's competetive industrial environment where not only the technical knowhow for designing and manufacturing has been changing rapidly but also the product demand of different designs, then the production engineer will have to develop the capability to make rapid changes in product design and manufacturing process design as per the requirements of the customer. In order to execute these requirements, the vast amount of information available in scattered form has got to be compiled and be made available to the production engineers for its purposeful utilization. So, to fulfil this requirement, this paper presents a comprehensive DATABANK which facilitates an easy selection of controlling process design parameters compatible to different work-materials and die-materials. A suitable coding system has also been adopted for efficient retrieval for required materials and other parameters. A formula given by Lambert and Kobayashi has been used for designing the extrusion-die data.

1.0 INTRODUCTION

The present trend of technological developments aims to free engineers from carrying out routine work and acquires flexible automation so as to satisfy the volatile nature of the market. Digital computers have played a significant role in the automation of process and assisting the designer in performing calculations and decision makings involving formal logic [1,2].

Due to the increasing and flexible demand of extruded products, the increase in available materials that can be extruded, and the increase in the availability of die-materials, it is essential that the developed process must be reliable and so designed that it must be capable of changing from one product requirement(s) to another product requirement(s) in the shortest possible time. The speed of execution and data storing capability of the computer has been used to problem solving and data processing.

In order to develop the databank for extrusion process design, it needs to acquire the knowledge of :

(a) reviewing the extrusion theories and selecting the process design parameters including die-design parameters;

(b) the work-materials that can be extruded and their codification for efficient retrieval;

(c) the die-materials that are available and their codification and the geometrical dimensions of the die.

The proposed model is capable of selecting the die-design details on the bases of work-materials and die-materials. The program, applicable to the direct extrusion of circular rods, is prepared and has the capability of determining geometrical parameters of circular-die, necessary to withstand the stresses developed in the die-wall during the extrusion process.

2.0 EXTRUSION PROCESS-SYSTEM APPROACH

An extrusion process can be modelled in different levels of details. Obviously, the more complete is the model, larger will be the amount of input data required. The algorithms necessary to describe the process will be more complex and the amount of output data may pose difficulties in interpretation. So, a simple approach is applied to define the extrusion process in terms of direct extrusion producing circular rods.

2.1 Parameters Identification

The properties and integrity of the final extruded product is a function of all the components of the extrusion system. Figure 1 shows the inputs to the process modelling. The CAD/CAM of extrusion system consists of the required product properties (mechanical properties and microstructural), geometry and the extrusion system components (preform, dies, lubricant, speed of applied force, press, material, etc.). The output will consist the process simulation (shape of the extruded product required at different time intervals as well as temperature distribution, strain and stress distribution). Interacting with the process parameters and iteratively simulating the process, it is possible to design the preform and optimise its shape, position and also the extrusion die.

Figure 2, illustrates the simple extrusion system where the distinction between the initial aggregate (the billet), the process and the final aggregate (extruded product) is made.

Figure 3 shows an idealised CAD/CAM extrusion system in which the user interacts with computer via a graphic terminal, designing and controlling the manufacturing process from start to finish [3].

Figure 4 presents the integrated information system for extrusion process-starting from the product planning upto the final extruded product. The complete process of extrusion can be automated with the help of CAD/CAM/CAPP system. The common integrated information system which bears a databank supplies information, that are within the system, the product planning [3].

2.2 Work-load Model Adopted

It is very significant aspect in developing the database. Many extrusion theories [4-8] have been reviewed to determine the work-load necessary for the deformation of extruded product. This paper takes a more realistic and simple deformation model developed by Lambert and Kobayashi

[9] in computation of extrusion die-stress. This model assumes realistic admissible velocity field approach, and gives more reliable extrusion loads as compared to upper bound approach and indicate the following process parameters that will affect the extrusion pressure in the proposed model:

(i) Yield stress of the work-materials to be extruded.
(ii)Two constrants depending on frictional conditions, die angle and extrusion ratio (Refer Table 1).

The extrusion pressure, in this model is related to constrants 'a' and 'b' and the extrusion ratio (R_1) as

$$P/Y = a + b \ln R_1 \qquad (1)$$

Therefore, efficient mechanical design of extrusion process (design of tools and equipments) requires the following:

(i) Systematic collection of the required data;and
(ii)Computer program for the design.

3.0 DATA COLLECTION-COMPILATION OF DATAFILE & INPUT VARIABLES

A gigentic treasure house of industrial knowledge available in scattered form is awaiting its purposeful utilisation. The primary aim of systematic data collection is to tap the useful information and make available to the benefits of Indian industries so as to improve the product quality and productivity through efficient utilisation of global resources. The information compiled in this paper pertains to various identified parameters which are to be used to design the extrusion process, thus serve the Indian industries.

(i) Yield strength of the work materials(MPa) that can be extruded.
(ii) Reduction in area (R_1) or extrusion area ratio.
(iii)Friction conditions and constants 'a' & 'b' (Refer Table 1).
(iv) Codification of work-materials
(v) Yield strength of die-materials (MPa)
(vi) Code for die-materials.

3.1 Data Compilation for Work-materials [10-15]

For the automation of the process, the 'raw data' is converted into 'coded input data'. Now a days a wide range of metals and their alloys of varying composition are being extruded either in cold condition or in hot conditions. However, higher work temperatures poses the practical problem of lubricant suitability. This model includes soft metals and alloys (Tinalloys, Al-alloys, Zn and its alloys etc.) as well as hard metals (Steels, Titanium-alloys, Tungsten, Vanadium, etc.). For efficient handling and processing, codes have been used to identify the metal and their alloys.

A code is one or more symbols to which an arbitrarily assigned meaning and/or arrangement has been given which, when deciphered communicates specific information or intelligence [16]. It is true that classification brings like things together, but until a coding system reflecting the

classification is introduced, handling and processing of families of similar data is cumbersome and inefficient. So, principals and methods of industrial coding [16] have been taken into account for codification. The pressure of extrusion depends upon the mechanical properties (yield stress, hardness, etc.) of the metal which is governed by the chemical composition of the metal. The chemical composition of metals will give an idea of the extrudability of a metal of like composition. Hence the codification of the extrusion metals and their alloys have been made on the basis of chemical composition. The following steps in codification are involved [16] :

1. A six digit coding has been introduced with a break in the string after two digits.
2. All the digits are numerical and none of the digits are alphabets in the work material coding.
3. The first two digits denote the metal group, the second two digits denote the group of major alloying element and the last two digits denote the percentage of major alloying element.
4. While making the sub-groups, the percentage of the major alloying element are not integrated with the hierarchical classification.

Meaning thereby that the first, second, third and fourth digits of each code qualifies the succeeding code, but the last two digits are not integrated with the hierarchical classification. This has been done so that more metals can be added to the present list without affecting the present codes. Table 2 gives the details of the present coding.

3.1.2 Example to explain table 2

122106, 122204 and 122406 denote that these are aluminium alloys in which the major alloying element is copper and the percentage of copper is 6,4 and 6 respectively. These three alloys come in the same order in the list as shown in Table 2. Now, if a new alloy containing 5% copper is being used to this list, it can be coded as 122505. Table 2 gives the details of the coding. Since brass (Cu-Zn alloy), carbon steel, alloy-steel and stainless steel are being used extensively for extrusion. These have been treated as separate groups.

3.2 Data Compilation for Die-Materials

A large number of die-materials for cold and hot extrusions are reported. Tables 3 and 4 give various die-steels for extrusion where for cold extrusion neither the tooling nor the work is normally preheated and for hot extrusion the system operates under severe conditions of temperature, pressure and abrasive wear. During coding the die-materials, alpha field is fixed and it is used to break a string of numbers (AISI codes).

4.0 DIE DESIGN

Once the data related to materials to be extruded and diematerials has been compiled, now the engineer can use this data for die-design as per customer's requirement.

Figure 5 shows the typical arrangement of extrusion die for the production

of rods. During extrusion process, the forces are very large resulting in lateral pressure on the die-walls and thus the die is stressed in tension. These stresses vary with the strength of material being extruded. Resistance to bursting is frequently achieved by shrinking the tool steel die ring into a massive die shoe so that the ring is normally in compression. Calculations involved in die-design have been given else where [17].

5.0 COMPUTER PROGRAM FOR EXTRUSION DIE DESIGN

The computer program based on the developed database for the extrusion process design has been developed and it has the following capabilities:

(i) The program is capable of selecting different values of extrusion ratios.
(ii) The program can be used for any given set of work and die materials, but it cannot select the die-material.
(iii) The program can be applied for any friction condition, but it cannot select the friction condition.
(iv) In case of supported dies, the program gives an estimate of the shrink fit contact pressure.
(v) The program can give as many die diameter ratio as required at a time.

The developed program, which, when applied with relevant data, will give the ratio of the outside and inside diameters of the die necessary to withstand the pressure encountered during extrusion. For very high pressure, it will also compute the shrink-fit contact pressure required for the supported die. This program, however, executes the die diameter ratio for all possible metals that can be extruded with three different die-materials and for three extrusion area ratios. Although, this program is applied to rods of circular cross-section, the program may be used for sections other than circular by updating the factor of safety or applying suitable correlation factors for the computation of pressures encountered during the extrusion of the required cross-section.

6.0 CONCLUSIONS

This identifies the extrusion process parameters, provides the database for design calculations and a scheme for storage of various data through a coding system. Coding helps in preparing the efficient software for the use of database for the desired extruded product.

The results obtained, after successfully running the developed software in DECSYSTEM-20 are listed in Table 5 for some of the materials given in the databank. The results reported are for fixed semicone angle and for full friction conditions which gives safest results.

REFERENCES

[1] Merchant, M.E., Industry-Research interaction in Computer Aided Manufacturing, Int. Conf. Production Technology (Inst. of Engrs., Australia), Melbourne, Aug.19-21,1974, p.21.

[2] Merchant, M.E., Currnt status of and potential for, Automation in the metal-working manufacturing industry, Annals of the CIRP Vol 32/2/ 1983, p. 519.

[3] Kozar, Z., Research and application of CAD and CAM systems in Czechoslovak Mechanical Engg. Industries, Proc. of the IFIP WG 5.2 Working Conference on CAD/CAM as a Basis for the Development of Technology in Developing Nations, Sau Paulo, Brazil, Oct.21-23, 1981, pp 177-186.

[4] Rowe, G.W., Principles of Industrial Metal Working Processes, Edward Arnold (Publishers) Ltd., 1977.

[5] Hoffman, O. & Sachs, G., Introduction to the theory of plasticity for engineers, McGraw Hill, 1953.

[6] Johnson, W. & Kudo, H., The mechanics of metal extrusion, Manchester Univ. Press, 1962.

[7] Farmer, L.E. & Pirog, B.Z., Estimation of maximum extrusion forces, Int. Conf. on Production Technology, Melbourne, Aug.19-21,1974.

[8] Johnson, W. & Mellor, P.B., Plasticity for mechanical engineers, Van Nostrand, 1972.

[9] Lambert, E.R. & Kobayashi, S., An approximate solution for the mechanics of axisymmetric extrusion, Proc. of the 9th Int. MTDR Conf., 1968.

[10]ASM Metal Reference Book, A handbook of data about metals and metal working, American Society of Metals, 1981.

[11]Creamer, R.H., Machine Design, Second Edition, Addison Wesley Publishing Company, 1976.

[12]Huml, P., Utilization of flow stress in metal forming calculations, CIRP Annals 1984, Manufacturing Technology, Vol 33/1/1984, p. 147.

[13]Metal Handbook, Ninth Edition, Vol 3 - Properties and selection: Stainless steels, Tool Materials and Special Purpose Metals, American Society for Metals

[14]Metals Handbook, Ninth Edition, Vol 2 - Properties and selection: Non ferrous alloys and pure metals, American Society for Metals.

[15]Metals Handbook, Eighth Edition, Vol 1 - Properties and selection of metals, American Society for Metals.

[16]Hyde, W.F., Improving productivity by classification, coding, and data base standardization - The key to maximizing CAD/CAM and Group Technology, Marcel Dekker, INC. New York, 1981.

[17]Dalela, Jain & Sen Gupta, An efficient approach for extrusion process design, J. of Inst. of Engrs(India) Vol 69, July 1988, pp 7-10.

Table 1 : Values of 'a' & 'b' [10]

Die-angle in degrees	Zero friction; m=0		Maximum friction;m=1	
	a	b	a	b
30	0.16	1.00	0.35	1.74
45	0.45	0.90	0.60	1.38
60	0.70	0.85	1.00	1.10

Tabl2 2 : Codes for Extrusion Metal and Alloys

ALUMINIUM 12	1-20 Pure Metal , 21-30 Cu 31-40 Mn,41-60 Mg,61-80 Si 81-99 Zn	(%) of Metal(Pure Metal) % of Major Alloying Element (Alloy)
Berlyllium 16	1-20 Pure Metal	-do-
Steel(Alloy) 60	1-20 Mn,21-40 Cr,41-60 Ni, 60-70 Si	(%) of Major Alloying Element in Tenths
Steel(Stainless) 64	1-10 Cr(Ni 5%),11-25 Cr (Ni 10%), 26-59 Cr(Ni 15%),51-60Cr(Ni 20%), 61-70 Cr(Ni 25%), 71-90 Cr(Ni absent),91-99 Ni	(%) Metal(Pure Metal) (%) of major alloying Element(Alloy)
Zirconium 92	1-20 Pure Metal,21-40 Sn, 41-60 Mo	-do-

-Key to Chart-

Metal Metal code	Field of major alloying Element along with the Alloying Element	As described above
First & Second Digit	Third & Fourth Digit	Fifth & Sixth Digit

NOTE: 1. 99 in the last two places indicates 99% or more metal.
2. 00 in the last two places indicates less than 0.5% of the alloying element.

Table 3: Die Steels for Cold Extrusion

Material to be extruded	Die steel (AISI specifications)
Carbon & alloy steel	A1,A2,D2,H12,H21,6F5,6H2,S1,L6
Aluminium alloys	W1,W2
Stainless steel	H12,H21,6F5,6H2

Table 4: Die Steels for Hot Extrusion

Steels	H11,H13,H21,S1
Copper & Copper alloy	H11,H12,H13,H14,H19,H21,H23,H26
Aluminium alloys	H11,H12,H13,H10
Magnesium alloys	H11,H12,H13
Titanium alloys	H11,H13,H21
Nickel alloys	H11,H13,H21
Lead & Lead alloys	1045
Refractory metal extrusion & high temp. metal extrusion	T15

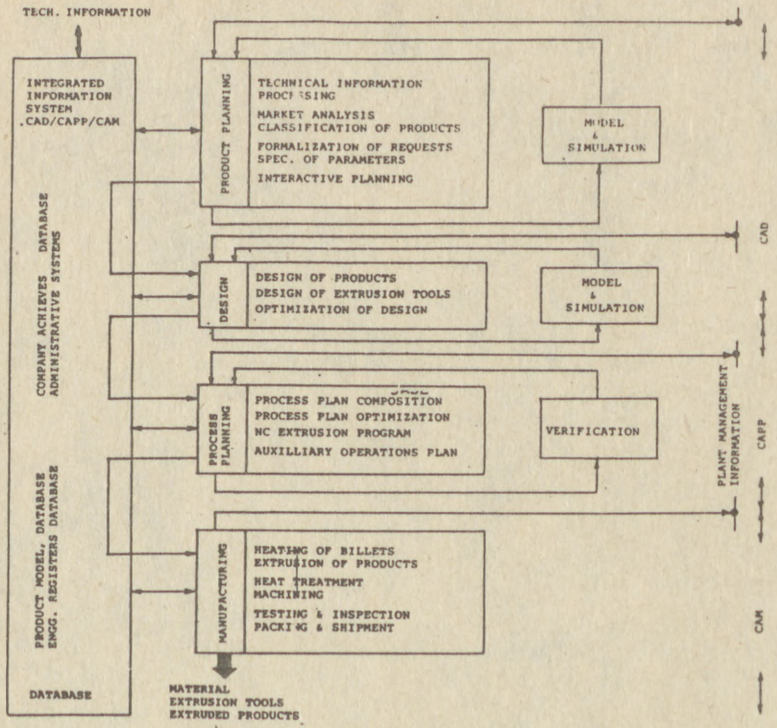
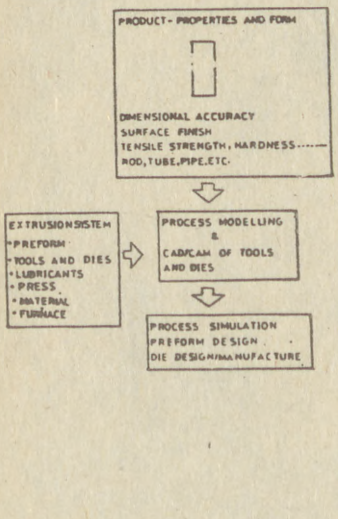
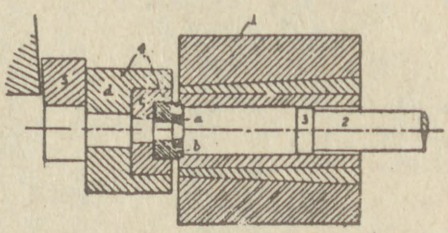


FIG. 4 INTEGRATED INFORMATION SYSTEM FOR EXTRUSION

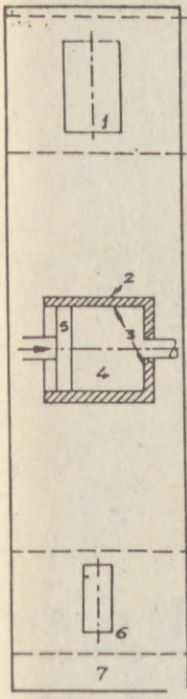




1. Container 2. Extrusion ram 3. Pressure disc or follower pad 4. Die assembly [(a) Die, (b) Die holder, (c) Bolster, (d) Wedge] 5. Wedge

Fig.3: A typical arrangement for production of rods of solid sections

Fig.1: Process Modelling and CAD/CAM of Extrusion System.



1. BILLET
FLOW, STRESS AS A FUNCTION OF STRAIN, STRAIN RATE, TEMPERATURE AND MICRO STRUCTURE, EXTRUDABILITY AS A FUNCTION OF STRAIN, STRAIN RATE, TEMPERATURE
SURFACE CONDITIONS
THERMAL/PHYSICAL PROPERTIES
EFFECT OF CHANGES IN MICROSTRUCTURE AND COMPOSITION UPON FLOW STRESS AND EXTRUDABILITY

2. TOOLING
GEOMETRY OF TOOLS
SURFACE CONDITION
MATERIAL/HEAT TREATMENT/HARDNESS
TEMPERATURE
STIFFNESS AND ACCURACY

3. TOOL-MATERIAL INTERFACE
LUBRICANT TYPE AND TEMPERATURE
INSULATION AND COOLING OF THE INTERFACE LAYER
LUBRICITY AND FRICTION SHEAR STRESS
CHARACTERISTICS RELATED TO LUBRICANT APPLICATION AND REMOVAL

4. DEFORMATION ZONE
DEFORMATION MECHANICS
METAL FLOW, VELOCITY, STRAIN RATE, STRAIN
STRESS (VARIATION DURING DEFORMATION)
TEMPERATURE (HEAT GENERATION AND TRANSFER)

5. EXTRUDING EQUIPMENT
SPEED/PRODUCTION RATE
FORCE/ENERGY CAPABILITY
RIGIDITY AND ACCURACY

6. EXTRUDED PRODUCT
GEOMETRY
DIMENSIONAL ACCURACY
SURFACE FINISH
MICROSTRUCTURE, MECHANICAL AND METALLURGICAL PROPERTIES

7. PLANT AND ENVIRONMENT

FIGURE 2: EXTRUSION PROCESS AS A SYSTEM

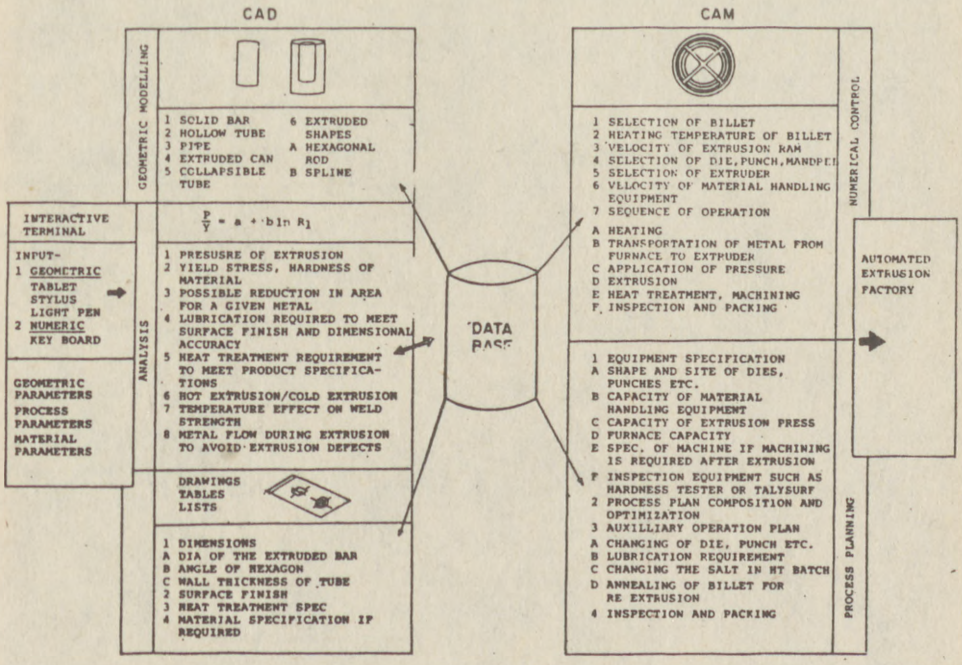


FIG. 3 AN IDEALISED CAD/CAM EXTRUSION SYSTEM

TABLE - 5

DIE DIMENSIONS FOR VARIOUS DIE MATERIALS USED IN EXTRUSION

Work Material No.	Die Material No.	Extrusion Area Ratio	Die Dia. Ratio	Shrink Fit Contact Pressure (MPa)
1	2	3	4	5
120199	H11	2.44	1.11	-
120199	D2	2.44	1.13	-
122106	H11	2.44	1.74	237.86
124204	A2	2.44	1.88	0.54
124204	D2	2.44	1.99	0.52
128406	A2	2.44	1.73	-
160199	H11	2.44	1.74	165.35
160199	H21	2.44	2.29	148.03
200199	H13	2.44	2.18	276.29
200199	H21	2.44	2.29	271.96
240199	H12	2.44	1.36	-
240199	H19	2.44	1.47	-
240199	H26	2.44	1.34	-
246203	H12	2.44	1.85	23.98
246203	H19	2.44	2.28	35.93
248901	H19	2.44	2.28	320.54
280313	H24	2.44	1.45	-
280415	H13	2.44	1.45	-
283315	H13	2.44	2.18	193.55
283315	H22	2.44	1.75	212.26
400199	H21	2.44	2.29	271.96
400199	S1	2.44	1.40	345.08
400199	L6	2.44	1.42	340.73
604535	H24	2.44	2.27	384.77
604535	D2	2.44	1.99	403.42
604535	O7	2.44	1.50	466.25
884612	A2	2.44	1.88	379.55
884612	A8	2.44	2.05	366.05
924101	H12	2.44	1.85	147.88
924101	S1	2.44	1.40	172.86
924101	L6	2.44	1.42	170.68
120199	H11	4.17	1.15	-
120199	D2	4.17	1.18	-
122106	H11	4.17	1.74	353.59
124204	A2	4.17	1.88	44.06
124204	D2	4.17	1.99	42.94
128406	A2	4.17	1.88	27.56
160199	H11	4.17	1.74	259.50
160199	H21	4.17	2.29	232.32
200199	H13	4.17	2.18	399.38
200199	H21	4.17	2.29	393.12
240199	H12	4.17	1.54	-

TABLE - 5 (contd)

1	2	3	4	5
240199	H19	4.17	1.72	-
240199	H26	4.17	1.49	-
246203	H12	4.17	1.85	94.26
246203	H19	4.17	2.28	86.89
248901	H19	4.17	2.28	456.19
248901	H26	4.17	1.76	506.78
280313	H13	4.17	1.68	-
283315	H22	4.17	1.75	320.25
400199	S1	4.17	1.40	498.82
400199	L6	4.17	1.42	492.52
604535	H24	4.17	2.27	539.58
604535	D2	4.17	1.99	565.72
604535	O7	4.17	1.50	653.83
884612	A2	4.17	1.88	535.84
884612	A8	4.17	2.05	516.79
924101	H12	4.17	1.85	235.57
924101	S1	4.17	1.40	275.35
924101	L6	4.17	1.42	271.97
120199	H11	7.72	1.20	-
120199	D2	7.72	1.24	-
122106	H11	7.72	1.74	486.58
124204	A2	7.72	1.88	94.07
124204	D2	7.72	1.99	91.65
128406	A2	7.72	1.88	73.22
160199	H11	7.72	1.74	367.70
160199	H21	7.72	2.29	329.18
200199	H13	7.72	2.18	540.84
200199	H21	7.72	2.29	532.36
240199	H12	7.72	1.82	-
240199	H19	7.72	2.23	-
240199	H26	7.72	1.74	-
246203	H12	7.72	1.85	157.79
246203	H19	7.72	2.28	145.44
248901	H19	7.72	2.28	612.06
248901	H26	7.72	1.76	679.95
280415	H24	7.72	1.96	12.51
280415	H13	7.72	2.14	-
283315	H13	7.72	2.18	405.19
283315	H22	7.72	1.75	444.35
400199	H21	7.72	2.29	532.36
400199	L6	7.72	1.42	666.99
604535	H24	7.72	2.27	717.49
604535	D2	7.72	1.99	752.25
604535	O7	7.72	1.50	869.40
884612	A2	7.72	1.88	715.46
884612	A8	7.72	2.05	690.02
924101	H12	7.72	1.85	336.34
924101	S1	7.72	1.40	393.14
924101	L6	7.72	1.42	388.18

FURU
Dept
JAPA
KAKA
Dept
OKIN
Dept

INTR

acti
is s
How
requ
of a
deve
arti
heur

PARAMETRIC DESIGN METHODS USING PETRI NET FOR CONTROLLING DESIGN PROCESS

FURUKAWA,Masashi
Dept. of Technology Information Integration,Asahikawa National College of Technology, JAPAN
KAKAZU,Yukinori
Dept. of Precision Engg., Faculty of Engg, Hokkaido University, Sapporo, JAPAN
OKINO,Norio
Dept. of Applied Mathematical Science, Faculty of Engg. Kyoto University,Kyoto, JAPAN

The design process is highly sophisticated because the design mechanism is still unclear. This paper represents on a design model and a design process control method to establish the parametric design system. A boundary factor model proposed by Prof.N.Okino is adopted as the design model. Boundary factors become parameters for the design information units. To put the design process foward, it is necessary to control a flow of the boundary factors among the design information units. The Petri Net is used for making a role of controlling the designing process after a structure of the design model is mapped to the Petri net. The design information is given shape to the Object and Operation (O/O) representation likely to the object oriented one.

INTRODUCTION

A design automation is considered as modelling and realizing intelligent human activities with the aid of a computer. As a mechanism of the intelligent activities is still unclear, it is highly difficult to embody such activities in a computer. However, the more the computer facility increase, the more usages of the computer are requested for the design automation. Under these circumstances, there are a lot of approaches to the design automation for the establishment of the system. These are developments of the theory to clear up the design mechanism, an application of the artificial intelligent technique to the design system, a systematization of the heuristic and experimental techniques, and so on [1][2][3].

This paper focusses on the design stage to which a design object is already given. In other words, the detial design method is presented after the conceptual and preliminaly designs are finished. At for this stage, this boundary factor model(BFM) [4] is proposed to perform the parametric design. The BFM is simular to a linear control theory from the view point of the system engineering. Though the linear control theory deals with the input-output parameters (variables) with respect to the time axis,the BFM deals with the input-output parameters with respect to a variety of factors. Taking into this point account, the BFM is a well modell for designing object. In constructing the practical CAD system on the basis of the BFM, these is a room to be solved. Those are on how the model is supervised and how the model is represented. The former problem is to control the designing process, step by step, toward finishing the design. The later one is to descrive the design information. To overcome these deficiencies, the Petri net is introduced which is mapped from the structure of the BFM to proceed to the designing process, and the Object and Operation (O/O) representation is proposed. The Petri net allows us to analyze the structure of the BFM. It give us valid information such as the initial design state, the final design state, the design control equation, the iterative design state and so on. O/O is representation of an entity likely to the object oriented representation. In the BFM, some O/Os take part in the parameters from the view point of the parametric design. O/O is taken shape to as a frame description.

THE BOUNDARY FACTOR MODEL

We accept that a designing object may be represented by a set of design information. Let M be the whole set of the design informationon the for desiging object and let M_i (i=1,2,$\cdots$,n) be a subset of one. This is expressed by

$$M = \bigcup M_i \ . \tag{1}$$

M_i is considered as a design unit and it is defined by

$$M_i = M_i\ (m_j^i,\ e_k^i : j=1,2,\cdots,u,\ \ k=1,2,\cdots,v) \tag{2}$$

where $\{m_j^i\}$ is the design information which has the relation with other units and $\{e_k^i\}$ is the one which has no relation with other units and is internally used in the unit M_i. $\{m_j^i\}$ is classfied into two groups, the input information and the output information. Then, we put the equation (2) into

$$\{\overline{m}_j^i\} = M_i\ (\{\underline{m}_j^i\}), \tag{3}$$

where $\{m_j^i\} = \{\underline{m}_j^i\} \cup \{\overline{m}_j^i\}$ and $\{\underline{m}_j^i\}$ and $\{\overline{m}_j^i\}$ correspond to the input and output information, respectively. If the unit relates to the other units, it is related to others with respect only to $\{m_j^i\}$. $\{m_j^i\}$ is named boundary factors and $\{\underline{m}_j^i\}$ and $\{\overline{m}_j^i\}$ are named the input and output boundary factors, respectively. when designing is performed, there arises a flow of the boundary factors. If the input boundary factors are given to the unit M_i for designing, the unit M_i is executed and $\{m_j^i\}$ and

$\{e_k^l\}$ are determined. After that, the output boundary factors $\{\overline{m}_j^l\}$ is output. The input boundary factors consist of the output boundary factors of the other units related to the unit M_i. This relation can be derived form the binary relation between two units, the unit M_i and another unit. In paying an attention to the flow of the boundary factors among the units, we have event-driven rules on the units from the equation (3). The rules are as follows,

rule 1 : Given $\{\underline{m}_j^l\}$, then start designing unit M_i.

rule 2 : Desiging unit M_i is over, then output $\{\overline{m}_j^l\}$.

Througt the designing process, the transit from the unit to others is caused in applying two rules to the units.

OBJECT AND OPRATION REPRESENTATION

The object and operation (O/O)[4] is dualism to describe an entity from a philosophical view of the application world. The O/O dualistic world is defined as follows :

(A) The element of the O/O dualistic world is a set of objects and operations which make their concept each other.

(B) The object means every physical object in the application world and it is expressed by a set of data such as variables, numerical values, words and atteributes.

(C) The operation means every operation such as relations, rules, prosedures, sentences, etc.

(D) The object is defined by a set of operations and the operation is defined by a set of objects.

The O/O representation is applied to the boundary factor such as

$$m_j^l = \{ob_{j1}^l, ob_{j2}^l, \cdots, ob_{jq}^l\} \,\%\, \{op_{j1}^l, op_{j2}^l, \cdots, ob_{jy}^l\}, \qquad (4)$$

where % means a delimitation symbol, ob_j^l is the object, and op_j^l is the operation. The equation (4) is also applied to the internal information e_k^l in the same way. We adopt the frame representation to describe the equation (4). In the frame representation, m_j^l is the frame name, ob_j^ls are pairs of the slot names and their variables, and op_j^ls are the slot relations. We regard the slot names and their variables as the parameters in the unit. The frame representation examples are shown in Figure 1.

DESIGN PROCESS CONTROL USING THE PETRI NET

The BFM is processed by the use of two rules described above iteratively. Two rules request the BFM to need a event-driven system for controlling the design process. Petri net [5] is adopted for this purpose. The Petri net is defined as follows.

1. $T = \{t_i : i=1,2,\cdots,n\}$, where n is the number of transisions,
2. $P = \{p_j : j=1,2,\cdots,h\}$, where h is the number of place,
3. $I = \{(p_j,t_i) : (p_j,t_i) \in T\times P\}$,
4. $O = \{(t_i,P_j) : (t_i,P_j) \in P\times T\}$,

where, T is a set of transisions, P is a set of places, I is a pair set of the place p_j and the transision t_i such as the place p_j becomes the input to the transision t_i, and O is a pair set of the transision t_i and the place of p_j such as the place p_j becomes the output from the transition t_i. Let the unit $\{M_i\}$ correspond to a set of the transisions T and all the boundary factors $\{m_j^1\}$correspond to a set of the places P. Then, pair sets of I and O are derived from two rules, respectively. Tokens are assigned to some places to show a current state of the Petri net. Movement of the tokens from some places to others means that the Petri net state is updated. It occurs when the transision is alive. The Petri net is equivalent to the directed bi-graph. The graph is shown in Figure 2. When designing (processing) the unit starts, we have to know which transitions are alive. It occurs when the tokens are located to the places determined by applying the rule 1. After this, the tokens are located to the places determined by applying the rule2. Updating the (k-1)-th Petri net state to the k-th state is represented by the following equation,

$$\mu^k = [\, C^+ - C^- \,]\, a^k + \mu^{k-1}, \quad \text{and } \mu^k \geq C^- a^k, \tag{5}$$

where μ^k is a vector whose element correspons to the place p_j and has the number of the tokens located to the place p_j, a^k is a vector whose element corresponds to the transition t_i and is 1 when the transision t_i is alive and is 0 when the transision t_i is not alive, and C^+ and C^- are the incident matrices derived from the directed graph whose elements means the number of arcs from the transision t_i to the place q_j (the output relation of the transition) and to the place t_i from the place q_j (the input relation) respectively. Each state of the Petri net corresponds to each design process. Through designing, we have

$$\mu^r - \mu^\circ = [\, C^+ - C^- \,] \sum a^k, \quad \text{and } \mu^k \geq C^- a^k \ (k=1,2,\cdots,r), \tag{6}$$

whre μ^r is the final design stage and μ° is the initial design stage. Using the equation (6),performing the design iteratively is now to find out a subsequent parade of $a_1,a_2,\cdots,a_r$. We call the equation (6) the design equation.

The equation (6) allows us to analyze the structure of the BFM. These are itemized as follows.

1. An initial state — finding the unit designed at first.
2. A terminating state — finding the unit desined at last.
3. Reachability — finding out pathes between two units.
4. Sensitivity — finding out the unit which is the most sensitive for designing among all the units.

SELF-ORGANIZATION OF UNITS TOWARD HIERACHY STRUCTURE

The Petri net can represent a hierachy structure in which one transision consists of some places and some transisions and one place consists of some places and some transisions. In machine design, we may deal with some units as one unit. If it is possible to find out which units can be regarded as the one unit, the design structure is able to be organized for the hierachy structure. We use the Petri net property to find out the hierachy structure. For this purpose, we rewite the equation (6) under below,

$$\mu = C\, a, \tag{7}$$

where $\mu = \mu^r - \mu^o$, $C = C^+ - C^-$, and $a = \Sigma\, a^k$. If some places and transitions are considered as the one transition, we name it a macro transition. We have

$$\mu_i = C_i\, a_i \tag{8}$$

within a macro transition and

$$\mu_i^o = C_i^o\, a_i^o \tag{9}$$

between the transitions within the macro transition and the places without it. And we have

$$\mu^o = C^o\, a^o \tag{10}$$

on the rest of the transitions and places which do not belong to any macro transitions. The equations (8)~(10) make the following diagonal form,

$$\begin{bmatrix} C_0^o & C_1^o & C_2^o & \cdots & C_s^o \\ 0 & C_1 & 0 & \cdots & 0 \\ 0 & 0 & C_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & 0 & \cdots & C_s \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_s \end{bmatrix} - \begin{bmatrix} \mu_0 \\ \mu_1 \\ \mu_2 \\ \vdots \\ \mu_s \end{bmatrix} \tag{11}$$

If the equation (7) is reformed to the equation (11), we can organize the Petri net to the hierachy structure. We have heuristic algolithms to reorder the equation (7) to the quation (11). The transitions found out to be the macro transitions correspond to the units are regarded as the one unit. By the use of this procedure, it becomes possible to self-organize the BFM structure toword the hierachy structure. This procedure is applicable to make up instances and to simplify the BFM model.

EXAMPLES

In order to verify our theory, a pilot system is developed. The program is coded by REXX languadge (IBM executable languadge). The system is implemented to IBM 4361-V and used via APPLO engineering work station DN4000. The system structure is shown in Figure 3. The model used for designing is an electric power winch. Figure 1 shows the frame representaion for a drum and a gear. Figure 4 shows the electric power winch model and figure 5 shows its Petri net. Figure 6 is the incident matrix of the Petri net shown in Figure 5. Figure 7 is a part of result after the designing

is finished. Figure 8 is a designing sequence of the unit automatically executed. Figure 9 is the reformed incident matrix from the incident matrix shown in the Figure 6 for a hierachy structure. Enclosed transitions and places in Figure 5 are corresponding to diagonal matrices located in the matrix shown in Figure 9.

CONCLUDING REMARKS

" The boundary factor model " as the design model, a control method of a design process by the use of the Petri net, " Object and Operation " representation for expressing the design kowledge are proposed for the parametric design. The Petri net is not only avairable for the controlling the design process but also for self-organizing the design structure. It is also applicable other models such as a manufacturing model, a robot model etc.

REFERENCES

[1] YOSHIKAWA,H, General Designing Process, J.S.P.E, Vol.47, NO.4 (1987)pp.405

[2] OKINO,N, An Integrated CAD/CAM System : TIPS-2, Proc.of PROLAMAT'76,(1976/4)pp. 385, Stirling, Scotland

[3] HUBKA,V, Principles of Engineering Design, Butterworth Scientific(1980)

[4] OKINO,N, O/O (Object and Operation) Dualism for CAD/CAM Software Architecture, Annals. of the CILP. Vol.34, No.1(1985)pp.179

[5] Peterson,J.L, Petri Net Theory and the Modelling of System, Prentin Hall(1981)

[6] FURUKAWA,M, Control of Design Process with Petri Net for CAD, Proc.of CADDM87 (1987/4)pp413, Beijin,China

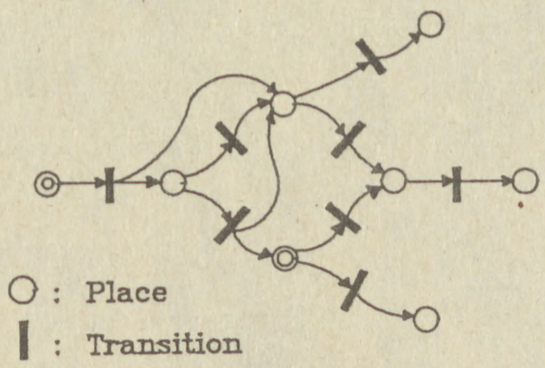


Fig.1 A Petri net graph.

```
.../icpe.88/rope_uni                                   R   1
ROPE(ROPE)

ROPE:
(
  SHEARING_LOAD            /(KG)   /T    ;
  WINDING_LOAD             /(KG)   /Q    ;
  SAFETY_COEFFICIENCY      /(-)    /S    ;
  ROPE_DIAMETER            /(MM)   /RD   ;
  ROPE_ELEMENT_DIAMETER    /(MM)   /RED  ;
  ROPE_TYPE                /(-)    /TYPE ;
  ROPE_COMPOSITION         /(-)    /COMP ;
Z
  ASS / TYPE = "NO.3" ;
  ASS / COMP = "6*19_NORMAL_Z-TWIST" ;
  REL / T = Q * S ;
  TAB / (RD,RED) = ROPE6_19(T) ;
);

/*     EDITING    87/01/30 10:49:33    */
```

```
.../motor_un                                           R   1
MOTOR(MOTOR)

MOTOR:
 (
   MOTOR_POWER             /(KW)   / L   ;
   MOTOR_RPM               /(RPM)  / N   ;
   WINDING_LOAD            /(KF)   / Q   ;
   SELF_WEIGHT             /(KG)   / G   ;
   INITIAL_ROPE_SPEED      /(M/MIN)/ V   ;
   WINDING_ROPE_SPEED      /(M/MIN)/ VW  ;
   ROPE_PITCH              /(MM)   / A   ;
   DRUM_DIAMETER           /(MM)   / DD  ;
   ROPE_DIAMETER           /(MM)   / RD  ;
   ROPE_TURNS_NO           /(-)    / NN  ;
   EFFICIENCY              /(-)    / ETA ;
   EFFICIENCY_OF_DRUM      /(-)    / ETAD;
```

```
.../mack/icpe.88/drum_uni                              R   1
DRUM(DRUM)

DRUM:
(
  DRUM_DIAMETER            /(MM)   / DD  ;
  ROPE_DIAMETER            /(MM)   / RD  ;
  ROPE_ELEMENT_DIAMETER    /(MM)   / RED ;
  WINDING_LOAD             /(KG)   / Q   ;
  DRUM_WEIGHT              /(KG)   / DDW ;
  MATERIAL                 /(-)    / MAT ;
  DRUM_GUARD_DIAMETER      /(MM)   / DGD ;
  DRUM_ROPE_TURN_NO        /(-)    / NN  ;
  ROPE_TURNS_NO            /(-)    / N   ;
  WINDING_LENGTH           /(M)    / L   ;
  DRUM_WIDTH               /(MM)   / B   ;
  ROPE_PITCH               /(MM)   / P   ;
  DRUM_THICKNESS           /(MM)   / T   ;
  ALLOWABLE_COMPRESS_STRESS /(KG/MM2)/ SIGMA.C ;
Z
  DEF / ROPE_ELEMENT_DIAMETER TO RED ;
  DEF / ROPE_DIAMETER         TO RD  ;
  DEF / WINDING_LOAD          TO Q   ;
  REL / B = NN * P ;
  IF  / MAT = "FC" ;
    REL / T1 = 0.02 * DD + 10 ;
  NOP / END ;
  TAB / (D2,BB,DGD) = DRUM_MIN(Q) ;
  REL / DD = MAX(D1,D2) ;
  REL / NN = 1000*L/PI/DD + 3 \INT ;
  IF  / MAT = "SC" ;
    REL / T1 = 0.01 * DD + 30 ;
  NOP / END;
```

```
pad01                                                  I   S
47 entries.
$ cpscrx unit
```

```
Command:                                               I
```

Fig.2 Examples of O/O frame representation.

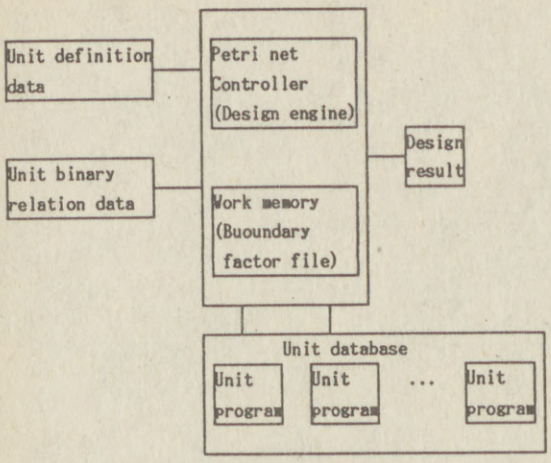


Fig.3 A system structure of the pilot system.

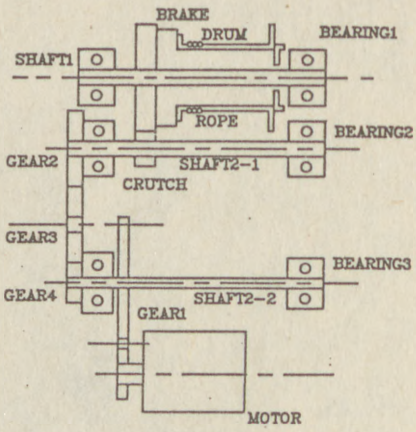


Fig.4 A model of an electric power winch.

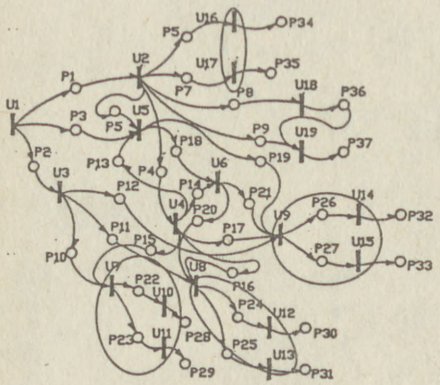


Fig.5 The Petri net graph for the model shown in Fig.4.

TRANS. NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
PLACE. NO 1	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 2	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 3	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 4	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 5	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
PLACE. NO 7	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0
PLACE. NO 8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0
PLACE. NO 9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0
PLACE. NO 10	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	-1
PLACE. NO 11	0	0	1	0	-1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 12	0	0	1	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
PLACE. NO 13	0	0	0	1	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0
PLACE. NO 14	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 15	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 16	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 17	0	0	0	1	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
PLACE. NO 18	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 19	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
PLACE. NO 20	0	0	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	0
PLACE. NO 21	0	0	0	0	0	1	-1	0	-1	0	0	0	0	0	0	0	0	0	0
PLACE. NO 22	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0
PLACE. NO 23	0	0	0	0	0	0	1	0	0	-1	0	0	0	0	0	0	0	0	0
PLACE. NO 24	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0
PLACE. NO 25	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	0
PLACE. NO 26	0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0
PLACE. NO 27	0	0	0	0	0	0	0	0	1	0	0	0	-1	0	0	0	0	0	0
PLACE. NO 28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
PLACE. NO 29	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
PLACE. NO 30	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
PLACE. NO 31	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
PLACE. NO 32	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
PLACE. NO 33	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
PLACE. NO 34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
PLACE. NO 35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
PLACE. NO 36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0
PLACE. NO 37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

Fig.6 An incident matrix for the Petri net shown in Fig.5.

.../user2/mack/mack/icpe.88/gear01_s R

SLOT : GEAR1/INIT

REDUCTION_RATIO	(-)	I	0.03099
DRUM_RPM	(RPM)	N	29.44
MOTOR_RPM	(RPM)	NM	950.00
WINDING_ROPE_SPEED	(M/MIN)	V	37
DRUM_DIAMETER	(MM)	DD	400.00
MOTOR_PINION_TOOTH_NO	(-)	Z1	24
DIRECT_GEAR_TOOTH_NO	(-)	Z2	85
IDLE_PINION_TOOTH_NO	(-)	Z3	20
IDLE_GEAR_TOOTH_NO	(-)	Z4	43
PINION_GEAR_TOOTH_NO	(-)	Z5	50
DRUM_PINION_TOOTH_NO	(-)	Z6	17
DRUM_GEAR_TOOTH_NO	(-)	Z7	62
MOTOR_PINION_RPM	(-)	N1	950.00
DIRECT_GEAR_RPM	(-)	N2	268.24
IDLE_PINION_RPM	(-)	N3	268.24
IDLE_GEAR_RPM	(-)	N4	124.76
PINION_GEAR_RPM	(-)	N5	107.30
DRUM_PINION_RPM	(-)	N6	107.30
DRUM_GEAR_RPM	(-)	N7	29.42

.../user2/mack/mack/icpe.88/rope_slo R

SLOT : ROPE/ROPE

SHEARING_LOAD	(KG)	T	12000.0
WINDING_LOAD	(KG)	Q	2000
SAFETY_COEFFICIENCY	(-)	S	6
ROPE_DIAMETER	(MM)	RD	16.0
ROPE_ELEMENT_DIAMETER	(MM)	RED	1.07
ROPE_TYPE	(-)	TYPE	NO.3
ROPE_COMPOSITION	(-)	COMP	6*19_NO

pad01 I S

```
$ cpserx $slot
```

Command: I

R 1

SLOT : WHEEL/WHEEL

MODULE	(MM)
TWISTING_MOMENT	(KG*M)
WINDING_LOAD	(KG)
DRUM_DIAMETER	(MM)
NAIL_ACTION_FORCE	(KG)
NAIL_WHEEL_DIAMETER	(MM)
TOOTH_WIDTH	(MM)
TOOTH_HIGH	(MM)
ROOT_THICKNESS	(MM)
TOP_THICKNESS	(MM)
BOLT_VALLEY_DIAMETER	(MM)
BOLT_NO	(MM)
BOLT_DIAMETER	(MM)
PALNE_PRESSURE_STRESS	(KG/MM
ALLOWABLE_PALNE_PRESSURE_STRESS	(KG/MM
BENDING_STRESS	(KG/MM
ALLOWABLE_BENDING_STRESS	(KG/MM
SHOCK_SHEARING_STRESS	(KG/MM
ALLOWABLE_SHOCK_SHEARING_STRESS	(KG/MM
ALLOWABLE_SHEARING_STRESS	(KG/MM

SLOT : WHEEL/SHAFT

BENDING_MOMENT	(KG/MM
NAIL_ACTION_FORCE	(KG)
LENGTH	(MM)
N.S_DIAMETER	(MM)
N.S_BENDING_STRESS	(KG/MM
N.S_SHEARING_STRESS	(KG/MM

Fig.7 Examples of result slot values.

```
PLACE NUMBER : 28 TOKEN :  1
PLACE NUMBER : 29 TOKEN :  1
PLACE NUMBER : 30 TOKEN :  1
PLACE NUMBER : 31 TOKEN :  1
PLACE NUMBER : 32 TOKEN :  1
PLACE NUMBER : 33 TOKEN :  1

>> THE DESIGN SEQUENCE TO BE EXECUTED IS AS FOLLOWS

| NO. | UNIT     |   FEATURE          |
 ----- ---------- --------------------
|    1|UNIT01    |ROPE                |
|    2|UNIT02    |DRUM                |
|    3|UNIT03    |MOTOR               |
|    4|UNIT14    |BRAKE               |
|    5|UNIT04    |GEAR1               |
|    6|UNIT15    |CLUTCH              |
|    7|UNIT16    |WHEEL               |
|    8|UNIT05    |GEAR2               |
|    9|UNIT06    |GEAR3               |
|   10|UNIT08    |SHAFT1              |
|   11|UNIT07    |GEAR4               |
|   12|UNIT09    |SHAFT2-1            |
|   13|UNIT11    |BEARING1            |
|   14|UNIT10    |SHAFT2-2            |
|   15|UNIT12    |BEARING2            |
|   16|UNIT13    |BEARING3            |
 ----- ---------- --------------------

SATISFIED DESIGN CONDITION

DESIGN PROCESS IS COMPLETELY DONE .
RESULTS ARE REGISTERED IN BOUNDARY FILE .
GOOD BYE !!
```

Fig.8 Final place and design sequence.

```
| TRANS. NO   |  1  2  3  4  5  6 18 19 17 16 14 15  9 12 13  8 10 11  7 |
|-------------------------------------------------------------------------|
| PLACE. NO  1|  1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  2|  1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  3|  1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  4|  0  1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  5|  0  1  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  6|  0  1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 |
| PLACE. NO  7|  0  1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  8|  0  1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO  9|  0  1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO 10|  0  0  1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1 |
| PLACE. NO 11|  0  0  1  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 |
| PLACE. NO 12|  0  0  1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0 |
| PLACE. NO 13|  0  0  0  1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 |
| PLACE. NO 14|  0  0  0  1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO 15|  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 |
| PLACE. NO 16|  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 |
| PLACE. NO 17|  0  0  0  1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 |
| PLACE. NO 18|  0  0  0  0  1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO 19|  0  0  0  0  1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0 |
| PLACE. NO 20|  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0 -1  0  0  0 |
| PLACE. NO 21|  0  0  0  0  0  1  0  0  0  0  0  0 -1  0  0  0  0  0  0 |
| PLACE. NO 36|  0  0  0  0  0  0  1 -1  0  0  0  0  0  0  0  0  0  0  0 |
| PLACE. NO 37|  0  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0 |
 .........................................................................
| PLACE. NO 35|  0  0  0  0  0  0  0  0| 1  0| 0  0  0  0  0  0  0  0  0 |
| PLACE. NO 34|  0  0  0  0  0  0  0  0| 0  1| 0  0  0  0  0  0  0  0  0 |
|                                        .....                            |
| PLACE. NO 32|  0  0  0  0  0  0  0  0  0  0| 0  1  0  0| 0  0  0  0  0  0 |
| PLACE. NO 33|  0  0  0  0  0  0  0  0  0  0| 0  0  1  0| 0  0  0  0  0  0 |
| PLACE. NO 27|  0  0  0  0  0  0  0  0  0  0| 0  0 -1  1| 0  0  0  0  0  0 |
| PLACE. NO 26|  0  0  0  0  0  0  0  0  0  0|-1  0  0  1| 0  0  0  0  0  0 |
|                                              .....                      |
| PLACE. NO 30|  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 1  0  0| 0  0  0 |
| PLACE. NO 31|  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 0  1  0| 0  0  0 |
| PLACE. NO 25|  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 0  0 -1| 1  0  0 |
| PLACE. NO 24|  0  0  0  0  0  0  0  0  0  0  0  0  0  0|-1  0  0| 1  0  0 |
|                                                            .....        |
| PLACE. NO 28|  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 1  0  0 |
| PLACE. NO 29|  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 0  1  0 |
| PLACE. NO 23|  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0| 0 -1  1 |
| PLACE. NO 22|  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0|-1  0  1 |
```

Fig.9 A diagonal form matrix for hiearchy structure.

OPEN MACROS OF GEOMETRIC LANGUAGE

Glushkov O.I.,
Menshchikov A.A.

The Institute of Engineering Cybernetics
The Byelorussian Academy of Sciences. Minsk. USSR

Keywords: geometric modeling, dimensional grid, geometric language, macros, 3D image

Introduction

It is better to use the models of the whole construction than it separate graphical images. At the same time, the construction should be represented by the geometric objects wich has been written into the storage. The different geometric modeling systems solve the above problem by lashing the local coordinate systems (LCS) of the objects to the host coordinate system (HCS) of the construction [1-3]. The distance between LCS and HCS is defined by performing the arithmetic operations on the dimensions. The result of this is the grid, in that the required dimensional relations are disappeared and the new relations are appeared. The new dimensional relations can be incorrect if the dimensions have the extreme deviations.

The approach to geometric modeling, that does not change the dimensional relations between parts is suggested. The approach uses the macros of the geometric language of interpreter type.

A Geometric Language (GIMAP)

A geometric macro language (GIMAP) for describing mechanical parts and assemblies is proposed, intended for 2D and 3D geometric model specification and modification, generation of engineering drawings, design analysis, storage of models and additional technological data, and arithmetic/logical operations. The 2D subset of the language is intended for describing and defining parameters of contours composed of lines, arcs, curves, points. This language is the user-friendly one of APT-type. The dimensions from drawing are used in GIMAP. The additional recalculations are not required that ensures accuracy of defining geometric elements.

Generating 3D geometric elements can be performed both by it projections and by 3D space parameters. The 3D GIMAP subset has facilities for forming complex models and for defining and preserving positional and dimensional relations between parts. There are few kinds of representing bodies:
- projections;
- edges;
- bounded surfaces;
- set-theoretic operations with basic elements;

- open macros.

The internal form of representation of different geometric elements is common for all kinds.

The GIMAP language can involve facilities for describing machining process for NC machine-tools depending on technique of organization connections between geometric and technological data. The commands of machining process and functional loads applied to construction elements or parts are put in square brackets after identificators of geometric elements in the GIMAP statements.

Macros of Language

The description of some construction by basic elements of language (lines, surfaces) is called the simple macroelement (ME). More complex ME can consist of lower-level ME's.

The GIMAP language was designed on base of principles of flexibility and extensibility. This was dependent of range of reasons. First, it is often necessary to enter new language constructions into the language. Second, using several problem-oriented languages in CAD system will lead to establishing correspondence between these languages. Thirdly, the grammatical chains are presented by the different users differently. As a result, the syntax and lexicon of the language are changed. In GIMAP, the user has a access to the linguistic tables. New ME included into these tables are considered by the translator as the natural language statements.

In general, the ME description stored into directory of translator consists of the language statements that contain formal parameters. The variable is any basic element and its characteristic included in this description. When it is call to ME the translator replaces formal parameters by real parameters. In other case, when a subprogram is called, the data predetermined in common area or list of parameters is only changed. Access to any basic element of ME is needed when the synthesis of the objects is performed, i.e. when the set of the geometric elements of the one object is described by the set of the geometric elements of the other object.

The operator of GIMAP for call to ME is follows:

$$\langle ME \rangle :\pm \langle TME \rangle, \langle BE \rangle, \ldots, \langle BE \rangle,$$

where <ME> denotes the identificator of ME, <TME> - the type of ME, and <BE> - the basic element.

The supposed macros in difference from traditional problem-oriented languages are open. The GIMAP language has facilities for access to the elements of ME that do not determined in list of formal parameters. The lower or first level of ME library can be represented the set of basic elements of shape (cylin-

der, sphere, parallelepiped, etc.). There are the constructive-technological elements on the next level. These elements in appropriated systems are basic and they contain ME of first level. The third level contains more complex constructions and so on. ME of language can have the levels of different detailing. Composition of complex models from ME is performed by the positional synthesis method. According to this method the elements of lashed object (lines, surfaces) are described as elements that agree with main/auxiliary elements of basic object. The auxiliary elements are specified by the geometric conditions and the dimensional relations with respect to the elements of the basic object. The auxiliary elements are:
- the elements of lashed object;
- the elements having alternative orientation;
- the elements constituted lashed object.

Identification of Elements

To use ME it is required to identify its elements. It is not necessary to describe the different ME by a lines and surfaces identifyed by same names. At the same time, each basic element of description of some construction should be have a unique name allowing to define a required data easy. The composed name in the GIMAP language is used, saving all intermediate identificators of ME through a point. So, the name of basic element of description of construction is as follows:

$$M_n.M_{n-1}...M_2.M_1.B,$$

where M_n - M_1 - the identificators of ME of modeled construction on different levels, B - the identificator of basic element of ME description.

The composed name determines the elements while a geometric modeling is performed. The composed name of the element changed is begin from the identificator of the level n-1 in the basis of operator of call to ME of the level n.

The basic elements of operator of call to ME are as follows:

$$<MBE> = <NEV>,$$

where <MBE> denotes the mark of basic element or parameter, determining the geometric element in description of ME; <NEV> - new basic element or new parameter value.

The identificators contained in the basis of the operator of call to ME are replaced with the new values specified at the right part of BE. The identificator of called ME is added (through a point) to the rest of identificators mentioned above.

If ME is called, it is not necessary to replace the basic element. Replacing is better does for the next operators of geometric modeling. In this case, the changed geometric element

should not be specified in the basis of the operator of call to ME. Hence, the list of basic elements in the operator of call to ME does not fixed.

There are several kinds of solid presentation in the GIMAP language. Consequently, the basic elements of shape can be described differently. Depending on the object description technique, the identificators of geometric elements needed for describing the synthesis conditions are differently defined too.

If 3D objects are modeled by means of elements which have smaller dimensionality (for example, a solids of revolution), the surfaces containing the edges are automatically identified. The identification method is discussed below.

The composed name of element to be chose from the object model must contain the identificators of all intermediate geometric elements needed for forming this model. The identificators are disjuncted by a note of underlining "_". It is possible that the element outlined above can be called by abbreviated identificator containing identificators of elements high or lower levels.

Examples of Using Macros

Suppose it is necessary to call a single surface, which contains a edge of solid of translation formed by a parallel moving of a planar contour (fig.1). The following text is the solid presentation of the set of the GIMAP statements:

```
L1: S,...  }
L2: O,...  }
.          }   Lines consisting a line segments and arcs,
:          }   and forming a contour
L8: S,...  }
G1: PLCO,L1+L2+...+L8+L1,SP'CO; - a planar contour
L10:S,...
L11:S,...
:
:
L:  LAYOUT,PR1=G7,PR2=G1; - layout/structure of a drawing
T:  TRB,G1,P10,L11; - solid of translation(translation bo-
                      dy)
```

A solid T contains a edges of surfaces which have the following identificators:

```
T_G1_L1;
T_G1_L2;
T_L1T;
```

The required surface can be called both by a full name, for example, T_G1_L2, and by a shorted name - T_L2. In order to use a shorted identificator it is necessary to exclude a dissimilarity when defining a required element. The user determines whether the identificator for synthesis of objects is shorted or full.

The translator selects from the list a first element having the shorted identificator and puts the diagnostic message in case there is a one more element.

We consider using a macros applied to example of generating a shaft model (fig.2). Suppose there is the description of the "cylinder" macro (fig.3). In general, to generate the model of one cylinder it is necessary to determine its diameter D, height H, and coordinate origin CO of LCS. The description of the shaft model consists of the macro calls to two "cylinder" ME: ME1 - the cylinder of greater diameter and ME2 - the cylinder of smaller diameter. The LCS of ME1 agrees with the coordinate system of the shaft. The LCS of ME2 lies on the plane SP2 of ME1 and the ME1 and ME2 axises are agreeded. The height and diameter of cylinder ME1 are determined with respect to the dimensions on the drawing. The height of the ME2 cylinder does not given. Subtraction the dimension H1 from the dimension H2 for determining the plane SP20 disturbs the dimensional grid and leads to recalculation of extreme deviations. Using the open macros of the GIMAP language allows to describe the plane SP2 of the ME2 cylinder as the plane to be agreeded to the auxiliary plane SP20, that is described as the plane moved off from the plane SP1 of ME1 on the distance H2. The plane SP1 of the ME2 cylinder agrees to the plane SP2 of the ME1 cylinder.

So, the shaft model is described as follows:

```
ME1: CYL,H=H1,D=D1,CO=C1;
SP20:PL,P=H2,-ME1.SP1;
ME2: CYL,D=D2,SP2=SP20,SP1=-ME1.SP2,L10=ME1.L10;
SHAFT:UN,ME1+ME2;
```

If the "cylinder" ME is described as in Fig.4 the cylinder presentation is as follows:

```
SP20:PL,P=H2,-ME1.T_L4;
ME2: CYL,D=D2,SP2=SP20,SP1=-ME1.T_L2,L10=ME1.L10;
```

Conclusions

Using a open macros in CAD systems allows: to expand the scope of ME, to reduce the time of their generation, to minimize the storage capacity.

Subsequently, it is possible that on the base of the approach suggested, synthesis the constructions and documenting can be performed in automatic mode.

References

1. Aristides A.G. Requicha and Herbert B. Voelcker. Solid Modeling: Current Status and Research Directions//IEEE Compt. Graph.Appl.,Vol.3,N7,October 1983,pp.25-37.

2. Aristides A.G.Requicha,H.B.Voelcker. Boolean Operations in Solid Modelling: Boondary Evaluation and Merging//Proceedings of the IEEE,Vol.73,N1,January 1985.-Pp.32-49.

3. Tony C.Woo. Interfacing Solid Modeling to CAD and CAM: Data Structures and Algorithms for Decomposing a Solid//Computer,Vol.17,N12,December 1984,pp.44-49.

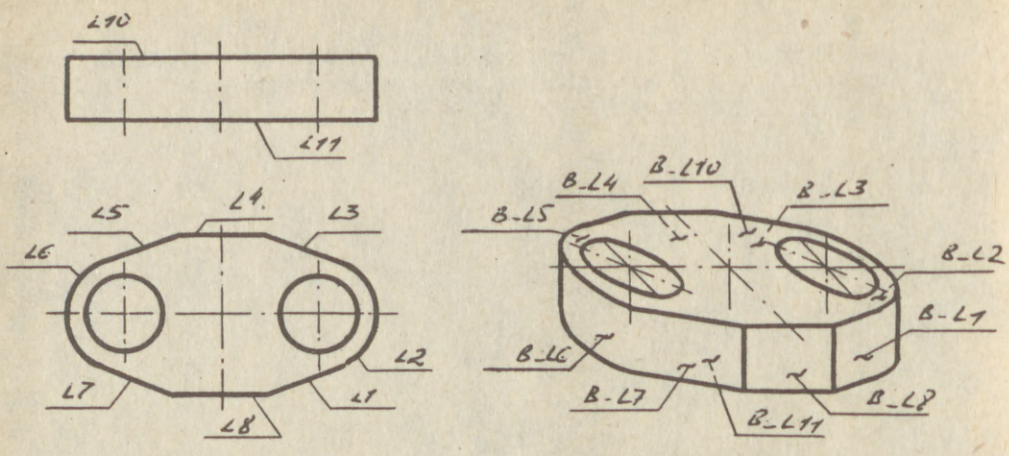

L10
L11
L5
L4
L3
L6
L2
L7
L1
L8
B_L4
B_L10
B_L3
B_L5
B_L2
B_L1
B_L6
B_L7
B_L8
B_L11

Fig.1

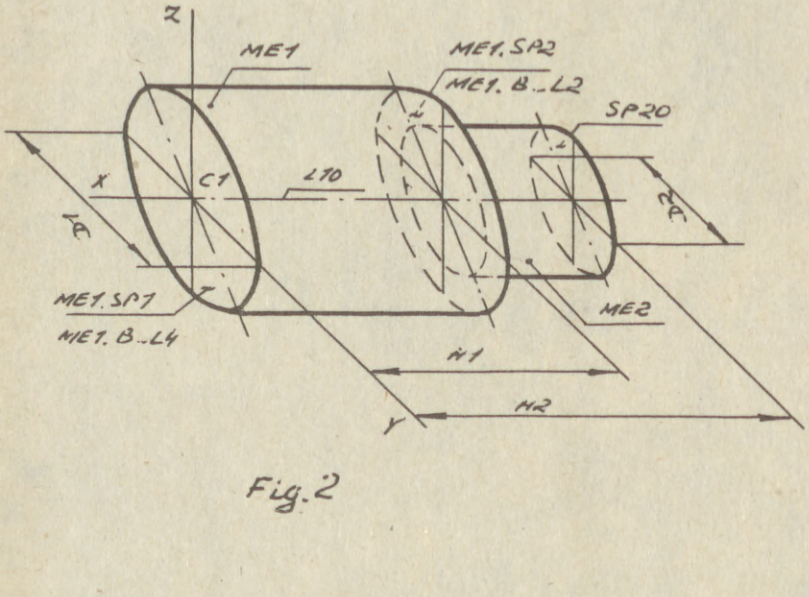

Z
ME1
ME1.SP2
ME1.B_L2
SP20
X
C1
L10
L
2R
ME1.SP7
ME1.B_L4
ME2
H1
H2
Y

Fig.2

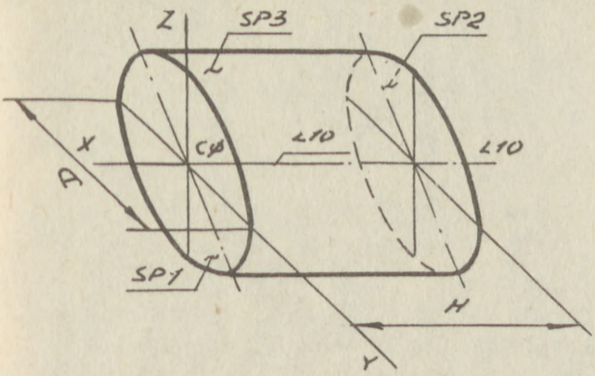
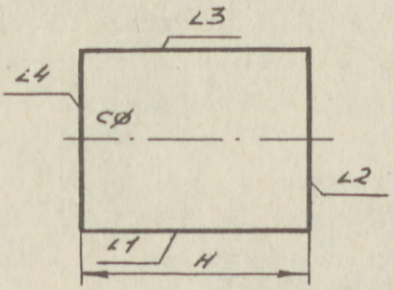
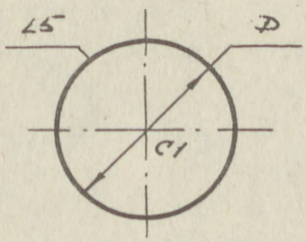


Fig.3

L1Ø: S3, +X'CØ;
S1: -PL, X=Ø, CØ;
S2: PL, X=-H, CØ;
S3: +CP, D=D, L1;
T: PP, S1 ∩ S2 ∩ S3;





C1: C, X=Ø, CØ;
L4: -SL, X=Ø, CØ;
L2: SL, SL=H, L4;
L5: O, D=D, C'1;
L1: SL, +L5, X'CØ;
L3: -SL, -L5, +X'CØ;
T: CLCO, L1+L2+L3+L4+L1, SP'CØ;
G2: CLCO, L5, SP'C1;
L: LAYOUT, PR1=G1, PR3=G2;
L10: L3, C1;
B: TRB, G2, L2, L4;

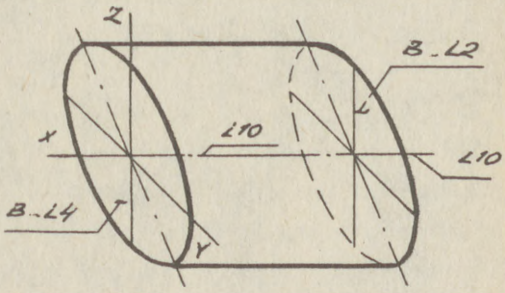


Fig.4

Prof.Dr.sc.techn. Gerhard Großmann
"Friedrich List" University of Transport and Communications
Dresden

Flexible Automation of Material Handling

1. What means flexibility?

In general flexibility means rapid adaption of working processes to changing working tasks of varying intensity for few motions and small stocks in the material flow.

The tasks of transport, handling and storage (TUL) are clearly defined by the conditions of time, place, goods volume and grade. A TUL system must fulfil these conditions and at the same time maintain the two optimality criteria, whichare quality preservation and minimumcosts. Presupposing the use of technical means this is only possible up to now if the range of variation of the four just mentioned conditions is narrow or when only one or two conditions at the most very largely. Yet flexibility is the ability of a TUL system to recognize informationally and realize materially the wide ranges of variation of all four conditions. Up to now this has only been possible with the aid of man, i.e. in systems of low technicalization. With a high mechanization and automation, which remained efficient anyway only in the case of large goods volumes in fixed chains, flexibility was lost.

Consequently flexibility of TUL processes means to handle also small and smallest goods volumes, even in large assortment scales, swiftly and according to demand without giving up the high technicalization and quality standards of the "large series". This requires a number of technologies to be kept available as highly productive and rapidly applicable services. As regards flexible manufacture TUL processes must offer a thoroughly automated solution not only for the roboter-adapted supply and disposal of flexible manufacturing cells but also for conventional working places arranged parallel with them.

2. Standard of goods handling 2

Goods handling has extremely differing standards dependent on its concentration and goods sort.

The handling of gases and liquids has reached a high technical standard and does no longer appear as a separate process in the material flow. This is due to the capacity of these materials to flow and to their use in closed container systems. The material and informational integration of goods handling into the logistics-based material flow has been greatly realized.

On the other hand the parcelled goods handling is, on an average, still far away from this standard. Although the handling of large and heavy parcelled goods is mechanized, it is nevertheless connected with many poorly mechanized or even manual auxiliary operations. Small and lightweight parcelled goods are even handled still manually to a large extent. The automation of parcelled goods handling and the integration into logistical concepts were restricted up to now to relatively few cases.

The handling of bulk material is taking an intermediate position:
In concentrated handling great quantities are already handled with a high degree of automation; computer control and integration into logistical concepts are well under way. Obstacles occur here when wet goods are handled in winter or when vehicles have to be cleared totally after unloading with a grab crane. As regards small bulk goods quantities often handled in decentralized facilities the standard is generally not higher than that of parcelled goods handling.

While in bulk material handling the working productivity amounts to 40 tons per man-hour, there is a value of 2 tons per man-hour in parcelled goods handling; as regards small parcelled goods which are mostly handled manually working productivity decreases to less than 0.5 tons per man-hour. But the parcelled goods sector is extremely vulnerable from the economic point of view: Owing to the low degree of mechanization a great number of workers are required for parcelled goods handling who have to work under

adverse conditions. Here a lack of workers has the most severe effects. In the course of refinement the portion of parcelled goods increases and at the same time their value intensity and time sensitiveness are also growing. Especially parcelled goods require a rapid and highly productive material flow.

3. Flexible parcelled goods handling - a crucial problem

Flexible parcelled goods handling requires the rapid adaption to many different goods sorts and the full mechanization in handling also small and light-weight goods, which is a prerequisite to automation and working productivity. This is one of the crucial problems on the way to a higher flexibility of TUL processes. Or expressed otherwise: the offer of highly efficient handling technologies must also become wider!

The "handy" parcelled goods up to about 100 kg of mass have at all times been dimensioned and designed in such a way that man is able to grasp them with his hands and to handle them by his own muscular force. Now as before these types of manual work are largely spread and bind a considerable number of workers who have to work under adverse working conditions due to the lack of suitable means of mechanization.

If there are large quantities of goods they are preferably palletized or packaged to larger load units which are handled with efficient machinery, as for instance fork-lift trucks or rack operating equipment.

But frequently only few parcelled goods of one sort come in. Sometimes the formation of greater load units is not even wanted because loading spaces can be far better used with small goods units (when palletized load units are arranged in large containers nearly one fifth of the surface area are not used!) or because small goods units are far more suited to supply production and consumption according to their demand. But at the same time in order to reduce clearly the still high working time expenditure for the manual handling of small and

light-weight parcelled goods and to integrate also those processes into complex automation solutions, it is a question of urgent necessity to develop mechanisms for a rationalization of these processes. Here is a technological gap which has to be closed.

Manipulators and microelectronically controlled robots are facilities which are suitable for handling mechanization and automation of small, light-weight parcelled goods. But the variety of these parcelled goods is so great that it occurs at first as a considerable obstacle for a broad application of manipulators and robots. Therefore it is necessary with regard to a TUL and robotadapted design to work on a thorough unification of these goods, which might be a lengthy process. If this aspect is already taken into account by the designers of producersa great obstacle for flexible automation of parcelled goods handling is overcome.

The start can be made with robots used for dispatch units or trade packages of a mass of about 1 to 100 kg. The lower weight range includes packed products of the light industries, the upper one retail trade bundles of chemicals, building materials and the like. They must be sufficiently stable for mechanical grasping.

Furthermore manipulators and robots should be suitable for filling and emptying receptacles and cargo spaces of any kind. If one also wishes to restrict the great variety to a clear-cut field a standardized large container seems suitable for the beginning.

4. Automated container loading robot in two variants

For filling and emptying large containers the following approach concept was developed: consumer goods packed in corrugated board folding boxes of 30 different sizes should be dispatched in containers as a mixed assortment.

The boxes palletized after production according to sorts are depallized by the robots until the required number of a spezial sort has been taken. The boxes move on a conveyor to the loading robot which will arrange them to half rows and stack them up in disks in the container. Due to this complex automation approach approximately six jobs will be eliminated in this first case of use, compared with the present situation, where the workers have to palletize and pile up the boxes in the container.

Although the dispatch of small light-weight parcelled goods will in future gain more importance, the forwarding of palletized load units in large containers will remain an important type of dispatch. For this purpose front stackers are used nearly exclusively. But during hard continuous operation they come to their bounds. The service life of large containers is relatively long. In a further pilot case of use a loading robot for palletized load units was developed: The palletized load units are moved on roller conveyors to a gantry robot which is putting them down on a platform according to the stacking scheme. The platform is mobile, has rollers and its dimensions are thus that it fits into the large container. If the container load has been stacked on the platform, it is moved as a whole into the container and the platform will then be pulled out again. While the container filled within minutes is made ready for dispatch and exchanged for another, the next load is already being prepared.

These two approaches are presented at the Congress.

5. Summary

The path to a universal manipulator or handling robot is still long. But due to the technical partial steps already taken today highly efficient approaches are to be expected. They will save jobs, increase the degree of technicalization, improve the use of cargo spaces, diminish the damage to goods and increase the flexilibity, especially in logistical concepts.

IS MAP 3.0 READY FOR CIM IMPLEMENTATIONS?

Klaus Grund, EDS Electronic Data Systems
Central European Div. Eisenstrasse 56, 6090 Rüsselsheim,FRG

Géza Haidegger, res. eng. HMUG

Dr. György Kovács, head of. res. dept.
Computer and Automation Institute, (CAI) SzTAKI
Hungarian Academy of Sciences, Budapest
1518. P.O.Box.63. tel.: (+36)(1)1811-143

ABSTRACT

The MAP (Manufacturing Automation Protocol) version 3.0 was accepted already in late 1988. According to the declaration, it will be a stable standard for at least 6 years on. This position encourages potential end-users and system integrators to take MAP/TOP products seriously for their factory automation projects. But what are these products? They are chips, modems, boards, systems, software, cabling, documentation and much more. One may ask whether users are well prepared to integrate these products, or not.

INTRODUCTION

There have been a number of exhibitions, demonstrations and announcements to convince system-integration engineers that MAP 3.0 compatible products are already available on the market. We will try to give an up-to-date overview on this market based on product announcements from all over the world. But for the fast spreading of MAP implementations, not only the "source" market should be analyzed, but one must take a look at the "drain" side as well, i.e. are the users ready to utilize MAP/TOP products? Are the system-integrators familiar with the technology and know-how of implementing and installing such systems based on MAP/TOP networks? The authors will try to give answers to the above questions and provide potential end-users with some hints for being well informed on this topic.

THE LAUNCH FOR A LONG-TERM PROJECT

The General Motors Corporation realized the growing burden of non-compatible computerized devices used in the manufacturing environment, and set up a Task Force to prepare a long-term solution for that problem. The first MAP documents appeared already in 1982, and the MAP Specifications version no. 1 was prepared in 1984. A 'graceful migrational approach' was proposed to raise the interest of other users and decrease the risk of the vendors. This transition was planned to take place according to a 5 step development process and a final MAP solution was estimated for 1988 [1]. The technical solution to connect the 'islands of automation' was declared to be conform with the international standards regarding the OSI (Open Systems Interconnection) schema. By 1987, MAP became recognized by leading industrial regions all over the world: in America, Europe, Japan, Australia and Asia.

FALLING BEHIND THE TIME SCHEDULE

The work on developing MAP had been carried out by a large number of experts' groups. Not only those contracted with GM, but dozens of independent companies were offering cooperation in this work, and ever since, the number of convinced companies are constantly raising. Despite of this fact of increasing interest and participation, the estimated time scale could not be met. There are detailed explanations to enlight all the effects, but now we will point out only the most important reasons.

- the following resources were underestimated:
  - * the work to prepare draft standard proposals;
  - * the time to push through DIS documents in ISO to get IS status;
  - * the computer speed and memory requirements for implementing MAP interfaces.
- the (V)LSI chip manufacturers could not produce MAP chips with all the planned functionality in due time;
- the potential future users were not pushing the vendors strongly enough to quit their efforts into non-MAP networking products;
- there was (and is) a lack of system-integrators, and not enough harmonization was achieved with (inter-)national standardizational organizations;
- the cost of MAP products was higher then that of the non-MAP industrial networking devices;
- lack of certified (conformance tested) products.

After some key demonstrations and exhibitions, the MAP 2.1 and 2.2 products have been declared to be the solutions only for experimental purposes. It was decided and confirmed, that the long-term stability of a MAP version could be planned only with the 3.0 version, where upward compatibility with previous version will not be met. This - of course - was loosening confidence among the potential MAP users, and vendors got chance to promote their previous, proprietary developments by filling present market needs.

THE MAP 3.0 IS HERE; "THE WAIT FOR MAP IS OVER"

The MAP version 3.0 was late to meet the originally estimated deadline. A demonstration version with some functions installed was exhibited in 1988 at the Enterprise Networking Event in Baltimore, and some months later in Europe at the Munnich SYSTEC show. The two major events proved to all participants, that on OSI basis, only MAP and TOP are adequate to serve as networking means for manufacturing and enterprise environment. Soon after the demonstrations, the IRSEC version of MAP 3.0 Specifications was superseded by the Final Specifications [2]. This document, that holds the fundamental description of MAP and TOP with the references to the dozen(s) of ISO DIS and IS status standards are available for a nominal fee for any vendor or user. The Specifications is printed on 2200 pages, and is divided into 17 chapters, 10 appendices and 11 attachments. A key document for MAP 3.0 is the MMS (Manufacturing Message Specifications) standard, that replaced the MMFS belonging to the 2.X version of MAP. This MMS is a standard (document on 630 pages) of EIA and ISO, but is only referenced in the 3.0 Final Specifications.

For Europe, the EMUG holds the exclusive rights for selling the Specifications [3], while from other 'Regions', one must turn to the World Federation of MAP/TOP Users Group (WFMTUG) to obtain a copy. In the long-term future, national translations will appear where interest in the MAP/TOP field can coincide with a coordination of efforts to serve market demands.

The MAP 3.0 Specification was launched by the MAP community with a frequently referred 'Stability Statement', promising that for at least 6 years, MAP will not come up with a new version. We feel it necessary, to add some comments to this statement, not to have a chance for anyone to misunderstand it: The purpose of giving a stability statement was to raise the confidence level in MAP, and avoid a possible fear from users, that a new version (i.e. 4.0) would turn their 3.0 based investments obsolete in the near future, just as the present version is not any more compatible with the former 2.X version. Naturally, the MAP will evolve and develop, since freezing a technical level for 6 years can not be justified in an environment with rapidly changing technology. Document or specification will naturally also evolve during that time. New chapters, attachments and

addenda or what-so-ever will be added, as needed, but what it will not do is the important: it will not result incompatible interfaces regarding the presently accepted version! It will be all the time through downward compatible, so equipment with 3.0 interfaces installed in 1989 will definitely be conformant with later installments. The enhanced, extended functionality and specifications might even have a 3.X notation in the future, but the 'Stability Statement' will still be true and valid.

CATEGORIES OF MAP PRODUCTS

When summarizing and classifying MAP products [4], one must inevitably define certain categories. These categories are sometimes overlapping, sometimes completely detached, so even by giving titles for categories could raise dispute among most of us. Nevertheless, we present a set of lists that seemed to be most appropriate for the time being. (One must also not forget, that we are dealing with a constantly enlarging topic, and by the time the submitted conference paper will be distributed, new items will have to be added to the lists, and even new structuring could be justified for sorting them.)

Thus, the basic categories of MAP 'products' are as follows:

* MAP Chip-level products
* MAP Board-level products
* MAP Software products
* MAP Kit products (boards+software+cabling + networking tools+doc.)
* Computers with integrated MAP interface
* Control equipment with integrated MAP interface
* MAP networking products (e.g. headends, bridges,tools)
* MAP migration products (e.g. gateways, PNIUs,software)
* MAP application products and tools
* MAP training, services, education
* MAP conformance and test services

(a category envisaged for the near future:)
* Manufacturing technology utilizing MAP(+MMS) networking

Figures 1 to 7 give a list of products for some of the above mentioned categories. Lists reflect announced or demonstrated products till the end of January, 1990 [4].

It might also be interesting to get an overview on pilot MAP projects and running industrial productions based on MAP. Figure 8 gives you that summary, and hopefully within half a year that list could get much longer.

MAP IS HERE, BUT WHERE ARE THE OTHER TOOLS?

This question was raised by Mr. Collin Hoptroff, Jaguar Cars,on an EMUG meeting when he tried to summarize the last ten years results in the progress towards CIM [5]. MAP achieved its aims defined almost a decade ago, but no other tool for CIM has been developed in accordance with that speed. Users are looking for full applications and not only for little results, thus present MAP achievements will not completely satisfy CIM implementors. We will need uniformity in applications, and effective, sound international standards. Presently the gap is increasing between technology development and standards development.

We must not make again the same time-consuming mistake we had to face, when users refused to apply MAP saying there were not enough MAP products on the market, and vendors refused to develop MAP products saying there were not enough market needs (and not stable specifications). Now, that 3.0 products are at last available, users must admit, that only few of them are really ready to use them. What the users should at least do:

* to prepare implementation plans, so as to get a clear picture of a possible future system environment.
* to get trained to understand all the benefits of MMS and other parts of MAP.

Users must have (and realize) a joint interest to adopt a basic CIM architecture to give a chance for application transportability. There must be a forum for exchanging information between and among user and vendor companies. User groups, such as EMUG or EEMIG (or NAMTUG, JMUG or even AMIG) could serve as a catalyst between these interested parties, where users must clearly define business requirements, and vendors must realize that by achieving uniformity, larger sales will follow.

USER GROUPS EMERGING ALL OVER THE WORLD

To harmonize MAP and TOP efforts and serve as catalyst, 'user' or 'interest' groups have been formed. Regions were defined to make the harmonization work international, but not running it on national levels (as ISO).In mid-1989, EMUG invited all East-European companies to join their group [6]. Some could take advantage of that invitation, and joined EMUG, as did the Hungarian MAP/TOP Users Group (HMUG), and the newly formed YUMUG (from Yugoslavia). Some made preparations for that, e.g. Bulgarian and Polish national groups. In February 1990, six East-European countries formed their regional center, and established EEMIG (East-European MAP/TOP Interest Group). The WFMTUG accepted EEMIG as the 5th member of the federation in March 1990. EEMIG plans to work in close cooperation with EMUG and tackle all regional questions and problems, that are independent of other xMUGs.

CONTACT ADDRESSES

For building a bridge between East and West, for helping technology transfer, all interested companies ought to join the regional MAP/TOP user group(s). National Groups (called Chapters, not necessarily present in a country) are harmonizing the efforts on a country level, but direct accesses to regional secretariats are also welcome. Should you need any information on recent MAP/TOP topics, on new products, services, training courses, tutorials, etc., get in contact with any address below, and also ask for information how to be a member of the group.

EMUG * European MAP Users Group
Cranfield Institute of Technology
College of Manufacturing
Building 70. Cranfield, Bedford MK43 OAL
tel.:+44-243-752794. fax.:+44-243-750882

EEMIG* East-European MAP/TOP Interest Group
Moscow, InterEVM, 123557 Presnenski val.19
tel.: +7-095-2520868, fax.:+7-095-2556052

HMUG * Hungarian MAP/TOP Users Group.
1518 P.O.Box 63. c/o CAI(SzTAKI),HAS Budapest
tel.:+36-1-1811143, fax.:+36-1-1667503

CONCLUSION

A definite answer of YES can be given to the question in the title of this paper. The MAP 3.0 is ready, it is there, more than 30 vendors are supporting it, and such giants as IBM, DEC, SIEMENS, AEG, MOTOROLA, HP, GE-FANUC, etc. have committed themselves to it. No other multivendor industrial networking solution can replace MAP for a long-long time. We must realize, that the fast application for using it can be a key issue for taking a step ahead towards CIM. The level of user-acceptance must definitely be raised, and user groups can be of great help in technical education, sharing information on experiences, etc. MAP alone can not support CIM, but other modules must also get as advanced and ready as MAP is by now.

REFERENCES

[1]: MAP Specifications version 2.1
[2]: MAP 3.0 Final Specifications. Through EMUG, Cranfield.
[3]: EMUG announcements
[4]: Klaus Grund: MAP 3.0 Product Overview. EMUG 25.Jan.1990.
[5]: EMUG Open Joint Workshop. 6 Dec.1989 Brussels. Collin Hoptroff: CIM and Computer Integrated Business for Europe.
[6]: G.Haidegger: EEMIG Newsletter No.2. June 1989. Budapest

MAP 3.0 APPLICATION PRODUCTS & TOOLS

Company	Application Software	Computer	OS	Status
GE Fanuc	Factory Monitoring & Control System	MVAX II	VMS	●
Lotus (Sisco / Concord / Computrol)	Lotus 1-2-3 Spreadsheet on MAP	PC	DOS	●
Burr-Brown	Data Collection System	PC	DOS	●
Procos	Factory Automation & Process Control Software	PC & PS/2	OS/2	●
Sisco	Device Management, Testing, User Interface	PC	DOS	●
Industrial Technology Institute	MMS Device Emulator for Controls	PC	DOS	◑
Grossenbacher Elektronik	Cell Controller Software Design Tool	Most WS		◑
Andersen Consulting	Cell Controller Software		UNIX	○
Reflex Manufacturing Systems	Area & Cell Controller Software & Tools		UNIX	○
Softing	Factory Automation & Process Control Software	PC & PS/2	OS/2	● 1)
Ship Star / MicroBased	CIMware Computer Aided Software Eng. Tool	PC	DOS	●

EDS - KG1234-3

● Available ◑ Demonstrated ○ Announced 1) Procos Based

CONTROLS WITH MAP 3.0 INTERFACE

Company	PLC	CNC	Robot Control	Other Controls	MAP Gateway	PNTV	MMS SW
Advanced Computer Comm.		◑					Sisco
AEG Modicon	● 4)				● 3)		Sisco
Allen-Bradley	●				● 3)		Own
April					●		
Cincinnati Milacron		○	○				
GEC Industrial Controls	○						
GE Fanuc Automation	● 1)	◑			●		Own
GM Fanuc Robotics			○				Own
Grossenbacher Elektronik		◑					Own
Mitsubishi	◑ 3)						Retix
Satt-Controls	● 2)						
Siemens	○				●		
Square-D					●		Sisco
Telemecanique	○						Retix
ComConsult						●	Sisco
Reflex Manufacturing Systems						●	Retix
Procos						●	Sisco
Softing						●	Sisco

EDS - KG1233-3

● Available ◑ Demonstrated ○ Announced ○ Expected in 1990

1) Mini-MAP Option
2) Mini-MAP Only
3) Third Party
4) Initially Mini-MAP Only

COMPUTERS WITH MAP 3.0 INTERFACE

Company	Computer	OS	MAP HW	MMS SW	MMS I/F	Status
AEG Modcomp	MC 9730	UNIX	Computrol	Sisco	MMS-Ease	◑
Apollo (*)	DN 4500	AGES/DOS	Concord	Sisco	MMS-Ease	●
Bull	DPX 2000	UNIX	Own	Own		○
Concurrent Computer	3200	OS32	Motorola	Sisco	MMS-Ease	◑
Digital Equipment	Micro VAX	VMS	Own	Own	Own	●
GE Fanuc Automation	CIMSTAR DX	VMS	DEC	Sisco	MMS-Ease	◑
Fuji Electric	FASMIC G 500	UNIX / OS				●
Hewlett-Packard	HP 9000/800	UNIX	Own	Own	MMS-I	●
IBM	9370, S/370	VM	Concord	Own	MMS-I	○
IBM	PC, IC, PS/2	OS/2	Concord	Own	MMS-I	●
Other PC Vendors	PC-XT/AT	DOS	Concord/ AEG Computrol	Sisco	MMS-Ease	●
Jupiter Technology (Intel)	S/370	MVS	Intel	---	---	●
Motorola	Delta	UNIX	Own	Sisco	MMS-Ease	●
Prime Computers		UNIX	Motorola	Sisco	MMS-Ease	◑
Stratus Computers	XA 2000	VOS				○
SUN (*)	3/160	UNIX	Motorola	Sisco	MMS-Ease	●
Tandem Computers	NonStop CLX	Guardian	Own	Own		○
Toyo Engineering	TAKE 55	DOS / OS/2	Concord	Retix	Own	●
NCR	Tower	UNIX	AEG Computrol	Sisco	MMS-Ease	●

EDS - KG1232-3

● Available ◑ Demonstrated ○ Announced ○ Expected in 1990 (*) Third Party

MAP 3.0 SOFTWARE PRODUCTS (MMS)

Company	IBM MS DOS	IBM PS/2 OS/2	DEC VAX VMS	Intel RMX	UNIX	NEC OS		Comments
Sisco	●	●	●	●	●			Own MMS
Concord	●	●						Based on Sisco MMS Retix FTAM
Motorola					●			Based on Sisco MMS Retix FTAM
AEG Computrol	●		●		●			Based on Sisco MMS Retix FTAM
Commsoft	●		●					Own MMS
ComConsult	●		●					Based on Commsoft MMS
Retix					●[1]			Own MMS Own FTAM
Terasaki						●		Based on Retix MMS

EDS - KG1231-2

● Available ◑ Demonstrated ○ Announced 1) Source Code Only

MAP 3.0 VENDOR / PRODUCT OVERVIEW

Company	Country	Interface Boards	MMS Software	Computers	Controls	LAN Equipment / Gateways	Application Products
Advanced Computer Comm.	USA				◑		
AEG (Computrol, Modcomp, Modicon)	Germany/USA	●	●	◑	●	●	●
Allen-Bradley	USA				●	●	
Apollo (*)	USA			●			
April	France					●	
Bull	France						
Burr-Brown	USA						●
Cincinnati Milacron	USA				○		
ComConsult	Germany		●			●	
Commsoft	USA		●				
Concord Communications	USA	●	●			●	●
Concurrent Computer	USA			◑			
Digital Equipment	USA			●			
GEC Industrial Controls	England						
GE Fanuc Automation	USA/Japan			◑	●		●
GM Fanuc Robotics	USA/Japan						
Fairchild	USA					●	
Fuji Electric	Japan			●			
Grossenbacher Elektronik	Switzerland				◑		◑
Hewlett-Packard	USA			●		●	
IBM	USA			●			
Industrial Technology Institute	USA					◑	◑
Jupiter Technology (Intel)	USA			●			
Mitsubishi	Japan				◑		
Moore Products	USA					●	
Motorola	USA	●	●	●			
Open Network Engineering	USA					●	
Prime Computers	USA			◑			
Procos	Denmark					●	●
Reflex	England					●	○
Retix	USA		●			◑	
SattControl	Sweden				●		
Siemens	Germany				◑	●	
Sisco	USA		●			●	●
Softing	Germany					●	●
Square-D	USA					●	
Stratus Computers	USA			○			
SUN (*)	USA			●			
Tandem Computers	USA			◑			
Telemecanique	France				○		
Terasaki	Japan	●	●			●	
Toyo Engineering	Japan			●		●	
Lotus	USA						●
NCR	USA			●			
Ship Star / MicroBased	USA						●

● Available ◑ Demonstrated ○ Announced ○ Expected in 1990 (*) Third Party

EDS - KG1139-3

MAP 3.0 INSTALLATION SUMMARY

NORTH-AMERICA

- GM Oshawa Car Assembly Plant
- GM Saturn Car Assembly Plant
- Other GM Projects in planning and implementation
- Boeing
- Eastman Chemicals
- Dupont Petrochemical Tank Car Loading System
- Xerox Plant Floor Data Collection System
- Union Camp Paper Mill Process Control System

JAPAN

- Isuzu Motors Car Assembly Plant
- Omron Electronic Parts Assembly Plant
- Kanematsu Small Press Machine Manufacturing

EUROPE
(Production & Pilot Projects)

England	• GM Vauxhall Motors - Spray Paint Unit • British Aerospace Manufacturing Cell CNMA Pilot Project • Lucas Diesel Systems DTI Pilot Project • National Engineering Lab DTI CIM Pilot Project
Germany	• Volkswagen Car Assembly Plant - Spray Paint Unit • EDS CIM Center Model Factory • Technical University Stuttgart CNMA Pilot Project • Bosch Manufacturing Cell Pilot Project • KFA Jülich CAD/CAM Pilot Project • Nuclear Research Center Karlsruhe Robotic Pilot Project • Mercedes Benz Pilot Project
France	• Renault Car Assembly Plant • Aerospatiale CNMA Manufacturing Cell Pilot Project
Sweden	• Joint Swedish Pilot Projects at Volvo and Saab Scania
Denmark	• DISA Pilot Project
Holland	• ITP TUE-TNO Manufacturing Cell Pilot Project
Norway	• Esso Automated Oil Drilling Platform Pilot Project

CIM ORIENTED INTELLIGENT INTEGRATING ENVIRONMENT

Shishkov I., Haydoutova J.
Central Institute for Automation, Sofia, Bulgaria

1. Introduction

Several interesting trends are at work on today's factory floor. Microcomputers are proliferating in manufacturing applications. The problem concerning the lack of simple, standardized communication techniques and large, integrated data bases which tended to fragment and isolate manufacturing functions, creating the so-called "islands of automation", has been partly overcome by the development and support of computer networking standards (MAP/TOP).

On the other hand, the growing awareness of the need to integrate the hardware and software automation products that continue to multiply within the manufacturing workplace has led to the concept of Computer Integrated Manufacturing (CIM). As a result CIM, which is really the act of combining or integrating technologies for improved manufacturing [1] is now almost everybody's goal.

Production systems of today comprise a large variety of functions [2]: product planning and development, technological planning for manufacturing, production planning and control, material flow planning and control, quality assurance and cost management, most of which are automated. But even within the limits of one automated function, the links between the sub-functions or functional modules of which it is constructed are poor and sometimes non-existent.

It is against this background that the need of developing an integrating environment, linking diverse computer hardware and software into overall systems solutions has emerged.

This report addresses some aspects of the integration processes in CIM - types, levels and characteristics of integration, with a special stress on the functional architecture of an integrated system. The possibility of automating these integration processes by means of an Integrating Environment (IE), an experimental IE and its trial implementation are also described.

2. Types of integration in CIM

Two main types of integration can be distinguished - between open systems or libraries of functional modules, and between closed or turn-key systems. The former case, as shown in Fig. 1., offers the possibility of creating a new functionality from the comprising modules, introducing the new function in a user-transparent way. In the latter case each of the independent modules has a different data model and its own user-interface means, and the developed integrated systems, as shown in Fig. 2. [3], require expert knowledge on every functional module which leads to non-transparency.

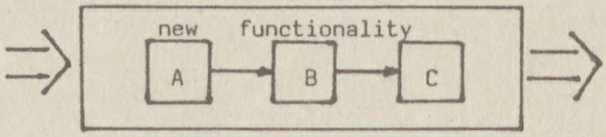


Figure 1. Schematic representation of open systems integration.

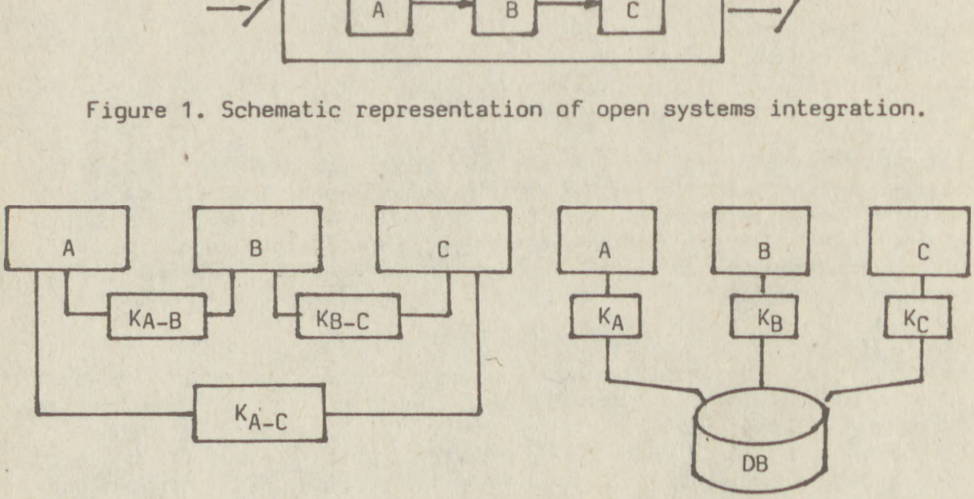


Figure2. Schematic representation of turn-key systems integration.

3. Levels of integration and IE

The aim behind developing an IE is to give the system integrator a unified environment for the integration of diverse applications to support complex problem areas. At that, the particular functional application modules should be integrated as "transparently" as possible - the end user should be unaware exactly which of the programs is executing its functions at a given moment and whether data are transformed or not. The main requirements to such an environement include openness, flexibility, a higher level operator's interface, higher intelligence.

From a system-architectural viewpoint we can recognize the following levels of integration:

- physical or virtual machine interface level - here the difficulties arising from the incompatibility of computer hardware and the operation systems,in the environment of which the functional program modules are working have to be overcome;
- functional architecture level which includes:
  . information flow level, in which the incompatibility of the data models of the different functional modules must be overcome, and
  . control flow level, which corresponds to the architecture of the system or the sequence of modules which have to be invoked for the execution of a given task;
- user operational level, in which the system is specified in terms of users operations.

The physical level of integration is determined by the manner of linking the hardware and software means, on the basis of which IE is constructed. This level is not directly included in IE, but being its base, it provides for the realization of the principal requirements to the environment. For example, the inclusion of network means qualitatively increases the "openness" of integrated systems, developed with a network IE. The character of the basic means influences the other system characteristics of IE as well - user-communicativity, effectiveness, intelligence, unification. Some necessary features of the computer environment for achieving a higher degree of integration are multiuser-multitasking possibilities, an extensible dictionary of the common data types, dynamic linking of programs, flexible management and communication of tasks, means for module programming, etc. The existence of a rich and common accessible library of system utilities for effective data manipulation and development of high-level user interface is also essential. Most of these possibilities are developed in the specialized workstations for CAD/CAM, e.g. SUN, APOLLO, VAXmateWorkstation.

The two "true" levels of integration of CIM functional modules - the functional architecture and the user operational levels, require language means support from IE and determine its basic components as a toolbox.

In the first component of the functional architecture level (the information flow level) there must exist such an ability in the information carrying mechanism, that the information derived from one module supporting a complex function can be reorganized to a different value of information which allows its use in another functional module. No intervention from end users in the corresponding fields should be necessary, which ensures the systems' transparency. Therefore, there is a need for automation both of transmission and transformation of the information between the different modules.

Figure 3. represents a generalized scheme for transmission and transformation of data in a two-module system. Usually, for effiency considerations, only one of the two converters and/or directions of the information flow are present. The language support of the information flow level comprises means for automated converter defining and their inclusion in the data interchange schemata. From an organizational viewpoint, in some cases it is more convenient to associate the converters to the interface memory, while in others - to the functional module itself. The data transformation process is facilitated by the existence and support of conventions (standards) for a unified data model (IGES, STEP).

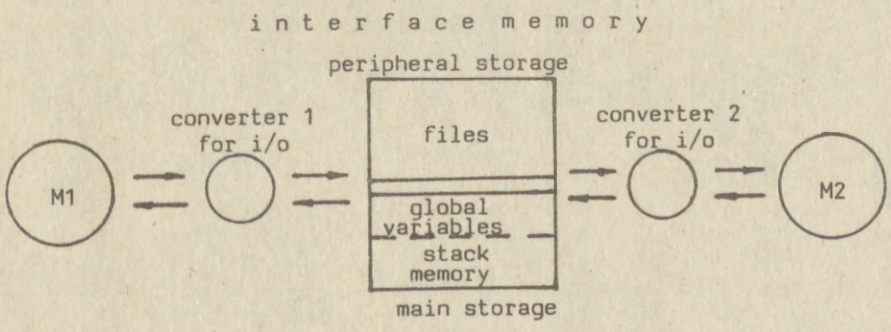


Figure 3. Schematic representation of data transmission.

The main goal of the integration at the control flow level is to generalize the functional characteristics of diverse programs (different language programs, operating systems, computers) by giving an appropriate formalization of the concept "module". This unifies the representation of any program activity in the system. The module comprises a couple of two basicunits-interface protocol (for access from the external world) and internal realization (true code invokation). The latter may be replaced (for efficiency reasons) without necessity of altering the programs, using the module - this is the basis of the object-oriented paradigm. The interface protocol is utilized in a unified manner in a module call-operator. From a language viewpoint, sequential and conditional calling of the separate functional components of the integrated system must be ensured. The main requirements - flexibility and openness may be achieved by the existence of a "construct" operator, combining several modules into one, as well as by means for easy expanding of the module library. The user tasks in this type of modular environment can be represented as passing through particular task-paths in the environment. The description of such a task-path - called scenario, comprises the generalized sequence of main steps for executing each task. This approach dramatically decreases the efforts of the systems integrator and increases the intelligence level, as it is close to the user's natural way of concept manipulation.

The highest level of specification of the integrated system in terms of user operations and activities is the user operational level. Technologically, it is supported by the dialogue means of IE which realize the link between dialogue techniques and the functional architecture of the integrated system.

4. Description of an experimental IE and its trial implementation

The aim of the developed IE called PIF(Program for Integrating Functions), is to provide the end user with a unified environment for the integration of diverse functional modules, which "intelligently" leads the user in the integrated system so that a preliminarily defined by him concrete task is executed. The advantages of such an IE are based in the first place on the possibility for representing different programs and the links between them as unified modules, and in the second place - on the declarative description of scenarios for task solving. In our opinion, most suitable means for the relization of these advantages are correspondingly the object-oriented [4] and logical[5] programming styles. These techniques of Artificial Intelligence (AI) are also recognized as most suitable for accomplishing the requirements to the integrated system - openness, flexibility, intelligence. PIF is developed by means of the knowledge representation environment INEX [6], combining in itself functional (LISP), logical(Prolog-like), and object-oriented programming styles. INEX is implemented by means of VAX-LISP and works in VAX/VMS environment. From a language viewpoint, PIF contains two declarative languages:

- a language for the description of modules and interface data, and
- a scenario description language.

The hierarchy of the modules in PIF is shown in Fig. 4. The basic object in this taxonomy is "module". Its basic attributes (slots) are prefix and postfix modules (invoked immediately before and after the current module), input parameters (containing the part of the call-arguments, necessary for the execution of the body of the module), and body (representing a LISP-expression which links the module with its realization program).

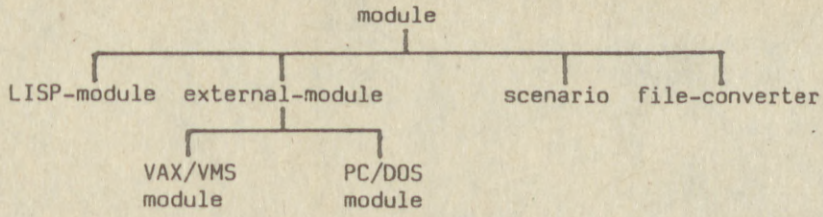


Figure 4. Hierarchy of the modules in PIF.

The main methods of the object module are run (applying the contents of the body attribute on the incoming arguments on invokation), and initialize (executing initializing and refresh functions on the attributes of the corresponding module).

The four basic module types are defined as subtypes (is-a) of the object module, and are as follows: LISP-module (whose body attribute is a call to a LISP function, message to an INEX object, or INEX logical call), external-module (whose body attribute invokes an external to LISP program) with two subtypes - VAX/VMS and PC/DOS modules (in which by default are defined the computer type and specific characteristics concerning the connection with the corresponding operating system), scenario (represented as a Prolog-like logical base), and file-converter (in the attributes of which the record format of the input/output files, as well as some simple manipulations over records of the input file are described).

The integration process at the user operational level can be facilitated by the menu and dialogue utilities of INEX and VAX-LISP, to which PIF has full access. Additionally, means for management of module and scenario execution are developed.

With the aim of examining the potentialities of PIF, we conducted its experimental implementation for the realization of a CAD integration task. This task consisted in integrating two independently developed functional modules, one working in the environment of PC/DOS, and the other - in VAX/VMS. The first of these functional modules is a Computer Aided Process Planning system, developed by means of the expert system shell AXEL [7], which supports the group approach in the realization of technological decisions. The result of its' activity is inputted transparently for the user to the second functional module by means of the networking possibilities supported by PIF, on the basis of DECNET VAX/VMS and DECNET PC/DOS. The second of the two independently developed functional modules is SIMGAPS [8] - a module for simulation and evaluation of the process planning decisions. The task of the overall system was represented as a menu for user-choice between the two basic tasks. This PIF application is illustrated in Fig. 5.

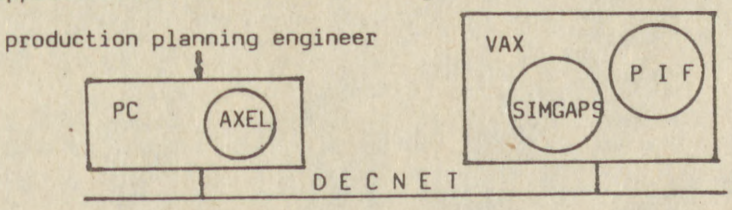


Figure 5. A trial implementation of PIF.

This experiment reveals that crucial for the integration in a network is the minimization of data communication between the nodes - the goal is to transport as little as possible information, i.e. only the data that has been modified.

5. Concluding remarks

- One of the problems we have encountered in our work was that most application programs are usually developed as "closed world" systems, which is why we had to resort to the realization of transformation programs between the modules. If during the stage of development of these application programs their future inclusion in integrated systems could be envisaged, the problem would be much simplified. This implies that the object-oriented approach again be used - the application programs should be constructed of two (or more) modules - an interface module, which could be modified according to the type of integrated system into which the program will be built in, and an actual module, realizing the concrete functions. An important issue here, of course, is standardization.

- As the IE inevitably follows the ways, approaches and abilities of the "expert" in integration (the systems integrator), the environment could be enhanced by the inclusion of an expert system with a knowledge base containing the knowledge (theoretical and empirical) of the systems integrator in the CIM area. An expert system, containing the knowledge of the field expert could also be included.

- A further enhancement of IE could be the development of a file (or data) converter of a higher semantic level, transforming technical object description (supported by the recognized standards IGES, PADL, etc.), on the basis of a specialized declarative IE transformation language.

Acknowledgements

The authors are obliged to the Central Institute for Automation, Sofia, Bulgaria, for the support of the currently developed integrating environment and its trial implementation.

References

1. T. Schaefer, Modular Approach to CIM: Integrate your factory in pieces, Production Engineering, April 1985, p.102
2. K. Ando et al., An approach to computer integrated production management, International Journal of Product Research, March 1988, p.333
3. CAM Developments in Computer-Integrated Manufacturing, ed. D. Kochan, Springer-Verlag Berlin Heidelberg 1986, p.212
4. S. Keene, Object-Oriented Programming in Common LISP, Addison Wesley, Keading Masachussetts and Symbolics Press, Cambridge, Masachussetts, 1989
5. W. Clocksin, C. Mellish, Programming in Prolog, Second edition, Springer-Verlag Berlin Heidelberg New York Tokyo, 1984
6. INEX User's Manual, Institute "INTERPROGRAMMA", Sofia, 1987 (in Russian)
7. AXEL User's Manual, Central Institute for Automation, Sofia, 1989 (in Bulgarian)
8. SIMGAPS User's Manual, Central Institute for Automation, Sofia, 1986 (in Bulgarian)

THE GLEDA COMPUTER-AIDED MANUFACTURING PROCESS PLANNING SYSTEM

dr László Horváth, ITC AMT Ltd., Hungary

Abstract

In this paper the GLEDA CAPP system, recently developed at the ITC AMT Ltd. in Hungary is presented. The interactive GLEDA system, which is universally applicable PC software tool for the machining process planning, have unique features of the comprehensive user defined knowledge base, the hierarchic decision making and the sophisticated machine shop model.

Introduction

The progress in CAD and CAM systems and the shortage of the skilled process planners in the metalworking industry generated the need to develop CAPP systems. The CAPP system represents a connection between CAD and CAM. Productivity has become a critical concern for the manufacturer. When the process planner selects the machine tools, machining methods and cutting tools for machining a workpiece, really he makes decisions to determine the economy of these expensive resources.

We have recognized, that the application of computers in this field has great potential. We developed the GLEDA computer - aided interactive process planning system for machined workpieces at the ITC AMT Ltd., in Hungary. Our aim was to develop an universally applicable system based on professional personal computers and suitable for dis-

covering all the possible solution variants available at the company. I' d like to show and emphasize the most important considerations of our development work and the GLEDA system.

1. The main functions and the scope of the application

At the present state of the development of the GLEDA system the following planning tasks can be performed:

- determining all the machining, heat treatment, inspection, surface treatment and other operations required by the manufacturing of the workpiece;
- generating the sequence of the operations and operation elements on the base of general and machine shop specific criteria and rules;
- choosing the machine tools, fixtures, machining methods, clamping methods and positions, and cutting tools from the choice available in the given machine shop;
- calculating estimated time and cost data for the purpose of comparison of the process plan variants;
- fine editing of the process plans and printing various process plan sheets and other documentation on the required form.

There are two independent, problem oriented subsystems in the GLEDA sytem:

- the GLEDA - F T for rotation - symmetric parts (shafts, disc-like parts, bushings etc.)
- the GLEDA - S Z for prismatic and cubic parts, arms and plates.

The scope of the application covers:

- process planning for conventional machine shop as well as FMS;
- virtually all the machine tool types (including both conventional and NC) as well as machining methods (fig. 1), part configurations applied in general;
- rough process plans for the production control and scheduling system.

2. Relying on machine shop model and hierarchic decision-making

The GLEDA system contains a knowlwdge-type data base which have to be elaborated always for the actual company. The data which depend on the manufacturing and process planning environment are stored in this data base. The most important elements of the knowledge:

- The available manufacturing possibilities for surface groups having given configuration, dimensions and tolerances.
- The knowledge concerning the rules and criteria of generating and sequencing of the operations and the operation elements. Naturally, this always contains the company - specific knowledge.
- The structure of the manufacturing environment, including the machine tools available for each departments as well as the cutting tools available for each machine tools.

Each GLEDA application presents its own problems and requirements. The system enables experienced planners to speci-

fy, maintain and improve the knowledge. The data base can be maintaned daily using interactive utilities.

The GLEDA system has adequately structured **hierarchic decision making**, which automatically requires the process planner to take into consideration all the obligatory criteria of the workshop, but allows him to use his creativity and experience. The decision hierarchy is illustrated in fig 2. If the process planner is not in agreement with the data of the knowledge base in the course of the planning, he have to modify the knowledge base if he is authorized for it.

3. The process planning logic and the dialogue

The task of the **process planning** has been **decomposed into three solving level** (fig 3).

At the **first level** the system search tipical machining sequence variants for the suitable gathered **groups of the surfaces**, taking into account of the actual manufacturing possibilities of the choosen machine shop (fig. 5).

At the **second level** the GLEDA system **generates rough process plan variants** according to the initial conditions determined by the system and the process planner.

The process planner can prescribe the main structure of the process plan and the scope of the machine tool types to be taken into consideration for the machining of the workpiece. The GLEDA system enables process plans to be generated taking into account of **predefined clampings** (fig 4) and

process plan features (fig 5). The planner can select the machining methods and machine tools from variants suitably judged by the system.

The rough process plan (fig 8) desribes the operations by machining methods choosen for the surface groups and contains the identification of the machine tools and fixtures.

At the **third level** of the planning the system **generates operation elements** from the rough process plan, determines the measurements of the machining and selects the cutting tools and conditions for the operation elements.The fig 8 shows the full detailed process plan obtained.

The system uncovers and preselects all the machining method, machine tool and cutting tool variants adequate to the machining requirements and prescriptions, and available in the manufacturing environment.

The GLEDA considering its basic principle is a **semigenerative (variogenerative)** system. It make use of decision tables, generative algoritms and process plan element variants.

4. Workpiece data input

The input of the **workpiece data** is derived **from CAD or given in interactive way**. The system controlls the input data and generate the surface groups for the planning. The input dialogue is guided and controlled by the system, supplying the planner all the information required. In the case of the input from a CAD drawing file, the process planner can comple-

te the drawing with his own instructions and markings in the CAD system.

5. The GLEDA as the part of a CIM

The GLEDA system can be connected with CAD, production control & scheduling, NC programming & tape preparating, tool management and production documentation systems. The stucture of the GLEDA system offers the opportunity of an integrated system. The flow of information between the the GLEDA and the systems connected with it illustrated in fig 7.

6. The results

The GLEDA system finally gives one or more process plan variants and stores this variants for later retrieval, modification and use. The important part of the implementation is the connection of the system with the documentary environment of the machine shop. The documentation (fig 6) can be custom - tailored.

Conclusions

The GLEDA not an expert system, but the user have a lot of benefits of the knowledge base systems. Our future develoment plans contains the realization of an fully knowledge based expert system, which make the use of services of a CAD and documentation editing systems.

References

[1] Dr. Horváth, L. - Szabó, K.: GLEDA - A computer-aided Manufacturing Process Planning System for Parts to be machined
AMPS-COMPCONTROL' 85 conference Budapest, 1985. p:618-629

[2] Dr. Horváth, L. - Szabó, K.: The GLEDA Interactive Manufacturing Process Planning System
MATAR' 88 conference Praha, 1988. p:60-67

[3] Dr. Horváth, L. - Szabóné, V. K.: A GLEDA rendszer továbbfejlesztése (in hungarian)
Gépgyártástechnológia, 1989. 10-11. sz. p: 496-498, 511-522

[4] Dr. Horváth, L. - Szabóné, V. K.: A GLEDA rendszer továbbfejlesztése (in hungarian)
Korszerü Technológiák, 1989. 10. sz. p: 42-47

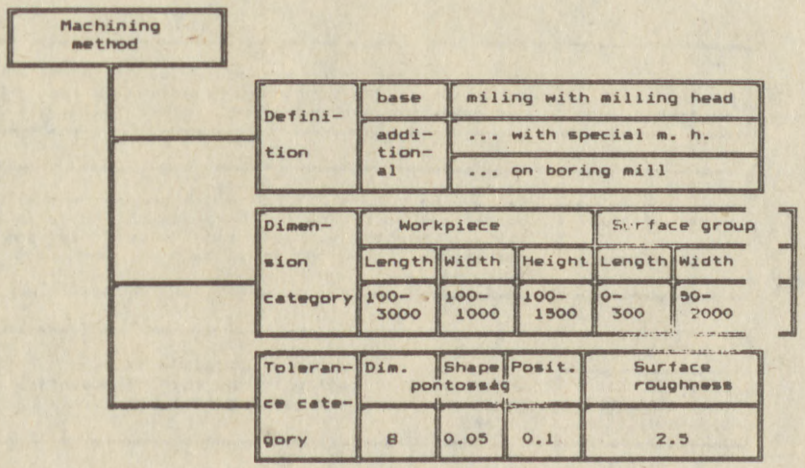


Fig. 1. Definition of the machining method

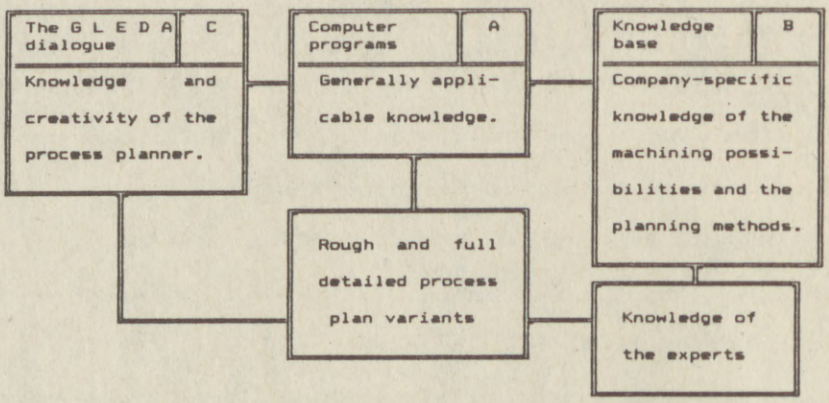


Fig 2. Knowledge types and their hierarchy in the GLEDA system

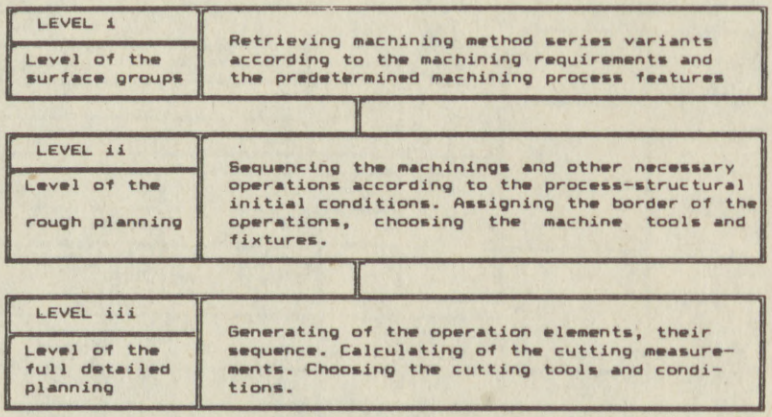
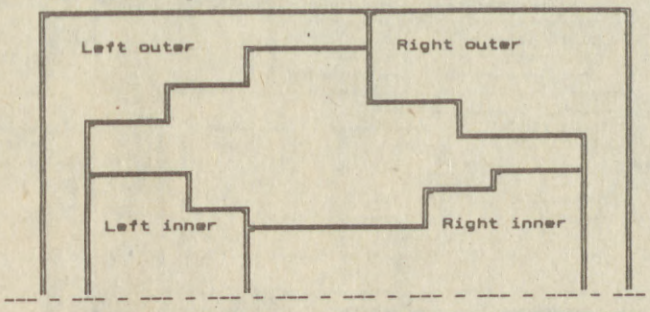


Fig 3 Decomposition of the process planning

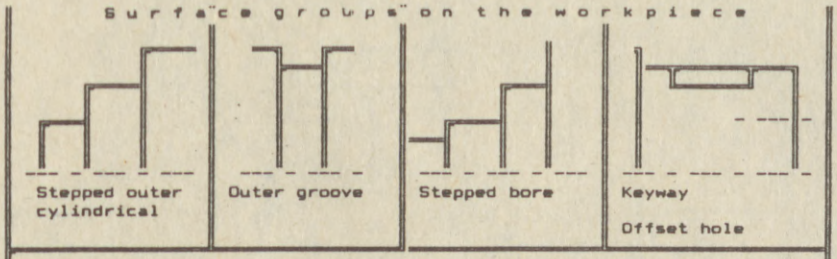
Main surface groups (SG) of the workpiece:



SG	Left outer			Right outer			Left inner			Right inner		
Vari	R	S	F	R	S	F	R	S	F	R	S	F
ants	No. of the clamping											
A	1	3	4	2	2	4	1	3	5	2	2	6
B	1	1	3	2	2	4	1	1	3	2	2	4
C	-	1	3	-	2	3	1	1	4	-	2	5

R = roughing S = smoothing F = fine smoothing

Fig 4. The preliminary plan of clampings



The preselected tipical process plan features	Type of the surface group	Process plan features
	Outer and inner rotation-symmetric groups Slots, keyways, plains Offset holes	Turning on NC lathe, grinding on conventio-centre grinding mach. Milling on conventional milling machine Drilling on column drilling machine

Machining method series for the surface groups

1.Roughing by NC turning 2.Smoothing by NC turning 3.Cylindrical grinding on conventional machine	1. NC grooving	1.Drilling on NC lathe 2.Roughing by NC boring 3.Smoothing by NC boring 4.Internal grinding on convent. machine	1. End milling on conventional machine 1.Drilling, 2.Counterb., 3.Threading on conv. mach.

Fig 5 Example for the choosing of the process plan features and the machining methods

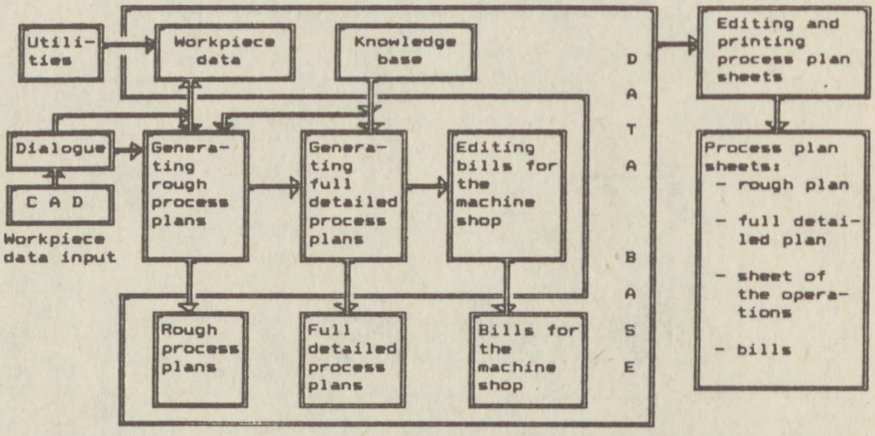


Fig 6. The main structure of the GLEDA system

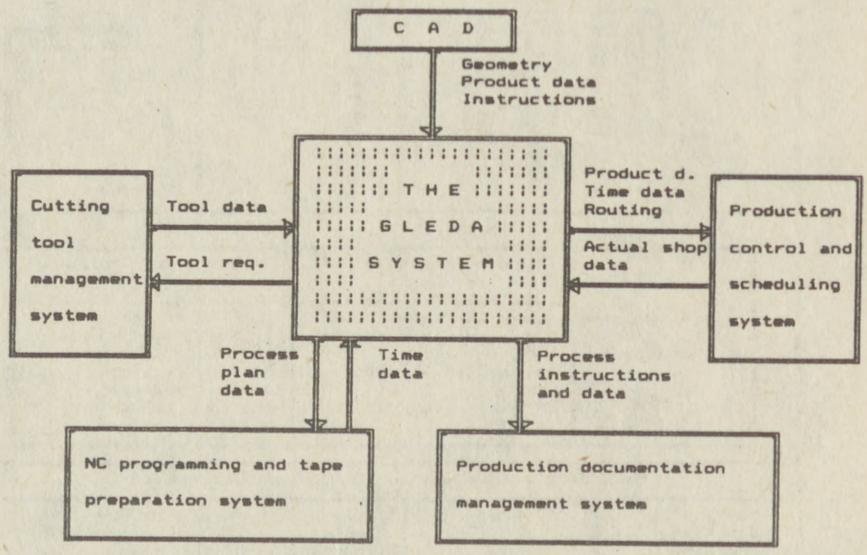


Fig 7. The outer connections of the GLEDA system

General data of the operation

Operation No. 3

Machine tool			Department		
Id. code	Type	Control	Shop	Group	Mfg. sys
1401	E3N	-			

Clamping data		Fixture	
Method	Side/SG/SE	Name	Id. code
Chuck	Left/ 1/ 4	Turning fixt.	F-T-003

Time and cost data				Remarks
Set up		Operation		
Time	Cost	Time	Cost	
41	47	42	89	

Rough process plan

Rough operation elements

No.	Name / mach. method	IT	Ra	SG id. code
1	Turning / 22112	9	5	2/ D 110
2	Boring / 21113	10	5	3/ D 35
3	Turning / 22111	8	2.5	2/ D 110
4	Boring / 21111	8	2.5	3/ D 35
5	Grooving/ 24212	11	5	8/ D52*5
6	Grooving/ 23212	11	5	9/ D35*5

Full detailed process plan

Operation elements

No.	Name & dimensions	Cutting tool ident. code	Cutting cond. e	f	fs	n	v
1	Siding length 145 on 9 SE	11013231DA20	0.2	1.5	2	355	124
2	Turning O. D. 54 length 28 on 8 SE	11013231DA20	0.2	1.5	20	385	119
3	Siding length 28 on 7 SE	11013231DA20	0.2	1	1	355	119

Fig. 8 Operation in the rough and the full detailed process plan

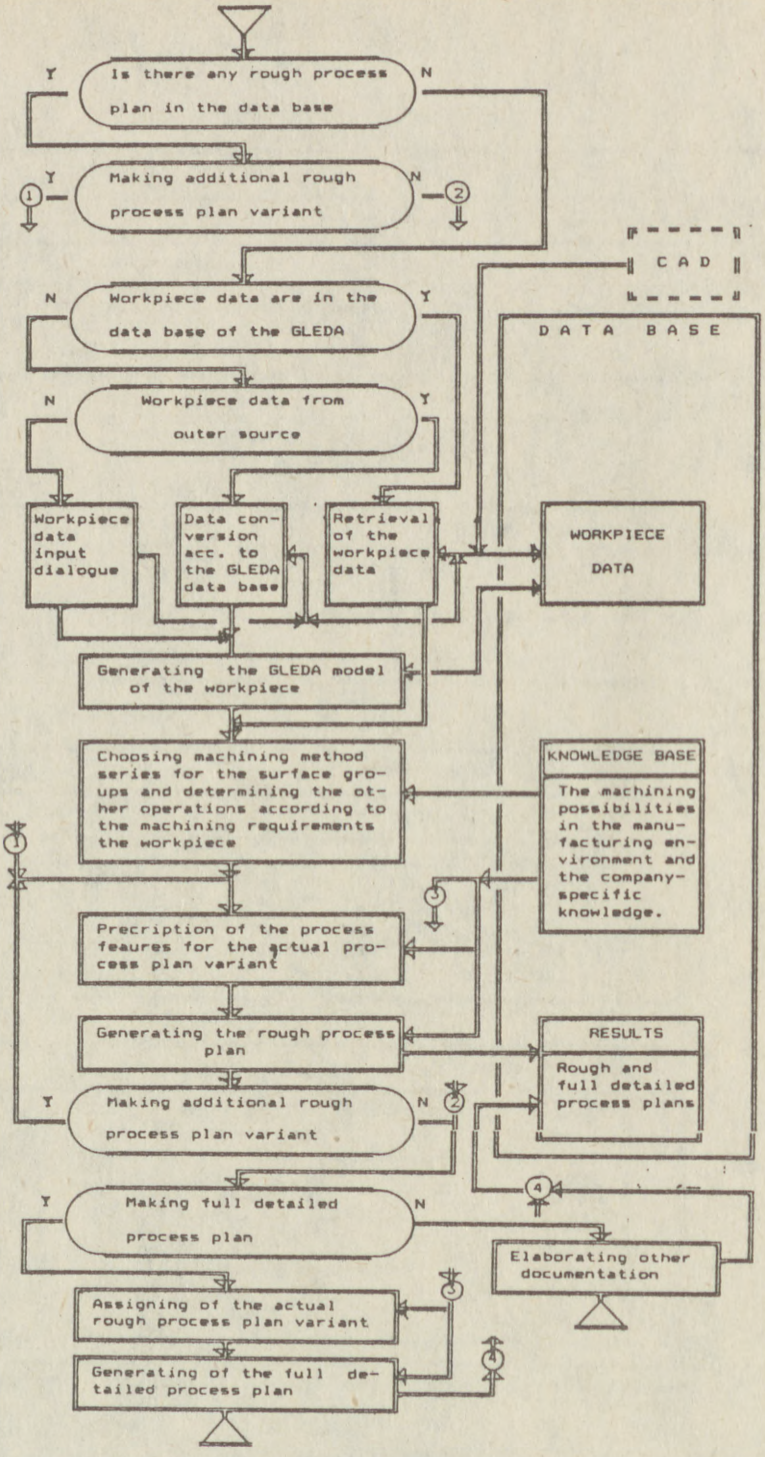


Fig 9. Operation of the GLEDA system

POSSIBILITIES OF ARTIFICIAL CREATIVITY IN DESIGN

Dr IMRE HORVÁTH
Budapest Technical University
Institute for Machine Design
Hungary

ABSTRACT

In the last few years, in the field of mechanical engineering design, the demand for computerization of the creative activities of design has emerged. Numerical and graphical data processing oriented CAD systems are not for this purpose since they are to support modelling, visual presentation, numeric analysis and administration of the part geometry, when it has been stated by the designer. With knowledge based expert system, formalized models and design activities, significant progress can be made in the field of automation of conceptualization and structure synthesis.

INTRODUCTION

A realistic design automation strategy must focus expertise on the conceptual design phase because that is during which the critical decisions are taken. The stategy must cover both the generalization of concepts and their formal optimization - ROTH(88). At present, however, formal optimization techniques are unknown in the earlier parts of the design process. The german design school has elaborated different informal optimization techniques that can be applied with the hope of succes in the process of conceptualization and structure synthesis. These methods mostly try to find the "optimum" solutions by use of past experience of the designers - LALO(85). We may add, this is frequently not only helpful but restricting as well. The real solution would be to develop and introduce formal conceptualizing methods for the conceptual phase of design. This is that place the emphasis onto the possibilities of artificial creativity.

Creativity is human capability that enables to generate and realize innovative ideas with - sometimes never practicized - activities. From another point of view, creativity means solving ill-defined real life problems with imagination and heuristics. There are a lots of publications on the various aspects of human creativity from many authors, e.g. from Rarnes and Harding (1962), Osborn (1957), Jackson and Messick (1967), Prentky (1980), Sandler (1985) and others. These works are very important since they are discussing the the basics and the essentials of the human induced creativity. This understanding can help us to practical implementation of the artificial creativity.

From the point of view of automatization of conceptual

design artificial creativity indispensible. Human creativity applied in design can be considered as a special implementation of that abilities by which a product can be further developed or a previously unknown products can be generated.

Experiments, having been done, shows that as it is with the human thinking, human creativity can also neither be fully copied nor emulated by present computers. Consequently, if we strive to form a computer-based implementation of it, on the one hand, we must apply the principles of general human creativity and, on the other hand, we must achieve a rigorous formalization of that. Formalized design creativity makes it possible to develop conceptualization methodology applicable for design expert systems (DES) that are innovative - YOSH(81).

As it was mentioned, in connection with the development of design expert systems the artificial creativity is crucial. Namely, the level of the creativity of expert systems limits the scope of problems that can be solved and the innovativity of the solutions. Innovativity needs the relaxation of the solution place and the limits\constraints. It may have many different practical implementation.

FORMS OF DESIGN CREATIVITY

Neither can design be characterized as entirely an inventive activity since design problems themselves cannot be formulated except in terms of some potential solution elements. Most design problems are solved by constructing a solution composed of known elements rather than selection of a solution out of hand. The representation of an object model must include the structure, attributes, property, functions and the behaviour in the working environment.

Following the initial conception of Fox, four basic forms of design creativity can be identified. They are as follows:

Selection

> It maps the user functional requirement onto product attributes and finds the known object from the available set of objects.

Configuration

> This can be directed or exhausting depending on the scope over the set of potential known elements. Its primary function is to find the appropriate connention among the needed elements.

Extrapolation

Altering some existing objects to meet the user specification by modifying the properties.

Discovery

Similar to configuration in that it takes components and combines them. The difference is that configuration uses more semi-finished components whereas discovery begins with more elementary entities.

In the categorization used by Fox, that makes difference between the specified approaches is the distance in the functionality of the components from the end product FOX_(87). Unfortunately, this feature which express a very important factor of creativity, does not emphasize the innovative aspect. If the innovativy is acknowledged it can be supported.

The key to succes in the application of DES for mechanical engineering tasks is the proper formalization and description of the problem. Solving mechanical engineering design problems with DES not easy because the system must achieve the creativity in a rather mechanical way while designers, as it is generally known, tend to create potential solutions based on intuition, heuristics and analogies. Scanning and manipulation of the solution element space that is broad enough to be fertile, generally leads to combinatorial explosion. The chance of it can hopefully be avoided, or descreased at least, if a really DES oriented problem solving methodology can be developed.

We must say that, presently, the systematical generation of concepts seems the only way of implementing creativity in DES environments. It comprises of special activities, as serch, selection, combination, matching and evaluation. The automatic generation of solutions, that can be expected of DES', can be made more effective by appropriate control strategies. Thus our task is to better understand and formalize that has been thought of as the creative activities. In the field of mechanical engineering design, developing a DES oriented methodology needs, first of all, the classification of design problems. Furthermore, formalization and structuring of the tasks involved is needed.

Formalization supporting the conceptual and structure design must be of multi-aspects. First of all the designed object is to be described by different model categories. Up till now data and parametric models are used, but more powerful prototype and generic models must be developed as well. Secondly, to help the management of the parts of the designed object, description schemes are to be developed for the description of object topologies, entities and relations. Thirdly, elementary activities of the design process must be represented

in symbolic form. Finally, having all of these mentioned here, done, formalization of the design problems is needed based on the principles and tools of set theory and knowledge engineering.

DESIGN MODELS FOR DES

Conceptual models of design can be divided into four groups that can be deduced from each other. These are as follows:

* generic model := G_i

  It describes an object-class from the point of view of the operational principles and the provided functions. From this object-class several, one or no objects will possible satisfy the requirements. This model contains the general prototype models of the different object-species. It can solely be represented in symbolic way.

* prototype model := P_i

  It describes the structural elements, their connections and abstract geometries of all of the possible instance-variation of a given object-species. This model contains the structural parameters and the explicite/implicite expressions specifying the relations. It makes it possible to define specialized prototype models (topologies) by manipulating the parameters of the generalized prototypes. In general, it can be represented using symbolics.

* entity model := E_i

  It is a specialized prototype, that contains the geometric parameters and numeric expressions needed to generate the set of instances satisfying the given requirements. In fact, it describes the geometry that belongs to the selected topology in parametrized form. From the point of view of programming this modell can be interpreted as a procedural representation. Typical examples are parametrized CAD computing models.

* instance model := I_i

  It can be derived from the entity model. It is a computer internal data structure that describes an individual object in its physical reality (specifying its dimensions, material and other attributes). An instance model is an end-product of the design process which represent an imaginary object that is suitable for implementation in all respects. Being a logically ordered set of data, its visual representation (e.g. view, drawing, icon) generally needed. Typical examples are CAD data models.

These models, defined above, may regard to complex objects, their functional units or elementary entities building up the parts. Consequently, it is expedient to take into consideration at least three levels, that is:

* assembly level := X_a
* unit level := X_u
* part level := X_p

Doing so, we permit to have, for instance, a prototype model or an entity model on assembly or part level. It is important from the point of view of making hierarchies, e.g. to define a prototype part of a prototype unit in a prototyped assembly. In other case, the same prototype assembly may have instance units and parts besides those that are prototyped.

FORMAL DESCRIPTION OF DES ACTIVITIES

Models can be generated from each other transitively. The main goal is to produce a set of instance data. It needs a series of processing steps. Activities needed to generate and manipulate models can be called as operations. The DES oriented operations, based on their effects, can be groupped as:

creative operations := Σ

and

investigation operations := Γ.

There are two typical occurences of creating operations, namely:

combining synthesis := Σ_c ,

that is for topological configuration of the structural elements of an assembly, a unit and a part, respectively, and

matching synthesis := Σ_m ,

that is for specifying functional and constructional quantities (parameters) among the structural elements. Investigative operations can also be divided into two subclasses. An investigation may be oriented towards finding the most suitable entities based on the qualitative comparison of attributes. This is a

selective analysis := Γ_q ,

Another type of investigation may be for finding the most appropriate parameter values based on a quantitative evaluation. Therefore, it can be called as

$$\text{evaluative analysis} := \Gamma_{s} .$$

Our experiments with DES system PANGEA has demonstrated that with the suitable combination of these typified DES operations it is possible to formalize engineering problems at a level which can be a great support to their solution with complex knowledge processing - HOTA(89). After adapting them to the problem classes concerned they serve as the activity elements of the applied artificial design creativity. In addition to that, these operations can be used to typify the design problem classes themselves. This way, it is not an exaggeration to say that the product (instance) model itself can be a by-product of the design process generation by formalized, and adapted, operations.

SEGMENTS AS ENTITIES FOR CREATIVE DESIGN

It is said, that features are the most elementary known building blocks of design and they represent the interface between design, analysis and manufacturing. In practice, there seems to be little agreement about a firm definition for what actually constitutes a feature. Informally, we may assume that a design feature is a part of an object that has geometric, design and manufacturing significance. In theory, a feature is defined as a region of a part that requires a manufacturing operation or operations. Thus feature-based design emphasizes mainly the shape that implies manufacturing processes to produce a real object. The capabilities for operations or the functions, however, is neither described explicitly nor used to select the required items and to combine them into a structure. However, only those entities can really support the conceptual design and the embodiment of the structure that have functional characterization besides shape and material description. The ideal case would be to have these entities as interfaces between the successive phases of MED.

Initially features has been defined such that the feature definition encompasses the machining rules (necessary to produce the feature) and the inheritance rules (which govern the combination of the features) - SHRO(88). Taking into consideration the possibility of specifying the primary (main) functions and the secondary (auxillary) functions for each of the decomposed elements (segments) of the parts of a machine, this functional information can be appended to their object-oriented data model. With this in mind, the concept of part segment can be introduced. From the point of view of information content a segment is an entity that has shape,

functional, manufacturing and operational information.

If segments are described from functional, geometric and interfacing point of view then they can be configured and matched to build up an operational structure of the needed object. The built-up object must, of course, satisfy the requirements derived from the original problem statement. The process of selection and configuration of segments to form a rational machine structure can not be else only an iterative process.

The kernel of the segment-based design is a straighforward, multiple-step process which covers the following activities:

* constructing the general function scheme (GFS) based on the object functional specification,
* defining the system and the sub-system boundaries on the GFS,
* making a topological structure diagram (TSD) with the specified sub-system names,
* reconstructing the TSD to simplify the topology and to make it more suitable for solution finding,
* selecting appropriate segments based on (function) pattern matching, combining them into topologies systematically, taking into consideration their interfacing parameters, operational values and possible geometric dimensions,
* applying the design rules relevant to the particular object,
* verification of the object topology for structural integrity,
* evaluation of dimensional parameters to find the optimum values
* visualization of the geometric model compiled automatically,
* documenting the design.

We must suppose that the system uses known segments only. Segments are stereotyped, consequently, the most appropriate way of their management is the frame approach, which is well known in object-oriented knowledge programing environments - BALL(89).

METHODOLOGY FOR SEGMENT MANAGEMENT

To establish a segment-based synthesis process, the user must define a comprehensive segment library that describes identification, interface characteristics, geometric parameters, manufacturing operations, functions and other needed details for every segments. Context sensitive structuring of the library files helps in making the selection process more straighforward. It is the task of the inference engine to find out which library file contains the relevant set of segments.

From the point of view of joining, the segments can be of parent (if giving base), children (if built onto) or partner (if simply linked) types. There is an interface specification for all of the adjoining segments. The frame can describe both the interfacing capabilities of the segments and their input and output shape parameters. The interface specification defines the presupposed direct connections but, in principle, indirect connections can be made if it is possible to generate special interfacing segment(s).

Since MED may be divided into object oriented design fields, it is reasonable to define segment libraries that are relevant to different application fields. It is the task of the designer who specifies the segments to characterize them from functional point of view - RODE(84). Naturally the set of functions supplied by a segment varies from segment to segment. There is the possibility to pre-select segment libraries based upon function sets, thus, providing segment libraries and sub-libraries that satisfy certain broad functional categories.

The configuration of segment then comes as a pattern matching. Except in special cases, design does not comprise searching all possible candidates of the segments libraries. Generally the knowledge engineer is to put heuristic rules of thumb, that have been gained from previous experience, into the knowledge base of the expert system. That was the case with PANGEA - TAKA(88).

PROTOTYPE EVALUATION FOR PRODUCT INSTANCES

In computerized systems, heuristic matching can do much to assist in this type of object design. As a strategy, upon selecting a candidate segments for accomplishing the set of the needed functions, a joining feasibility checks are made with the neighboring segments. The candidate segments can be accepted only if their "joining" compatible with the existing structure. Conditions of matching are stated on four levels. These are as follows:

* function level,
* inteface parameter level,
* operating parameter level,
* geometric parameter level.

The function level is the most decisive for selection. That segment is to be selected which provide the most complete covering of the requested functions. If a segment can not provide the required functions it must not be selected. The interface level, i.e. the evaluating methods pertaining to this level, determine if the selected segments have the appropriate interface parameters. Next level of matching is for evaluating the proper transformation between the input and the output operating parameters. By the methods and rules

of the fourth level the system determines the optimum values of the (macro- and micro-) geometric parameters.

During the matching, the system must evaluate all usable items of the segment library to find those segments that match the functional specifications. In principle, with this type of design, all functional requirements can be fulfilled since the user cannot select functions that are inconsistent with the segment library. In practice the combination and joining of segments can create situations that cannot be satisfied with a limited segment library. Thus, the larger the segment library is, the greater is the possibility of finding satisfactory design solutions.

Selection of segments that match exactly to a given function is optimal but this is not always possible. In cases where the functions of a given segment overlap that of another segment, the topology may be satisfied by selection of one segment in place of two or more other segments or visa versa.

Unfortunately, in the overwhelming majority of cases there is no complete harmony between the needed set of functions and the set of functions provided by defined segments that are available from a segment library. If a segment can be selected that differs only slightly from the ideal, it may be worth redesigning or redefining the segment, if it is possible at all. In the ideal case, segments can be selected to provide all the functions required by the object.

For the several subsets of functions defined for the topological elements, several function carriers (segments) may be found that accomplish a desired function. By configuring and matching the various candidates qualitatively, the system generates solution variants. The available prototype variants, however, are to be quantitatively evaluated throughfully for acceptance.

In general, the object structure (the topology) is a segment-network in which several numerical integrity checking processes are necessary. If the integration tests on the first and the second level fails, new candidate segments must be selected and matched. Often more than one configuration seems to be acceptable since there are alternatives for satisfying a given function set. All of these variant designs may be stored and numerically evaluated to find an optimum solution.

A useful approach in conceptual design is the use of prototypes. After having the prototypes, the design process itself becomes one of modifying and testing the prototype - GERO(89). Ultimate goal is to derive object instances that meet the operating requirements of the environment. For the expert system oriented design system, the prototype typifies the artifact(s) being designed. In the prototype the object

topology has been fixed - YOSH(72).

REFEENCES

FOX_(87) Fox, M.S.: Industrial Application of Artificial Intelligence; in Artificial Intelligence in Manufacturing, ed. by Bernold, T., Elsevier Science Publishers B.V., CDI, 1987, pp. 1. - 18.

LALO(85) Lane, V.P., Laucopoulos, P.: Knowledge-based systems as a mechanism for optimization of conceptual design in civil engineering; in Optimization in CAD, ed. by Gero, J.S., Elsevier Science Publisher B. V., IFIP, 1985, pp. 81. - 100

BALL(89) Balla, Z.: Gépelemek alaki sajátosságainak szintézisére alkalmas módszer kidolgozása és programozása, Diplomaterv, Budapest Technical University, Institute for Machine Design, Budapest, 1989, (in Hungarian).

GERO(89) Gero, J.S.: Prototypes: a basis for knowledge based design; in: Knowledge-Based Systems in Architecture, ed. by Gero, J.S., Oksala, T., Acta Polytechnica Scandinavica, Helsinki, 1989, pp. 11. - 17.

HOTA(89) Horváth, I., Takáts, I.: Szakértörendszerváz-fejlesztés géptervezési feladatokra, Automatizálás, XXII. évf., 9. szám, 1989. szeptember, pp. 2. - 9., (in Hungarian).

RODE(84) Rodenacker, W.: Methodisches Konstruiren, Springer-Verlag, Berlin, 1984, (in German).

ROTH(88) Roth, K.: Übertragen von Konstruktionsintelligenz an den Rechner; VDI Berichte, Nr. 700.1, Düsseldorf, VDI-Verlag, 1988, pp. 49. - 70., (in German).

SHRO(88) Shah, J.J., Rogers, M.T.: Expert Form-Features Modelling Shell; CAD, vol. 20, No. 9, 1988. november, pp. 515. - 524.

TAKÁ(88) Takáts, I.: Következtetö mechanizmus és programozási környezet fejlesztése géptervezési feladatokhoz; Diplomaterv, Budapest technical University, Institute for Machine Design, Budapest, 1989, (in Hungarian).

YOSH(72) Yoshikawa, H.: Kikai-no toporoji; Seimitsu-kikai, Japan, Vol. 38, No. 12, 1972, pp. 30. - 35.

YOSH(81) Yoshikawa, H.: General Design Theory and a CAD System; in: Man-Machine Communication in CAD/CAM, ed. by Sata, T., Warman, E., North Holland Publishing, 1981, pp. 35. - 58.

ROBOT SELECTOR AND 3D GRAPHIC MODELING PROGRAM

Dr. Anowar Hossain - Csaba Krajcsovics - Gyula Roman
Dept. of Manufacture Engineering
Technical University of Budapest
HUNGARY

Robot selector Program

The task of the Robot selector program is to handle robot data base. The data base contains the most important pieces of information of the robots, necessary for the user.

The recent data base is from the low level program RobotCalc widely used in North America. It's data were transformed from English units to metric .
The stored data are the following:

- the name of the manufacturer
  the address of the manufacturer
  the phone number of the manufacturer

- the name of the robot
  the load capacity
  the joint configuration
  the number of axis
  the drive type
  the base rotating angle
  the gripper type
  the repeatability
  the year of issuing
  the control system
  the method of programming
  the size of program memory
  the horizontal / vertical envelope
  the horizontal / vertical reach
  the applications of the given robot.

This data base will be enlarged with the appropriate parameters of the robots made or available in Hungary. To make easier the user's task, the base is in ASCII format. It can be edited in a simple editor. The robots are grouped according to their manufacturers and listed in alphabetical order. (This is not a requirement)

Started the program it searches for a ROBOTS.RBT file, or, if it's not found the data base file name will be read

from the command line. This file is loaded into the memory, which is sufficient to store approximately 500 robots. The program generates a special data structure to ease further processing. The program is flexible, so the parameters can vary. After the initialization of the data base the main menu is activated. (see Fig. 1.)

The program is menu driven. The required function can be easily selected using the cursor keys.

The Features of the Main Menu:

- Help

The Help Window describes the functions and the usage of the program. The program operates with an interactive Help system, so the information is displayed in the Help Window in connection with the actually active function if necessary. This can be used with each function of the program.

- Robot Listing (see Fig. 2.)

It helps the user to get the information needed about a certain robot or a manufacturer. The data base is systematically organized. First of all it is grouped according to the manufacturers. The manufacturer can be selected from a list given in a separated window using the cursor keys. Then, in an other window the robots of the chosen firm appear. The user can examine the detailed description of a specific robot in this list.

- Robot Selection

This is the main function of the program. (see Fig. 3.) The user can prescribe 11 parameters , the matching criteria for a robot. The program searches through the data base for a robot matching the prescribed parameters, and, if any are found, the first is displayed. Then, the user can skip to the next robot matching the criteria, using the function keys.

The program can search according to the following parameters:

- the name of the manufacturer (a)
- the name of the robot (a)
- the number of axis (b)
- the drive type (a)
- the load capacity (b)
- the repeatability (b)
- the horizontal envelope (b)
- the vertical envelope (b)
- the horizontal reach (b)
- the vertical reach (b)
- the applications (a)

The items marked with (a) need text type parameters, which can be selected from a list displayed in a specific window. The user can only select from the strings existing in the data base. The items marked with (b) need numerical parameters typed in on the keyboard. It's s not obligatory to specify all the items. (An unspecified item will be left out of the searching criteria.)

Anyhow, to perform an effective selection, the more parameters are specified the better.

The program was developed in Turbo C to construct a flexible data base structure and to optimize the searching time. This program can be connected to the Den-Hart program, which expands the features of the Robot selector program with displaying the 3D vision of the selected robot. The geometric data base needed for visualization is under development.

- Further Developing Strategies

With the help of the Den-Hart program the Robot selector will be able to support the user in selecting the appropriate robot for the specific task. Integrating other modeling functions the program can be effectively used for industrial applications, and the probability of a bad selection can be reduced.

Modeling and Displaying Robot Manipulators

The Den-Hart program based on the Denavit-Hartenberg model is capable of displaying and simulating the movements of each joints of robots with different arm architectures.

Connecting to the Robot selector program it supports the user by displaying the selected robot in action. The user can see the physical capabilities of the robot, and decide, whether the robot is sufficient for the given task, or not.

The following schematic system is used to describe the robots :

- the arms are built up of green prisms (this program requires an EGA card and monitor), while the different joints are drawn with the following figures:
(see Fig. 4.)

In the beginning, the robot appears in base position, then the joints are moved under the control of a driving program. The control data are numeric, so those can be generated with the help of any programming languages. This feature can be very useful on testing a robot controller program written for a specific task.Using an interface program, for example a PAL interface, the controller program itself can be tested.

The figures below illustrate different robots in different positions. (see Fig. 5.)
To generate these movements, the program uses transformation matrices constructed with the Denavit-Hartenberg model. Some of these matrices can be seen below :

rotation matrix 1

$$\begin{bmatrix} 1 & 0 & 0 & 65 \\ 0 & \cos(q1) & -\sin(q1) & 0 \\ 0 & \sin(q1) & \cos(q1) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

translation matrix 1

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 50+d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

rotation matrix 2

$$\begin{bmatrix} 0 & \sin(q3) & \cos(q3) & 0 \\ 0 & \cos(q3) & -\sin(q3) & 130 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

translation matrix 2

$$\begin{bmatrix} 0 & 0 & 1 & d4 \\ 1 & 0 & 0 & 32.50 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

rotation matrix 3

$$\begin{bmatrix} \cos(q5) & -\sin(q5) & 0 & 0 \\ \sin(q5) & \cos(q5) & 0 & 0 \\ 0 & 0 & 1 & -70 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

rotation matrix 4

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(q6) & -\sin(q6) & 0 \\ 0 & \sin(q6) & \cos(q6) & -70 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The program has already been used in the education since 1989 at the Dept. of Manuf. Eng. Technical University Budapest.

It is aimed to use the program, especially its data base for CAD of flexible assembly cells using artificial intelligence tools.

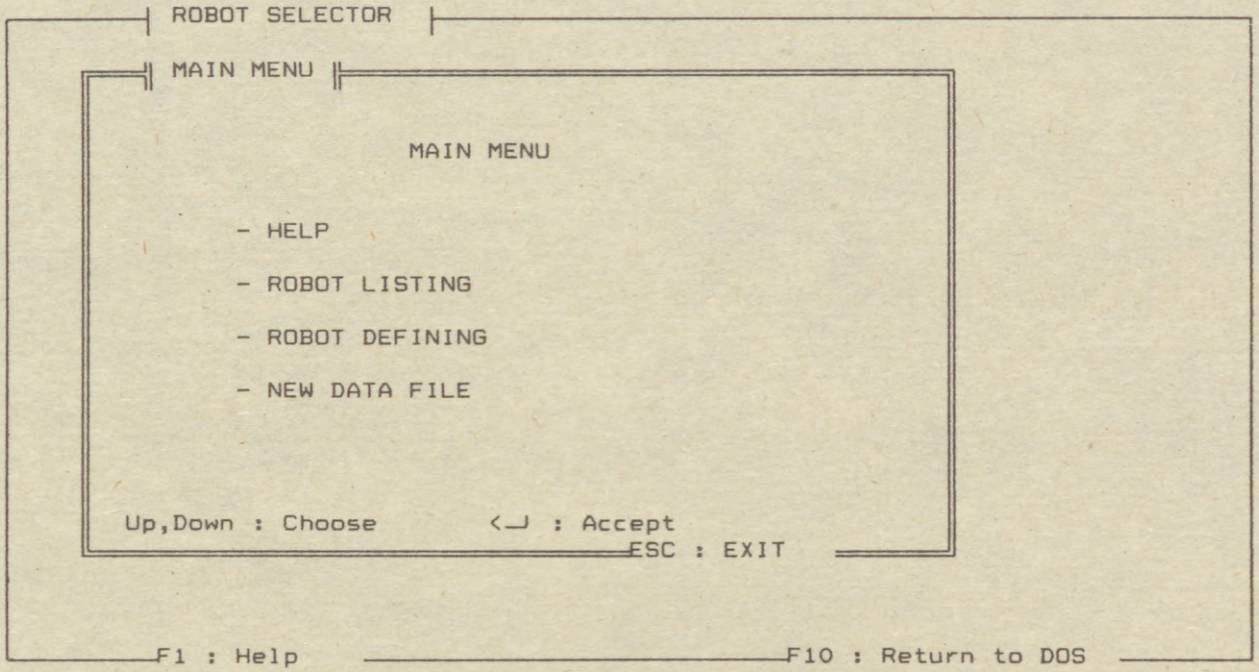

ROBOT SELECTOR
MAIN MENU
MAIN MENU
- HELP
- ROBOT LISTING
- ROBOT DEFINING
- NEW DATA FILE
Up,Down : Choose
<↵ : Accept
ESC : EXIT
F1 : Help
F10 : Return to DOS

FIGURE 1.

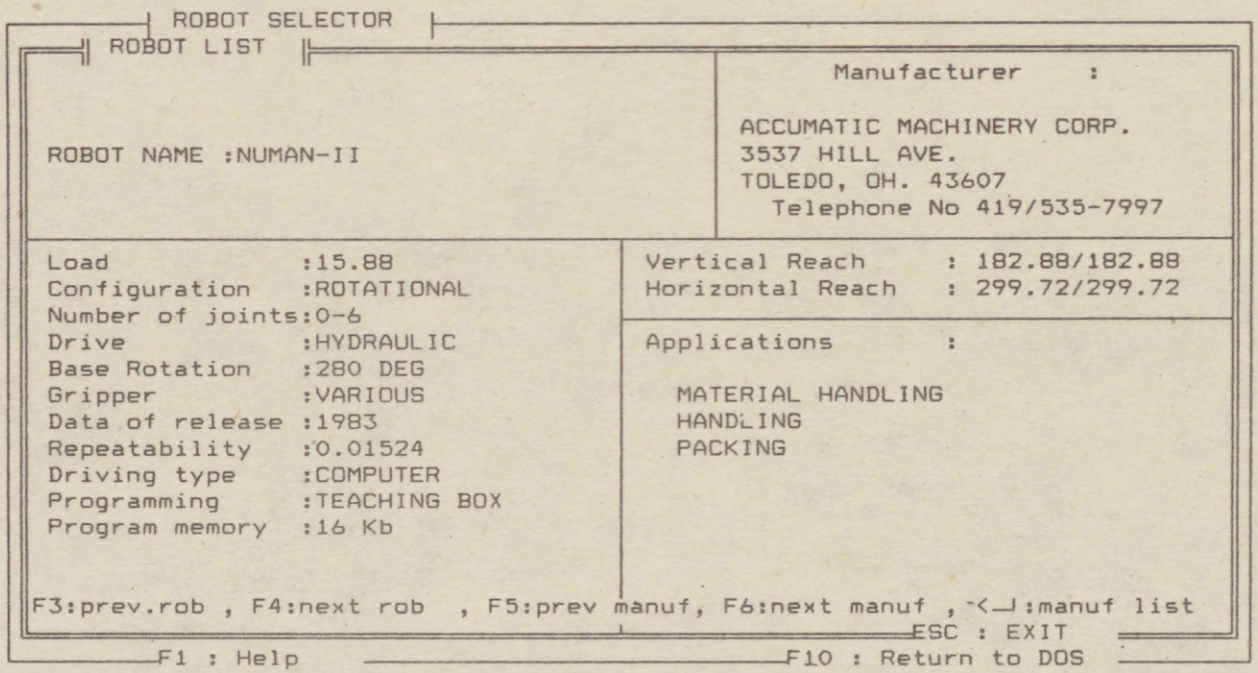

ROBOT SELECTOR
ROBOT LIST
ROBOT NAME :NUMAN-II
Manufacturer :
ACCUMATIC MACHINERY CORP.
3537 HILL AVE.
TOLEDO, OH. 43607
Telephone No 419/535-7997
Load :15.88
Configuration :ROTATIONAL
Number of joints:0-6
Drive :HYDRAULIC
Base Rotation :280 DEG
Gripper :VARIOUS
Data of release :1983
Repeatability :0.01524
Driving type :COMPUTER
Programming :TEACHING BOX
Program memory :16 Kb
Vertical Reach : 182.88/182.88
Horizontal Reach : 299.72/299.72
Applications :
MATERIAL HANDLING
HANDLING
PACKING
F3:prev.rob , F4:next rob , F5:prev manuf, F6:next manuf , ↵ :manuf list
ESC : EXIT
F1 : Help
F10 : Return to DOS

FIGURE 2.

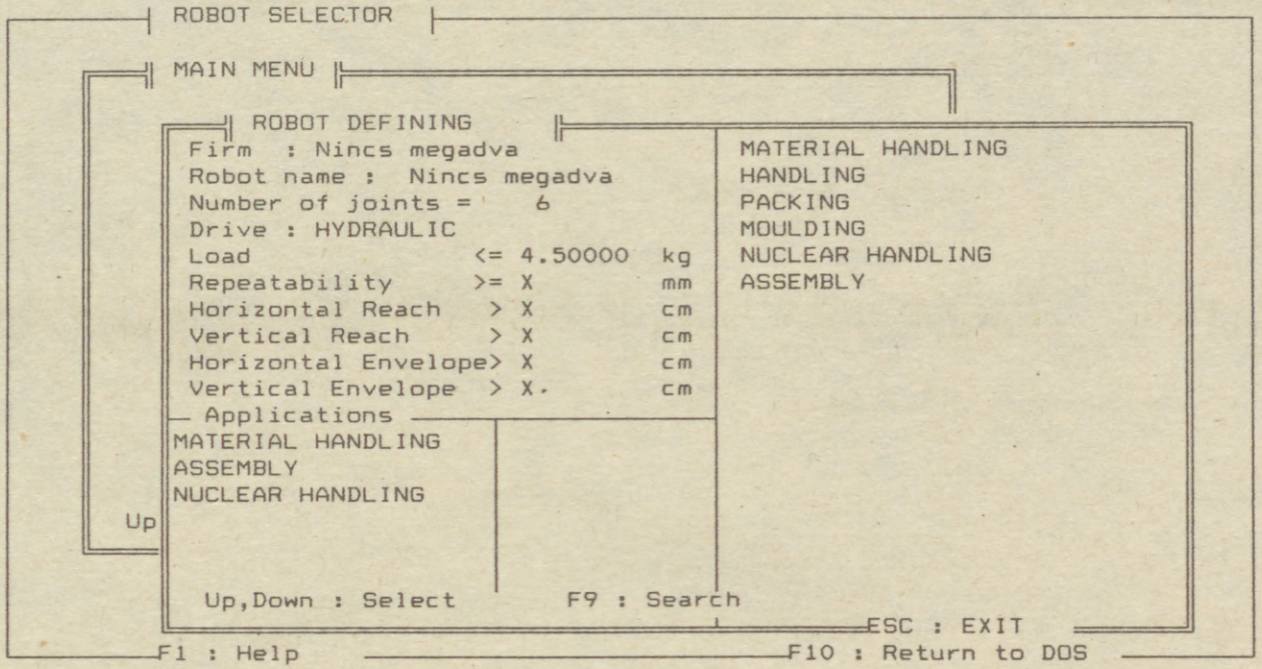

ROBOT SELECTOR
MAIN MENU
ROBOT DEFINING
Firm : Nincs megadva
Robot name : Nincs megadva
Number of joints = 6
Drive : HYDRAULIC
Load <= 4.50000 kg
Repeatability >= X mm
Horizontal Reach > X cm
Vertical Reach > X cm
Horizontal Envelope> X cm
Vertical Envelope > X. cm
Applications
MATERIAL HANDLING
ASSEMBLY
NUCLEAR HANDLING
Up
Up,Down : Select
F9 : Search
MATERIAL HANDLING
HANDLING
PACKING
MOULDING
NUCLEAR HANDLING
ASSEMBLY
ESC : EXIT
F1 : Help
F10 : Return to DOS

FIGURE 3.

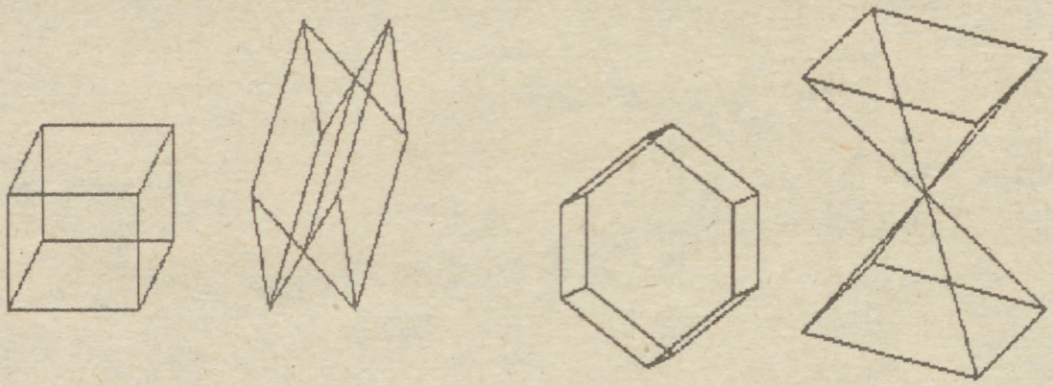
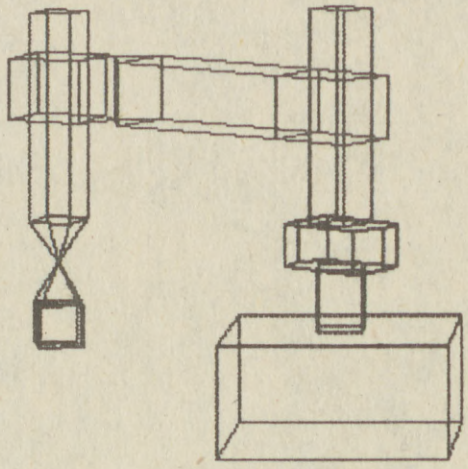
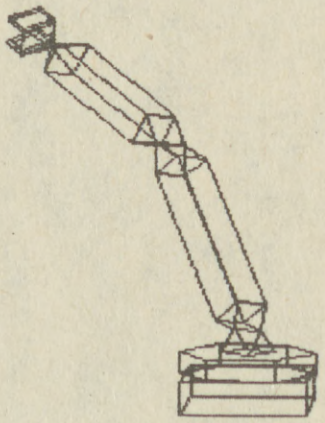


FIGURE 4.



PICMAT-2



NORKYB-570

FIGURE 5.

"CAD - DAE" system for footwear production

D. Ilinsky, D. Sc., Prof.

The system comprising in itself to others "Computer-Aided-Design" (CAD) and "Decision Assistense and Expert" (DAE) was developed and put into operation via personel computer for interactive mode system. The system "CAD-DAE" is able :

1) to find the optimal (the best) variant among the many given sets of tehcnical units for predetermined industrial conditions ;
2) to make decisions,aimed at technological product innovations.

The system is of multilevel hierarchical structure , there being levels of technology,engineering, and production management. Such characteristic of system is stipulated by the fact,that each perspective decision of the previous level is thoroughly worked out, i.e. - being detalized and conctretized at all following levels apart from the rest of all.

The system "CAD-DAE" is based

- on the correspondence tables , wich are bilt on an scheme "if...,then..." ;
- statement calculus and predical calculus; ideas and techniques of dynamic programming.

Reviews determinate and probability models.It describes general optimization problem. In exchange for heuristic reasoning and method of trial and error mathematical method is offered. This method may be used for determining the structure and parameters of optimal variant of machine (or

line) of shoe industry.

Optimization procedures are as follows : movement step-by-step in the descrete phase space , arithemical procedures for evalution of effectiveness criterious and cost criterious,exception on each step of all non-dominance solving. Non-dominance solving had effectiveness and/or cost worse others.

Compatibility of local solutions within general solution controls by test of correspondence. If local solutions are comparatible,borrow from predical calculus testing logical function automaticaly gives rezult "true", if local solution are not comparatible - rezult "false".

"CAD" rate is applied,when a user inputs a certain set of preditermined conditions. For example, we show a fragment of these conditions: technology of the shoe-bottom manufacturing-molding (direct injection); predetermined regime (temperature - degrees by C., time - seconds, etc.) annual output (productivity,pairs/year), the type of technological equipment and robots recommended as well as other industrial mean; limits of capital investments and number of operatives; all these poduction investments being the optimum criteria. The display ,then, shows an answer containing specification of the set of equipment (technological complex), which ensures the fulfilment of production plan under the given conditions.

Explains how to find the optimal solution of practical problems. Examines an output model as the goal of engineering design systems : initial,boundary and terminal conditions.

Unknows are structure of machines and lines , parametrs of its modular blocks,the revims of maintenance and repair ,

the manufacturing organization,the tactics of exploitation.

As example concrete problem examined : great variety of possible alternatives is know - approximately 3 000 000 ; it is necessary to change only one alternative , which is optimal variant. This problems cannot be solved by another means.

At the "DAE" rate a user inputs the set of predetrmined conditions, depicting his production realities. Below we show the fragment of such conditions : there is the certain type of equipment with a given number of positions for bottom-moulding manufacture, the estimated production programme per day and the number of each size of shoes in every production lot. At the display one can see ,then, the answer,dealing with the following data :

- the strict sequence of positions in which all the necessary pairs of shoes of the given sizes should be manufactured to fulfil the production plan,the equipment being used as efficiently as possible (i.e. with minimal delays of positions).

It follows from this that in the "CAD" rate the system gives an answer to the question " what equipment must be used ? ", but in "DAE" rate the question to be answered is : "How can we use the available equipment ?".

Always our knowledge about something is no absolute owing to all world is being fulled of probability and man's mind is no perfect. In this situation the computer simulation is the most perspective and very strong means of remote rezult forecast.

This method uses the common sence,the empirical data and production statistics, also many fragments of technological sciences. For example , it is uses multiposition machines for molding of shoe soles and produc-

tion lot must consist of all sizes of shoes in target proportion , it is necessary to follow the rule : the ratio of number of pair in the lot to number of machines positions have to be the whole number. Otherwise, the utilization factor of machine will be lowered by other things being equal (in detail see : D. Ilinsky "Foundations of the Technological Machines and Lines Design", Moscow,The Publishing House for Light Industry - 1989).

Simulation models formes by programme blocks. Each of them is correspond to the component part of automatical machines system. This reduces development time and increases friendliness of Simulation Modeling Systems. To the best advantage problem of risk definition in technological,design and organization decisions has been solved by this method only.

A STUDY OF NORMAL FORCE CHANGE UNDER THE STABILIZING THRESHOLD IN LATHE CHATTER

Yoshiaki IWATA

Faculty of Science and Technology, Kinki University,
Kowakae 3-4-1, Higashi-Osaka, Osaka 577 (Japan)

SUMMARY

The chatter vibration is influenced by the change of normal force in the work cutting. The normal force change under the chatter vibration is shown by the product of the specific cutting resistance in normal force direction under the chatter vibration and the cutting area change before and after one rotation of work.

In the stabilizing threshold, the specific cutting resistance of the normal force direction under the chatter vibration is replaced by the specific cutting resistance in normal force direction before the chatter vibration. The size of lip part of bit under the chatter vibration which relates in cutting of work is taken as the same condition before chatter vibration.

The variation of normal force change is led on the difference of normal force change after one and two rotations of work under the chatter vibration. The normal force change which is altered by the size of bit and cutting condition is advanced with the analysis from phase difference before and after one rotation under the chatter vibration.

As the results, the variation of normal force change in after one and two rotations of work causes larger approach to 0.5 from 0.1 and diminishes to 0.9 from 0.5 by the fraction of chatter mark on work circumference.

On condition that the nose radius is fixed, the more side cutting edge angle increases the more variation of normal force change increases.

On condition that the side cutting edge angle is fixed, the bigger nose radius becomes the more variation of normal force change increases.

The variation of normal force change by the change of nose radius of bit is bigger than that of side cutting edge angle.

INTRODUCTION

The study is taken by the external cutting of a round bar by right handy blade bit with side cutting edge angle.

The bit is fixed tightly in the tool post of lathe. A round bar fitted between the both centers is treated as the bending vibration.

The change of normal force under the chatter vibration is shown by the product of the specific cutting resistance in normal force direction under the chatter vibration and the

cutting area change before and after one rotation of work.

In the stabilizing threshold, the specific cutting resistance in the normal force direction under the chatter vibration is replaced by the specific cutting resistance in normal force direction before the chatter vibration. The specific cutting resistance of the normal force direction in right handy blade bit with side cutting edge angle before the outbreak of chatter vibration is expressed by ks_1.

The cutting area of lip part of bit cut in toward the work before the outbreak of chatter vibration is expressed by A_0.

When the bit is fed only S_0 by one rotation of work, the condition of size of bit is treated as the same before one rotation. The cutting area of lip part of bit under the chatter vibration is expressed by A_1. The change of normal force dP_1 after one rotation of work can be expressed as follows:

$$dP_1 = ks_1(A_1 - A_0)$$

Moreover, the bit is fed only S_0 after one rotation of work under the chatter vibration. The chatter vibration in lathe cutting has the phase difference between tool and work. The phase difference has a direct effect upon the chatter vibration. In this case, if the revolution of work is replaced by N(r.p.m.), the time of one rotation of work becomes 60/N sec/rev. If frequency of sine wave on work is replaced by f(c/s), the chatter mark on work circumference after one rotation becomes:

$$\frac{60}{N} \times f = I(\text{integer}) + \varepsilon(\text{fraction})$$

The relation between fraction ε and the phase difference ϕ before and after one rotation under the chatter vibration becomes:

$$m = \frac{2\pi}{\phi}, \quad \varepsilon = \frac{1}{m} \quad 0 < \varepsilon < 1$$

The cutting area of lip part of bit under the chatter vibration is expressed by A_2. The change of normal force dP_2 after two rotation of work under the chatter vibration can be expressed as follows:

$$dP_2 = ks_1(A_1 - A_2)$$

In this case, the angle of vibration for the normal force direction of work is not changed under the cutting. The lip part of right handy blade bit is in the deepest position into the direction of normal force from the chatter vibration before one rotation. After that, the bit is fed by only feed with one rotation of work. The lip part is treated as cutting deeply into the direction of normal force as the same before one rotation. Where, the lip part of the cutting of right handy blade bit is treated as follows:

1) Side cutting edge and nose part.
2) Side cutting edge, nose and end cutting edge part.
3) Nose part.

1. THE CHANGE OF NORMAL FORCE BY LIP PART OF BIT

1.1. THE CASE OF SIDE CUTTING EDGE AND NOSE PART

The lip part of right handy blade bit is treated as side cutting edge and nose part. The quantitative relations among the end cutting edge angle Ce, side cutting edge angle Cs, nose radius r_n, depth of cut d and feed S_0 are as follows:

$$d \geqq r_n(1-\sin Cs),\quad S_0 \leqq 2r_n \sin Ce,\quad S_0 < 2r_n \cos Cs$$

When the cutting area change before and after one rotation put in place of the approximate expression, the change of normal force after one and two rotations of work dp_1, dp_2 is shown as follows:

$$dp_1 = k_{s3}\left[\{d-r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s + \frac{S_0}{2}\right] x\cos\theta\cos\omega t \qquad (1)$$

$$dp_2 = k_{s3}\left[\left[\{d-r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s - \frac{S_0}{2}\right] x\cos\theta\cos\omega t + \left[\{d-r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s + \frac{S_0}{2}\right] x\cos\theta[\cos\omega t - \cos(\omega t+\phi)]\right] \qquad (2)$$

In formula (1),(2), θ shows the fixed angle facing normal force component under the cutting. $x\cos\omega t$ shows vibration and ϕ shows the phase difference between before and after one rotation of work.

1.2. THE CASE OF SIDE CUTTING EDGE, NOSE AND END CUTTING EDGE PART OF BIT

The lip part of right handy blade bit is treated as side cutting edge, nose and end cutting edge part. The quantitative relations among the end cutting edge angle Ce, side cutting edge angle Cs, nose radius r_n, depth of cut d and feed S_0 are as follows:

$$d \geqq r_n(1-\sin Cs),\quad 2r_n \sin Ce < S_0 < 2r_n$$

When the cutting area change before and after one rotation put in place of the approximate expression, the change of normal force after one and two rotations of work dp_1, dp_2 is shown as follows:

$$dp_1 = k_{s3}\left[\{d-r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s + S_0\cos^2 C_s - r_n\sin C_s\cos C_s\right] x\cos\theta\cos\omega t \qquad (3)$$

$$dp_2 = k_{s3}\Big[[\{d - r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s - S_0\sin^2 C_s - r_n\sin C_e\cos C_e]x\cos\theta\cos\omega t + [\{d - r_n(1-\sin C_s)\}\tan C_s + r_n\cos C_s + S_0\cos^2 C_s - r_n\sin C_e\cos C_e]x\cos\theta(\cos\omega t - \cos(\omega t+\phi))\Big] \quad (4)$$

1.3. THE CASE OF NOSE PART OF BIT

The lip part of right handy blade bit is treated as nose part. The quantitative relations among the end cutting edge angle C_e, side cutting edge angle C_s, nose radius r_n, depth of cut d and feed S_0 are as follows:

$$d < r_n(1-\sin Cs),\quad S_0 \leqq 2r_n\sin Ce$$

When the cutting area change before and after one rotation put in place of the approximate expression, the change of normal force after one and two rotations of work dp_1, dp_2 is shown as follows:

$$dp_1 = k_{s3}\left\{\sqrt{d(2r_n-d)} + \frac{S_0}{2}\right\}x\cos\theta\cos\omega t \quad (5)$$

$$dp_2 = k_{s3}\Big[\left\{\sqrt{d(2r_n-d)} - \frac{S_0}{2}\right\}x\cos\theta\cos\omega t + \left\{\sqrt{d(2r_n-d)} + \frac{S_0}{2}\right\}x\cos\theta(\cos\omega t - \cos(\omega t+\phi))\Big] \quad (6)$$

2. THE VARIATION OF NORMAL FORCE CHANGE OF NUMERICAL EXAMPLE

dp_1 shows the increased normal force change by the outbreak of chatter vibration before and after one rotation of work.

dP_2 shows the decreased normal force change from increased normal force change dp_1 before and after one rotation of work under the chatter vibration.

The variation of normal force change before and after one rotation of work under the chatter vibration is expressed as follows:

$$dp_1 - dp_2 = k_{s3}x\cos\theta[(H_2\cos\phi - H_1)\cos\omega t - H_2\sin\phi\sin\omega t] = k_{s3}Hx\cos\theta\cos(\omega t+\varphi) \quad (7)$$

where

$$H = \sqrt{H_1^2 + H_2^2 - 2H_1H_2\cos\phi},\quad \varphi = \tan^{-1}\frac{H_2\sin\phi}{H_2\cos\phi - H_1}$$

H_1, H_2 show as follows:

$$d \geqq r_n(1-\sin C_s),\ S_0 \leqq 2r_n\sin C_e,\ S_0 < 2r_n\cos C_s$$

$$H_1=\{d-r_n(1-\sin C_s)\}\tan C_s+r_n\cos C_s-\frac{S_0}{2}$$

$$H_2=\{d-r_n(1-\sin C_s)\}\tan C_s+r_n\cos C_s+\frac{S_0}{2}$$

$d\geqq r_n(1-\sin Cs)$, $2r_n\sin Ce<S_e<2r_n$

$$H_1=\{d-r_n(1-\sin C_s)\}\tan C_s+r_n\cos C_s-S_0\sin^2 C_e-r_n\sin C_e\cos C_e$$

$$H_2=\{d-r_n(1-\sin C_s)\}\tan C_s+r_n\cos C_s+S_0\cos^2 C_e-r_n\sin C_e\cos C_e$$

$d<r_n(1-\sin Cs)$, $S_e\leqq 2r_n\sin Ce$

$$H_1=\sqrt{d(2r_n-d)}-\frac{S_0}{2}$$

$$H_2=\sqrt{d(2r_n-d)}+\frac{S_0}{2}$$

Next, the setting of k_{s3} and θ are gained by tangential force P_1, axial force P_2 and normal force P_3 in cutting experiment with tool dynamometer. The size of bit and cutting condition are as follows:
The round bar: ϕ 15 × 600mm, S35C, The bit: P20, Inclination of lip part: 0°, End relief angle: 6°, Side relief angle: 6°, End cutting edge angle: 15°, Side cutting edge angle: 15°,

Table 1. The specific cutting resistance of the normal force direction and fixed angle facing normal force component

$Cs=15°$

r_n (mm)	S_e (mm/rev)	P_1 (kgf)	P_2 (kgf)	P_3 (kgf)	k_{s3} (kgf/mm², θ°)
0.5	0.10	27.1	17.3	13.3	$k_{s3}=\mathrm{Exp}(4.12-0.36\log_e S_e)$ $\theta=18.36S_e+61.70$
	0.16	42.1	26.0	20.0	
	0.23	56.9	32.0	25.3	
	0.33	74.0	33.3	30.7	
	0.50	103.3	35.3	35.3	
1.0	0.10	28.0	18.7	16.0	$k_{s3}=\mathrm{Exp}(4.05-0.45\log_e S_e)$ $\theta=25.49S_e+59.01$
	0.16	44.0	22.7	21.3	
	0.23	56.0	26.7	26.3	
	0.33	80.7	30.0	32.0	
	0.50	108.7	32.7	37.3	
1.5	0.10	24.7	13.3	16.0	$k_{s3}=\mathrm{Exp}(4.08-0.44\log_e S_e)$ $\theta=29.53S_e+55.05$
	0.16	38.7	18.7	21.3	
	0.23	52.7	24.0	29.3	
	0.33	70.7	25.3	32.0	
	0.50	99.3	28.0	37.3	
2.0	0.10	28.0	24.0	16.0	$k_{s3}=\mathrm{Exp}(3.94-0.50\log_e S_e)$ $\theta=29.68S_e+59.90$
	0.16	49.3	21.3	21.3	
	0.23	62.0	25.3	26.7	
	0.33	88.0	28.0	28.7	
	0.50	114.7	32.0	34.7	

r_n=0.5mm

C_t (°)	S_o (mm/rev)	P_1 (kgf)	P_2 (kgf)	P_3 (kgf)	k_{s_3} (kgf/mm²) θ(°)
30	0.10	26.7	26.7	10.7	$k_{s_3}=\mathrm{Exp}(4.16-0.23\log_e S_o)$ $\theta=9.31S_o+69.15$
	0.16	51.3	36.7	16.0	
	0.23	63.3	47.3	21.3	
	0.33	84.7	52.7	26.7	
	0.50	120.0	58.0	36.0	
45	0.10	28.0	26.0	18.7	$k_{s_3}=\mathrm{Exp}(4.23-0.45\log_e S_o)$ $\theta=25.45S_o+53.85$
	0.16	40.0	36.7	26.7	
	0.23	53.3	44.7	29.3	
	0.33	74.7	52.0	37.3	
	0.50	100.0	56.7	45.3	

30°, 45°, Normal side rake angle: 5°, Nose radius: 0.5mm, 1.0mm 1.5mm, 2.0mm, Cutting speed of high-speed lathe: 100m/min, Depth of cut: 1.0mm, Feed: 0.10mm/rev, 0.16mm/rev, 0.23mm/rev, 0.33mm/rev, 0.50mm/rev.

These experimental result and regression equation of k_{s_3}, θ are shown in Table 1.

From Table 1, normal force change after one and two rotation of work dP_1, dP_2 and variation of normal force change after one and two rotation of work dP_1-dP_2 are gained by formula (1), (2), (3), (4), (5), (6), (7). The variation of normal force change after one and two rotation of work dP_1-dP_2 is shown from fraction ε in Table 2 (a), (b).

x shows the amplitude of vibration.

3. VARIATION OF NORMAL FORCE CHANGE AND CONSIDERATION

From Table 2 (a), (b), an example of variation in the difference of normal force change dP_1-dP_2 by the influence of side cutting edge angle is shown in Fig. 1. An example of variation in the difference of normal force change dP_1-dP_2 by the influence of nose radius is shown in Fig. 2. An example of variation of normal force change dP_1 and difference of normal force change dP_1-dP_2 by vibratory amplitude x are shown in Fig. 3.

From these result, the increased normal force change from the outbreak of chatter after one rotation of work continues in the after two rotation of work under the chatter vibration.

The increased normal force change after one rotation of work causes larger approach to 0.5 from 0.1 and diminishes to 0.9 from 0.5 by the fraction ε .

The more feed increases, the more increased normal force change after one rotation of work dP_1 decreases from Table 2 (a), (b).

The more side cutting edge angle of bit increases, the more variation of the difference of normal force change increases from Fig. 1.

The bigger nose radius of bit becomes the more variation of normal force change increases from Fig. 2.

The influence of dP_1-dP_2 by the change of nose radius of

Table 2. The relation between dP_1, dP_2 and dP_1-dP_2 normal side rake angle 5°

(a) Case of d=1.0mm

C_1 (°)	r_ε (mm)	C_2 (°)	S_0 (mm/rev)	k_{s2} (kgf/mm²)	θ (°)	dp_1 (kgf)	dP_1-dP_2 (kgf) ε 0.1, 0.9	0.3, 0.7	0.5	x (mm)	
15	0.5	45	0.1	193.67	56.40	134.75×cosω'	180.61×cos(ω'+179.271)	209.45×cos(ω'+137.721)	258.78×cosω'	0.02	$d\geq r_\varepsilon(1-\sin C_1)$, $S_0\leq 2r_\varepsilon\sin C_2$, $S_0<2r_\varepsilon\cos C_2$,
			0.2	141.78	58.94	95.61×cosω'	156.32×cos(ω'+186.301)	143.12×cos(ω'+139.441)	176.59×cosω'	0.04	
			0.4	103.79	64.03	66.15×cosω'	139.27×cos(ω'+181.881)	192.93×cos(ω'+142.601)	114.10×cosω'	0.06	$d\geq r_\varepsilon(1-\sin C_1)$ $2r_\varepsilon\sin C_2<S_0<2r_\varepsilon$
			0.5	93.87	66.58	57.78×cosω'	134.81×cos(ω'+177.351)	179.17×cos(ω'+143.961)	196.91×cosω'	0.06	
		30	0.1	108.81	70.08	33.96×cosω'	120.15×cos(ω'+182.081)	151.99×cos(ω'+138.401)	164.21×cosω'	0.02	$d\geq r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_2$, $S_0<2r_\varepsilon\cos C_2$,
			0.2	92.77	71.01	29.16×cosω'	117.15×cos(ω'+188.441)	142.45×cos(ω'+140.801)	152.28×cosω'	0.04	
			0.4	79.10	72.87	25.96×cosω'	115.87×cos(ω'+174.051)	134.89×cos(ω'+145.031)	142.59×cosω'	0.06	$d\geq r_\varepsilon(1-\sin C_1)$ $2r_\varepsilon\sin C_2<S_0<2r_\varepsilon$
			0.5	75.15	73.81	25.31×cosω'	115.91×cos(ω'+169.221)	133.05×cos(ω'+146.741)	140.14×cosω'	0.06	
		45	0.1	141.02	63.54	44.09×cosω'	126.01×cos(ω'+185.291)	166.36×cos(ω'+139.191)	181.90×cosω'	0.02	$d\geq r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_2$, $S_0<2r_\varepsilon\cos C_2$,
			0.2	109.88	65.37	34.42×cosω'	120.39×cos(ω'+182.721)	148.58×cos(ω'+142.361)	159.68×cosω'	0.04	
			0.4	85.62	69.04	15.31×cosω'	117.64×cos(ω'+166.671)	135.41×cos(ω'+147.731)	142.86×cosω'	0.02	$d\geq r_\varepsilon(1-\sin C_1)$ $2r_\varepsilon\sin C_2<S_0<2r_\varepsilon$
			0.5	79.01	70.88	12.76×cosω'	117.11×cos(ω'+162.001)	132.03×cos(ω'+149.741)	138.46×cosω'	0.04	
	1.0		0.1	161.77	61.56	83.61×cosω'	149.84×cos(ω'+180.461)	129.13×cos(ω'+138.011)	159.52×cosω'	0.06	
			0.2	118.42	64.11	58.71×cosω'	131.52×cos(ω'+188.571)	186.84×cos(ω'+140.01)	107.07×cosω'	0.02	$d\geq r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_2$, $S_0<2r_\varepsilon\cos C_2$,
			0.3	98.67	66.66	46.34×cosω'	127.39×cos(ω'+183.971)	165.85×cos(ω'+142.011)	180.95×cosω'		
			0.4	86.69	69.21	38.02×cosω'	122.91×cos(ω'+177.271)	152.08×cos(ω'+143.991)	163.72×cosω'		
		15	0.1	162.90	58.00	126.39×cosω'	175.89×cos(ω'+178.211)	197.58×cos(ω'+137.471)	244.14×cosω'		
			0.2	120.08	60.96	88.19×cosω'	152.14×cos(ω'+184.281)	133.57×cos(ω'+138.941)	164.88×cosω'		
	1.5		0.3	100.08	63.91	69.11×cosω'	140.62×cos(ω'+189.921)	101.40×cos(ω'+140.411)	124.96×cosω'	0.04	$d<r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_2$,
			0.4	88.52	66.91	56.14×cosω'	133.16×cos(ω'+184.461)	180.01×cos(ω'+141.871)	198.38×cosω'		
			0.5	80.24	69.82	45.68×cosω'	127.55×cos(ω'+179.421)	163.87×cos(ω'+143.321)	178.31×cosω'		
			0.1	162.60	62.82	132.14×cosω'	179.69×cos(ω'+177.081)	207.36×cos(ω'+137.201)	256.88×cosω'		
			0.2	114.93	65.84	86.23×cosω'	151.17×cos(ω'+182.681)	132.02×cos(ω'+138.401)	163.04×cosω'		
	2.0		0.3	93.88	68.80	63.88×cosω'	137.60×cos(ω'+186.921)	195.31×cos(ω'+139.601)	117.58×cosω'		
			0.4	81.30	71.77	49.13×cosω'	128.89×cos(ω'+188.441)	171.52×cos(ω'+140.801)	188.10×cosω'		
			0.5	72.72	74.74	37.94×cosω'	122.42×cos(ω'+184.051)	153.93×cos(ω'+141.991)	166.30×cosω'		

bit is bigger than the change of side cutting edge angle.

4. CONCLUSION

The normal force change before and after one rotation of work under the chatter vibration is analysed. And the variation of normal force change after one and two rotation of work under the chatter vibration is analysed. The result is as follows:

1. The difference of normal force change after one and two

Table 2. The relation between dP_1, dP_2 and dP_1-dP_2 normal side rake angle 5°

(b) Case of d=1.5mm

C_1 (°)	r_ε (mm)	C_2 (°)	S_0 (mm/rev)	k_{ij} (kgf/mm²)	θ (°)	dp_1 (kgf)	dp_1-dp_2 (kgf) ξ 0.1	0.9	0.3	0.7	0.5	x (mm)	
15	0.5	45	0.1	193.67	56.40	188.34×cosω'	113.55×cos(ω'+177.15°)	1296.14×cos(ω'+137.22°)	1365.97×cosω'	0.02	$d'\geq 2r_\varepsilon(1-\sin C_1)$, $S_0\leq 2r_\varepsilon\sin C_1$, $S_0<2r_\varepsilon\cos C_1$,
			0.2	141.78	58.94	132.19×cosω'	178.42×cos(ω'+182.22°)	1202.23×cos(ω'+138.44°)	1249.74×cosω'		
			0.4	103.79	64.03	88.87×cosω'	152.25×cos(ω'+188.68°)	1129.52×cos(ω'+140.73°)	1159.55×cosω'	0.02 0.04 0.06	$d'\geq 2r_\varepsilon(1-\sin C_1)$, $2r_\varepsilon\sin C_1<S_0<2r_\varepsilon$.
			0.5	93.87	66.58	76.44×cosω'	145.11×cos(ω'+184.84°)	1109.14×cos(ω'+141.77°)	1134.23×cosω'		
		30	0.1	108.81	70.08	44.66×cosω'	126.69×cos(ω'+179.59°)	169.29×cos(ω'+137.80°)	185.61×cosω'	0.02	$d'\geq 2r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_1$, $S_0<2r_\varepsilon\cos C_1$,
			0.2	92.77	71.01	37.87×cosω'	122.29×cos(ω'+186.92°)	156.51×cos(ω'+139.60°)	169.71×cosω'		
			0.4	79.10	72.87	32.68×cosω'	119.45×cos(ω'+180.90°)	145.67×cos(ω'+142.89°)	156.04×cosω'	0.02 0.04 0.06	$d'\geq 2r_\varepsilon(1-\sin C_1)$, $2r_\varepsilon\sin C_1<S_0<2r_\varepsilon$.
			0.5	75.15	73.81	31.36×cosω'	118.97×cos(ω'+176.31°)	142.71×cos(ω'+141.29°)	152.24×cosω'		
		15	0.1	141.02	63.54	52.51×cosω'	131.09×cos(ω'+183.08°)	179.97×cos(ω'+138.65°)	198.74×cosω'	0.02	$d'\geq 2r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_1$, $S_0<2r_\varepsilon\cos C_1$,
			0.2	109.88	65.37	40.55×cosω'	123.88×cos(ω'+186.61°)	158.45×cos(ω'+141.28°)	171.94×cosω'		
			0.4	85.62	69.04	31.66×cosω'	119.61×cos(ω'+171.56°)	141.93×cos(ω'+145.89°)	151.06×cosω'	0.02 0.04 0.06	$d'\geq 2r_\varepsilon(1-\sin C_1)$ $2r_\varepsilon\sin C_1<S_0<2r_\varepsilon$.
			0.5	79.01	70.88	29.17×cosω'	118.66×cos(ω'+166.74°)	137.51×cos(ω'+147.70°)	145.40×cosω'		
15	1.0	45	0.1	161.77	61.56	99.58×cosω'	156.15×cos(ω'+179.50°)	1145.83×cos(ω'+137.78°)	1180.16×cosω'		$d'\geq 2r_\varepsilon(1-\sin C_1)$ $S_0\leq 2r_\varepsilon\sin C_1$, $S_0<2r_\varepsilon\cos C_1$,
			0.2	118.42	64.11	65.64×cosω'	138.64×cos(ω'+186.75°)	198.02×cos(ω'+139.56°)	120.93×cosω'		
			0.3	98.67	66.66	51.58×cosω'	130.38×cos(ω'+186.46°)	174.29×cos(ω'+141.33°)	191.43×cosω'	0.02	
			0.4	86.69	69.21	42.14×cosω'	125.13×cos(ω'+178.69°)	158.67×cos(ω'+143.08°)	171.97×cosω'		
		15	0.1	162.90	58.00	138.36×cosω'	183.25×cos(ω'+177.66°)	1216.94×cos(ω'+137.34°)	1268.09×cosω'	0.04	
			0.2	120.08	60.96	96.36×cosω'	157.04×cos(ω'+183.21°)	1146.64×cos(ω'+138.68°)	1181.06×cosω'		
	1.5		0.3	100.08	63.91	75.24×cosω'	144.24×cos(ω'+188.56°)	1111.28×cos(ω'+140.01°)	1137.22×cosω'		
			0.4	88.52	66.91	60.97×cosω'	135.71×cos(ω'+186.38°)	187.78×cos(ω'+141.35°)	1108.03×cosω'		
			0.5	80.24	69.82	49.92×cosω'	129.65×cos(ω'+181.64°)	170.04×cos(ω'+142.67°)	185.99×cosω'		
		45	0.1	162.60	62.82	147.31×cosω'	189.03×cos(ω'+176.54°)	1232.39×cos(ω'+137.08°)	1287.20×cosω'		
			0.2	114.93	65.84	95.85×cosω'	157.04×cos(ω'+181.03°)	1147.58×cos(ω'+138.15°)	1182.29×cosω'		
	2.0		0.3	93.88	68.80	70.82×cosω'	141.76×cos(ω'+185.41°)	1106.52×cos(ω'+139.22°)	1131.46×cosω'		
			0.4	81.30	71.77	54.33×cosω'	131.94×cos(ω'+189.63°)	179.91×cos(ω'+140.29°)	198.50×cosω'		
			0.5	72.72	74.74	41.85×cosω'	124.65×cos(ω'+186.33°)	160.24×cos(ω'+141.36°)	170.13×cosω'		

rotation of work under the chatter vibration causes larger approach to 0.5 from 0.1 and diminishes to 0.9 from 0.5 in the fraction.

2. The difference of normal force change after one and two rotation of work under the chatter vibration diminishes as increasing of feed.
3. The difference of normal force change after one and two rotation of work under the chatter vibration is influenced

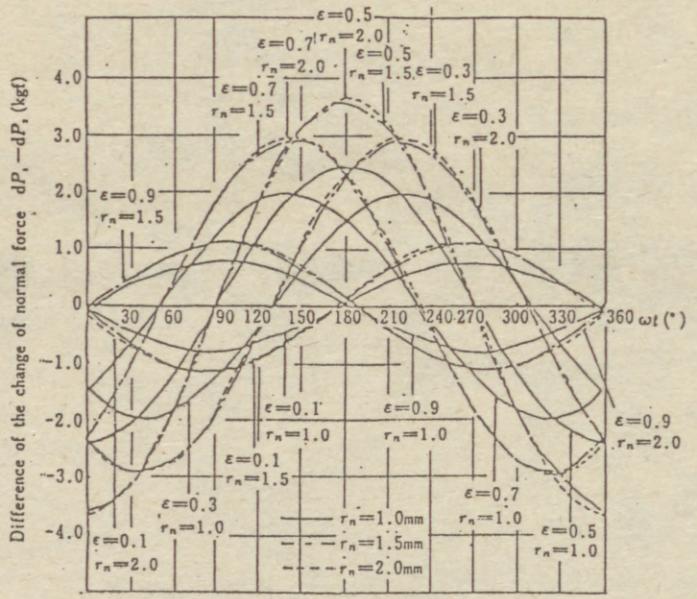


Fig. 2. The changes of $dP_t - dP_r$ under the condition of chatter vibration by the nose radius.
($Ce=15°$, $Cs=15°$, $d=1.5mm$, $S_o=0.2mm/rev$, $x=0.02mm$ constant)
($d \geq r_n(1-\sin Cs)$, $S_o \leq 2r_n \sin Ce$, $S_o < 2r_n \cos Cs$)

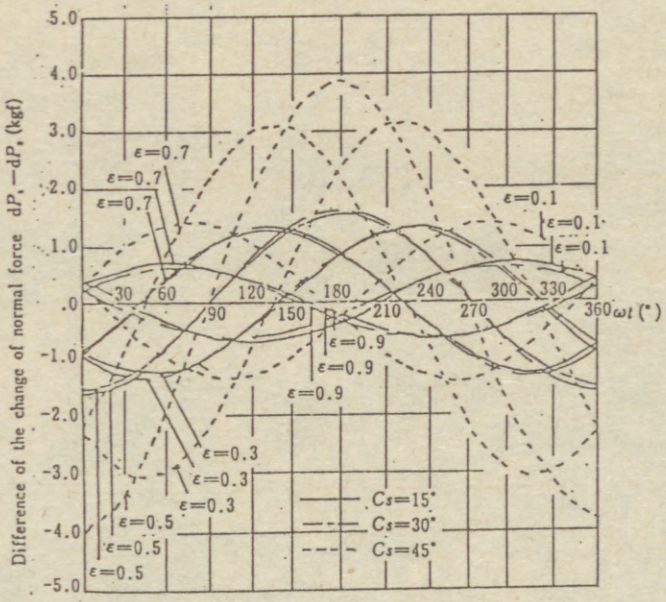


Fig. 1. The changes of $dP_t - dP_r$ under the condition of chatter vibration by the side cutting edge angle.
($Ce=15°$, $r_n=0.5mm$, $d=1.0mm$, $S_o=0.5mm/rev$, $x=0.04mm$ constant)
($d \geq r_n(1-\sin Cs)$, $2r_n \sin Ce < S_o < 2r_n$)

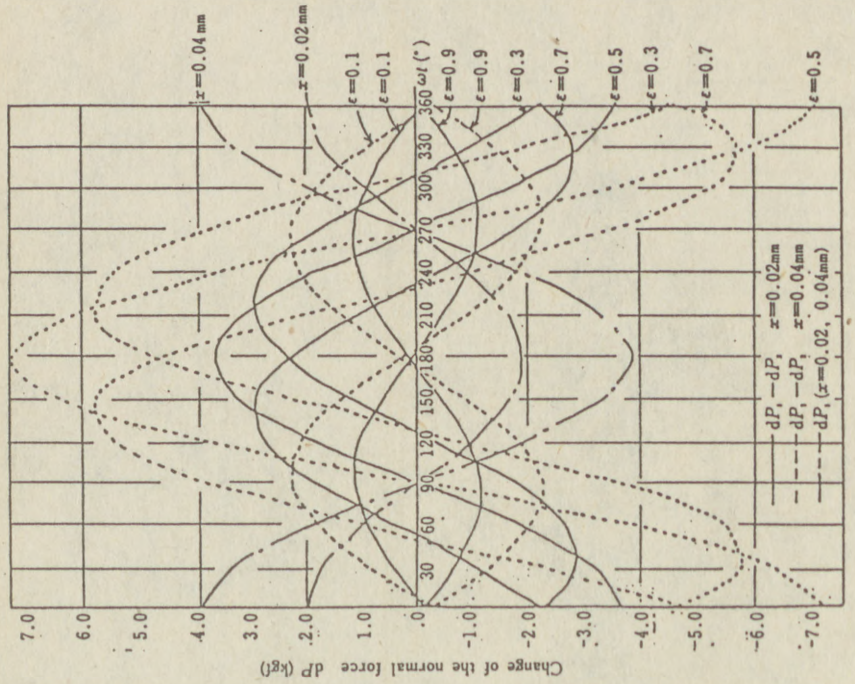


Fig. 3. The changes of normal force under the condition of chatter vibration. (dP_1, dP_2, dP_3)
(C_e=15°, C_s=15°, r_n=1.5mm, d=1.5mm, S_1=0.2mm/rev)
($d \geq r_n(1-\sin C_s)$, $S_1 \leq 2r_n \sin C_e$, $S_1 < 2r_n \cos C_s$)

by the size of bit. The more side cutting edge angle and nose radius increase, the more the difference of normal force change increases. The influence of difference of normal force change by the change of nose radius of bit is bigger than the change of side cutting edge angle.

ACKNOWLEDGEMENT

The author is indebted to Prof. Y. Kume at Osaka Prefecture University.

REFERENCE

Y. Iwata, A Study of Stabilizing Threshold in Lathe Turning Chatter, Proceeding of IXth International Conference on Production Research, 1987, pp 788-794
Y. Iwata, A Study of Cutting Area Change under the Chatter Vibration in Lathe Turning, Proceeding of Xth International Conference on Production Research, 1989, pp 238-239

RESEARCH ON FAST ALGORITHMS OF SURFACE MODELLING AND TECHNIQUES OF SOFTWARE REALIZATION

Jiafu Bao Yimin Deng
Department of Precision Machinery and Instrumentation
University of Science and Technology of China
Hefei, Anhui
People's Republic of China

ABSTRACT

Surface modelling and its research work has always been a popular and key subject in Computer Aided Design (CAD). In the past, it could be carried out only by middle or large computers. But nowadays, people tend to do this work by microcomputers.

This paper puts forward a series of fast algorithms of surface modelling worked on microcomputers and also the techniques of software realization. With the help of B-Spline theories, the paper gives the methods of how to produce the smooth link between surface patches and how to acquire control points from the original data points. Also, the paper makes deep inquires into the fast drawing of 3D surface when under shape control. At the end of the paper, a micro system of surface modelling realized on micro-computers is proposed.

1. Introduction to surface modelling

Curved surfaces are widely existed in engineering field. The irregularity of its shape makes the designing and manufacturing work very difficult. The traditional method for the design of the surface is what we call "Curves Description". By this method, a series of parallel planes are used to cut the surface, and the intersections, surely curves, are used to describe the surface. It is quite clear to see the disadvantages of this method, for instance, difficulty in description of designer's idea, long period of design process, and low efficiency when the surface is with complicated shape or when the design precision is highly demanded.

With the development of many applied mathematics, such as Theory of Functional Approximation, Topology, Algebraic Geometry, Computational Geometry, Theory of Splines, and so on, "Curves Description" is gradually being repalced with more rational and more accurate method, which is based on many algorithms, for examples, algorithm of Coons Surface, Bezier Surface, B-Spline Surface, etc. With this new method, surfaces could be described and represented by surface equations. Besides this, computers are widely used

in this method, for the reason of the rapid development of computer science. This new method is just what we call "Surface Modelling". Thus we can see that surface modelling is based on mathematical algorithms and supported by computer hardware and software.

However, as vast quantity of data have to be dealt with during surface modelling, especially during dynamic modelling, it is generally required that computers should be with high speed of computation and large amount of memory space. In the past, it was only by middle or large computers could the modelling and its research work be carried out. But nowadays, people pay much attention to the work by microcomputers. For this reason, it is quite imperative to choose and develop fast algorithms, so as to save the computational time. This paper is just aiming at the research of this theme.

2. Fast algorithms on surface modelling

There are several algorithms used in surface modelling, for example, algorithm of Coons Surface, Bezier Surface, and B-Spline Surface. Coons algorithm is simpler, but it has disadvantages when used in shape control. The main one is that there is no obvious and direct relation between change of control points and change of the surface. Comparatively, Bezier algorithm and B-Spline algorithm are better and are widely used in engineering field. In this paper we choose the latter, the reason for it are as follows:

(1) In Bezier algorithm, the side number of control polygon equals to the order number of Bernstein polynomial, while in B-Spline algorithm, the side number of control polygon has no relation with the order number of B-spline basic functions. Thus, if we use the latter, the order number of surface descriptive equation could be stable when the surface is getting complicated, so that the computational time could be stable, too.

(2) Bezier algorithm uses the entire approximation, while B-Spline algorithm uses the partial approximation, that is to say, when one control point is changed, only part of the surface changes correspondingly. This merit makes the design very convenient.

Using the general B-Spline algorithm[1], we can gain B-Spline surface in any rank number. But when the rank number gets higher, the order number of the surface equation gets higher, too. Besides, the B-Spline basic functions are very complex. These all limit the computational speed. We choose the uniform 3-order (4-rank) B-Spline algorithm. In fact, this simple algorithm can meet the need of almost any kinds of engineering surface modelling.

Usually, the entire surface is divided into many patches. The surface equations are just used to represent these patches. For 3-order B-Spline surface patches, we rearranged the original equations[3] to the following style:

$$P_{i,j}(u,w)=\frac{1}{36}\begin{bmatrix}-u^3+3u^2-3u+1\\ 3u^3-6u^2+4\\ -3u^3+3u^2+3u+1\\ u^3\end{bmatrix}^T\begin{bmatrix}V_{ij} & V_{i,j+1} & V_{i,j+2} & V_{i,j+3}\\ V_{i+1,j} & V_{i+1,j+1} & V_{i+1,j+2} & V_{i+1,j+3}\\ V_{i+2,j} & V_{i+2,j+1} & V_{i+2,j+2} & V_{i+2,j+3}\\ V_{i+3,j} & V_{i+3,j+1} & V_{i+3,j+2} & V_{i+3,j+3}\end{bmatrix}\begin{bmatrix}-w^3+3w^2-3w+1\\ 3w^3-6w^2+4\\ -3w^3+3w^2+3w+1\\ w^3\end{bmatrix} \quad \langle 1\rangle$$

where, $0\le u\le 1$, $0\le w\le 1$;

$V_{i,j}$ ($i=0,1,2,\ldots,n+1$; $j=0,1,2,\ldots,m+1$) are control points, they form the control polygon with the side number of n+1 and m+1.

We can see that there are (n-2)(m-2) patches. The smooth link between the adjacent patches gets to C^2 continutity. With these rearranged equations, the computational steps are reduced quite considerably, and the computational speed is raised correspondingly.

3. How to acquire control points from the original data points

During the actual surface modelling, the control points are usually gained from the original data points. This gives rise to the question of how to acquire them.

Now let's assume the original data points be $D_{i,j}$ ($i=1,2,\ldots,n$; $j=1,2,\ldots,m$), then the relevant control points should be $V_{i,j}$ with $i=0,1,\ldots,n+1$ and $j=0,1,\ldots,m+1$.

We use a simple and fast algorithm to calculate $V_{i,j}$:

Step 1: Calculating control points in w direction, assuming them be $Q_{i,j}$ ($i=1,2,\ldots,n$; $j=0,1,\ldots,m+1$);

Step 2: Calculating $V_{i,j}$ from $Q_{i,j}$ in u direction.

The side conditions (see Fig.1) can be calculated as follows (Here we use Coons signs):

$$\begin{cases} i|_w=(i_2-i_1)*f\\ im_w=(im-i_{(m-1)})*f \end{cases}\quad (i=1,2,\cdots,n) \qquad \langle 2\rangle$$

$$\begin{cases} 1j_u=(2_j-1_j)*f\\ nj_u=(n_j-(n-1)_j)*f \end{cases}\quad (j=1,2,\cdots,m) \qquad \langle 3\rangle$$

$$\begin{cases} 11_{uw}=[(12_u-11_u)+(21_w-11_w)]/2\\ n1_{uw}=[(n2_u-n1_u)+(n1_w-(n-1)1_w)]/2\\ 1m_{uw}=[(1m_u-1_{(m-1)u})+(2m_w-1m_w)]/2\\ nm_{uw}=[(nm_u-n_{(m-1)u})+(nm_w-(n-1)m_w)]/2 \end{cases} \qquad \langle 4\rangle$$

where f is magnitude factor (f>0).

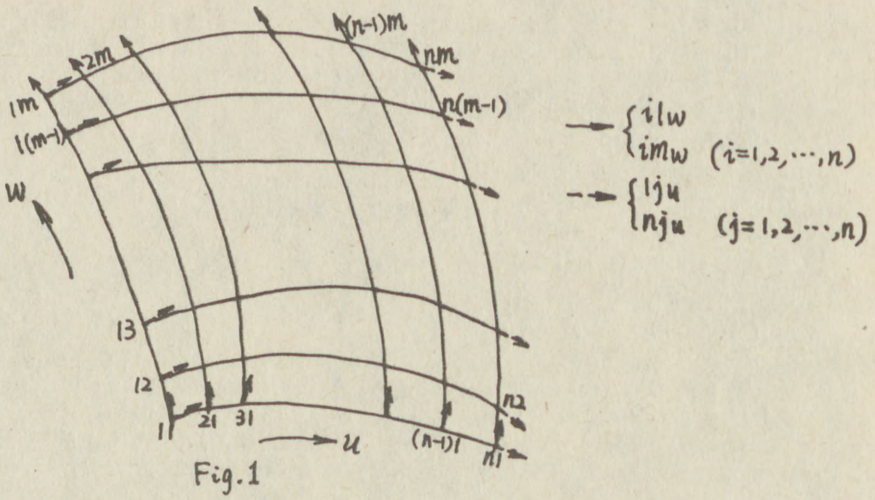


Fig.1

In step 1, we can use the above side conditions il_W and im_W $(i=1,2,\ldots,n)$ directly. Yet in step 2, as the data points now is $Q_{i,j}$ instead of $D_{i,j}$, we have to calculate the new side conditions.

According to theories of 3-order B-Spline algorithm, the new side conditions should be,

$$\begin{matrix}(V_{20}-V_{00})/2 \\ (V_{21}-V_{01})/2 \\ \vdots \\ (V_{2,m+1}-V_{0,m+1})/2\end{matrix} \quad \text{and} \quad \begin{matrix}(V_{n+1,0}-V_{n-1,0})/2 \\ (V_{n+1,1}-V_{n-1,1})/2 \\ \vdots \\ (V_{n+1,m+1}-V_{n-1,m+1})/2\end{matrix}$$

From Equ.<1>, we have,

$$1l_u=\tfrac{1}{12}[(V_{20}-V_{00})+4(V_{21}-V_{01})+(V_{22}-V_{02})]$$

$$12_u=\tfrac{1}{12}[(V_{21}-V_{01})+4(V_{22}-V_{02})+(V_{23}-V_{03})]$$

$$\vdots$$

$$1m_u=\tfrac{1}{12}[(V_{2,m-1}-V_{0,m-1})+4(V_{2,m}-V_{0,m})+(V_{2,m+1}-V_{0,m+1})]$$

Still,

$$1l_{uw}=\tfrac{1}{4}[(V_{22}-V_{02})-(V_{20}-V_{00})]$$

$$1m_{uw}=\tfrac{1}{4}[(V_{2,m+1}-V_{0,m+1})-(V_{2,m-1}-V_{0,m-1})]$$

Thus, we can get,

$$\begin{bmatrix} 1 & 2 & & & & \\ 1 & 4 & 1 & & & \\ & 1 & 4 & 1 & & \\ & & \ddots & \ddots & \ddots & \\ & & & 1 & 4 & 1 \\ & & & & 2 & 1 \end{bmatrix} \begin{bmatrix} (V_{20}-V_{00})/2 \\ (V_{21}-V_{01})/2 \\ (V_{22}-V_{02})/2 \\ \vdots \\ (V_{2,m}-V_{0,m})/2 \\ (V_{2,m+1}-V_{0,m+1})/2 \end{bmatrix} = 6 \begin{bmatrix} 1l_u/2-1l_{uw}/6 \\ 1l_u \\ 12_u \\ \vdots \\ 1m_u \\ 1m_u/2+1m_{uw}/6 \end{bmatrix} \qquad \langle 5 \rangle$$

Similarly, we have,

$$\begin{bmatrix} 1 & 2 & & & \\ 1 & 4 & 1 & & \\ & 1 & 4 & 1 & \\ & & \ddots & \ddots & \ddots \\ & & & 1 & 4 & 1 \\ & & & & 2 & 1 \end{bmatrix} \begin{bmatrix} (V_{n+1,0}-V_{n-1,0})/2 \\ (V_{n+1,1}-V_{n-1,1})/2 \\ (V_{n+1,2}-V_{n-1,2})/2 \\ \vdots \\ (V_{n+1,m}-V_{n-1,m})/2 \\ (V_{n+1,m+1}-V_{n-1,m+1})/2 \end{bmatrix} = 6 \begin{bmatrix} n_{1u}/2-n_{1uuw}/6 \\ n_{1u} \\ n_{2u} \\ \vdots \\ n_{mu} \\ n_{mu}/2+n_{muuw}/6 \end{bmatrix} \quad \langle 6 \rangle$$

Until now, the new side conditions are gained, and V (i=0,1,...,n; j=0,1,...,m) can easily be acquired.

4. Fast drawing of 3D surface when under shape control

All the above algorithms, simple and fast, make it possible that surface modelling and its research work be carried out by microcomputers. Yet, there are still lots of particular problems over the software realization. Here we give some techniques of fast drawing of 3D surface, especially when under shape control.

(1) Method of convertion from 3D to 2D

We assume the observing distance be "r", observing angle be "θ" and "φ" (see Fig.2), then we can use a subprogram to initialize the following variables:

```
s1=sin θ
c1=cos θ
s2=sin φ
c2=cos φ          <7>
s3=c1*s2
s4=s1*s2
s5=c1*c2
s6=s1*c2
```

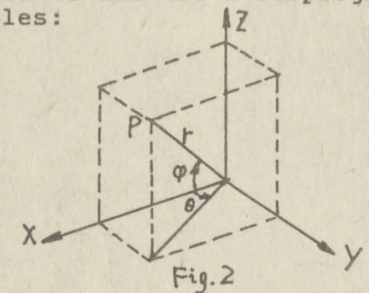


Fig.2

With these initial values, we can make the convertion from 3D to 2D with ease, and the computational steps can be reduced to the limit. Thus the running speed is raised.

(2) Method of convertion from 2D to screen coordinates

Suppose the CRT display be raster scanner, and its resolution be 640X200, then the screen coordinates varies from (0,0) to (639,199). The above 2D coordinates should be converted to the screen coordinates.

```
Aim:  (xmin,ymin) ---> (5,195)
      (xmax,ymax) ---> (635,5)
```

Assuming the converting factor be "d" and the screen Vertical-Horizontal adjust factor be "hv", then we have the brief steps of convertion as follows:

```
Step 1:  d1=630/(xmax-xmin)
         d2=190/hv/(ymax-ymin)
         d=min(d1,d2)
Step 2:  xm=(xmin+xmax)/2
         ym=(ymin+ymax)/2
Step 3:  tx=320+int[(x-xm)*d]
         ty=100-int[(y-ym)*d*hv]
```

As for the need of fast convertion, we can put Step 1 and Step 2 to one subprogram. Afterwards, whenever we need convertion, just run Step 3. This method saves the computational time and also simplify the programs.

(3) Creation of subprogram of fast line-drawing

The surface is displayed by means of network of curves at the end of the modelling. This relates to the question of line-drawing, besides, there may be a great amount of lines to be drawn. Thus, we have to consider the drawing speed of these lines.

In the normally used method of line-drawing, the pixels the line passes are calculated first, then DOS interruption "int 10h" is called for each pixel. This method simplify the subprogram, but the running speed is low.

Here we develop a new method which avoids calling of DOS interruption and manipultes the display memory directly. The followings are the brief steps of it:

Step 1: Using Brensenham algorithm[5] to calculate the relative coordinates of the pixels the line passes (supposing these points be 0,1,2,..., n), that is to say,
Assuming Point 0 be (0,0),
Then Point 1 be (X10,Y10),
Point 2 be (X21,Y21),
:
:
Point n be (Xn,n-1,Yn,n-1);

Step 2: Calculating the related memory address of Point 0;

Step 3: From (X10,Y10), (X21,Y21), ... , (Xn,n-1, Yn,n-1), getting the memory address of Point 1,2,...,n.

Step 4: Settimg values (all "1" when under monochrome status) to the calculated memory address.

With this method, we avoid calculation of the memory address from the absolute coordinates of each pixel. This saves the runing time.

5. A micro system of surface modelling

In using of the above algorithms, we've developed a micro surface modelling system run on microcomputers. The followings are its working environment:

. CPU INTEL 8088 (with 8087 coprocessor);
. Memory Space 640KB;
. Speed 4.77KIPS;
. Raster Dipslay Resolution 640X200;
. Operating Syetem DOS;
. Programming Language Microsoft C4.0 and MASM4.0;
. Drafting Software Package AutoCAD2.6.

Fig.3 shows the brief schematic diagram of the system.

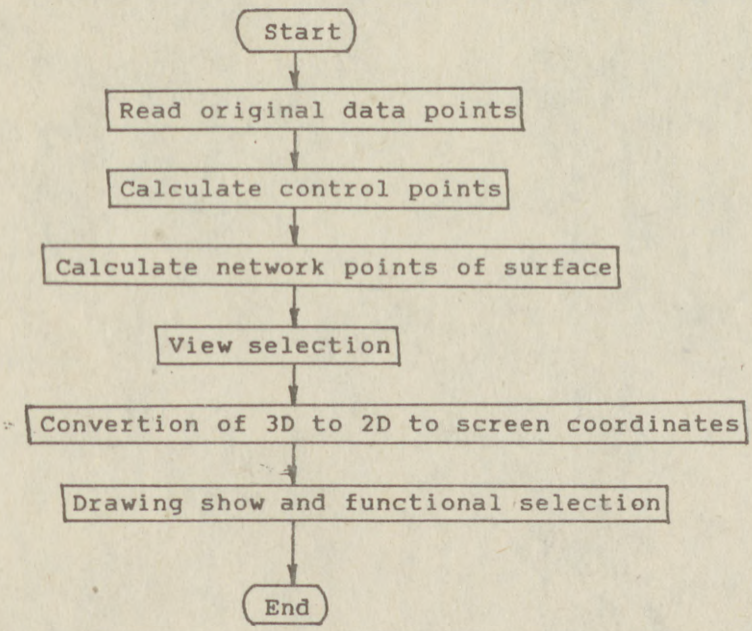


Fig.3

The functional selection menu oriented to user are as follows:

. ENTER Go on to show next drawing;
. ESC Go back to show the previous drawing;
. TAB Redraw the current drawing;
. Alt-H Show functional selection menu (see Fig.4);
. Alt-Q Exit the system;
. Alt-S Slow down drawing speed in order to see the process;

. Alt-R Rotate the current drawing;
. Alt-L Restore the drawing before last rotation by Alt-R;
. Alt-O Turn on/off the signs of original data points and control points;
. Alt-A Interface with drafting package AutoCAD;
. Alt-V Change control points so as to change the surface (shape control);
. Alt-L Restore the drawing before last change of the surface by Alt-V;
. Alt-C Cut the surface by planes to get the curves of the intersections.

Fig.4 shows the network of original data points and functional selection menu. Fig.5 shows the network of surface when under rotation.

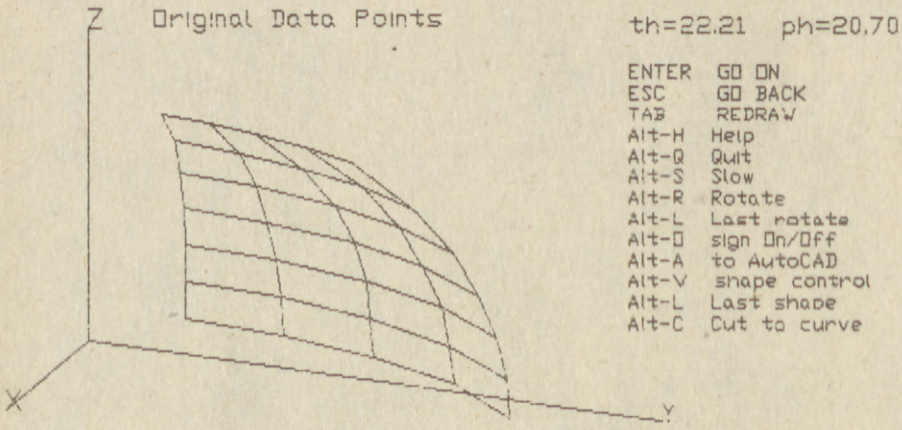


Fig.4

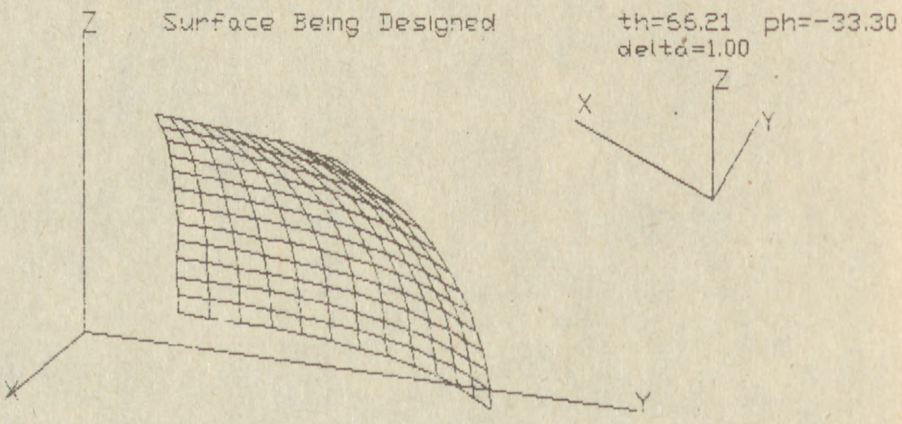


Fig.5

(1) When under rotation ("Alt-R" to enter), we defined the following functional keys oriented to user,

. Left decreasing of θ (observing angle);
. Right increasing of θ ;
. Up increasing of φ (observing angle);
. Down decreasing of φ ;
. PageUp increasing of increment of θ and φ (delta);
. PageDown decreasing of increment of θ and φ ;
. ENTER approving of rotation;
. ESC cancelling of rotation.

It is not possible to drag the surface with the change of observing parameters (θ,φ), because of the speed limit of microcomputers. Thus we set small coordinates axes on the right of the screen and let them be dragged (see Fig.5). This technique allow us to see the effect of rotation without change of the entire surface. Once we are satisfied with the effect, just press ENTER key, the result will be given, that is to say, the entire surface will be rotated.

(2) When under shape control (Alt-V to enter), the normally used method is, exitting the system, revising the original data points, and then re-running the system. This method is not only inefficient, but also static. Here we give a dynamic control method. When "Alt-V" key be pressed, a crossing cursor will be shown on the screen. The user can move this cursor by means of functional keys (We omitted the description of them) to select and pick any of the control points. After that, the selected point can be changed by user, and the surface will be changed correspondingly. This method allow user to change (or design) the surface interactively.

6. Conclusion

Due to the rapid development of computer science, many kinds of microcomputers with higher speed and larger memory have been put to use. This gives us the possibility to do research work of surface modelling by microcomputers. Under this situation, it is imperative to choose and develop efficient and fast algorithms. Our work is just for this purpose. We strongly hope that new, faster algorithms will continuously be developed.

REFERENCE

[1] B-Spline Curves and Surfaces, W.J.Gordon and R.F. Riesenfield, Computer Aided Geometric Design, 1974, 95-126

[2] 计算机辅助几何设计，俞伐高，上海交通大学出版社，1986

[3] 计算机辅助几何设计，胡瑞安，华中工学院出版社，1986

[4] 计算几何，苏步青、刘鼎元，上海科学技术出版社，1980

[5] 计算机图形学，孙家广、许隆文，清华大学出版社，1986

[6] Surface patches and B-Spline Curves, S.A.Coons, Computer Aided Geometric Design, 1974, 1-16

RESEARCH ON A NEW ON-LINE DYNAMIC MEASURING DEVICE

JIN Taiyi,LI Shengli,GE Yun,
XU Yu,CHENG Feng,LI Ming
(University of Science and
Technology of China)
(The People's Republic of China)

A simple and effective non-contact method of on-line measuring dynamic displacement or thickness of moving workpiece is presented in this paper.The measuring device,which called "ZCH-1 Vibration Thickness Measurement",was developed in our laboratory recently,and is the first one of such kind instrument in China.A new type of Position Sensitive Detector (PSD) is used as the transducer and IC 8031 as CPU.

The main characteristics of this device are listed as follows:

Working Temperature: 0-60°C
Measuring Range: Amplitude -1.000 to +1.000 mm
Variation of thickness --
-2.000 to +2.000mm
Thickness 0 to 96 mm
Resolution : 1 micron
Repeatability : 2 micron
Dynamic Response : 500 Hz
Data Acquisition
Frequency : 6 KHz

This device may be applied to many industrial fields,such as:metal cutting,paper-making,steel mill etc.,for remote measuring soft or hot workpieces.

Key word:optical measurement,on-line measurement,laser diode,optical triangular principle

1. Introduction

With the development of science and technology,modern measurement methods and instruments have been greatly improved.The modernization and automation in the industrial production have supplied wide applied places for the on-line measuring technology.For example,on the modern rolled-steel production line controlled by computers,the optoelectric on-line measuring technology is adopted.The dimensional tolerance of the profile is measured real time,the rolling equipment is adjusted and controlled.This not only secures the successful and continuous process of the production,but also is important to improve the production,

quality,productivity and the economic gain.For another example,the deformation and damage of the key components (components with heavy load) in the large working mechanism which is in the process of operation,need monitoring.In this case,to prevent the mechanical failure,the on-line measuring method can be used to predict and indicate the faults and failure.

In a word,the on-line measurement is progressing fast with the development of science and technology,and has got much attention from the reseachers of many countries.In China,the academic society of on-line measurement has been set up and the academic conferences have been held.The on-line measurement presents not only the real time data for experiments and the production,but also the intelligent judgement and decision.To keep pace with the latest development of technology,the "Optoelectric Technology Laboratory " in the University of Science and Technology of China has designed a novel on-line measurement instrument.

2. Structure and Principle of the Instrument

The structure of the instrument is shown in Fig.1.

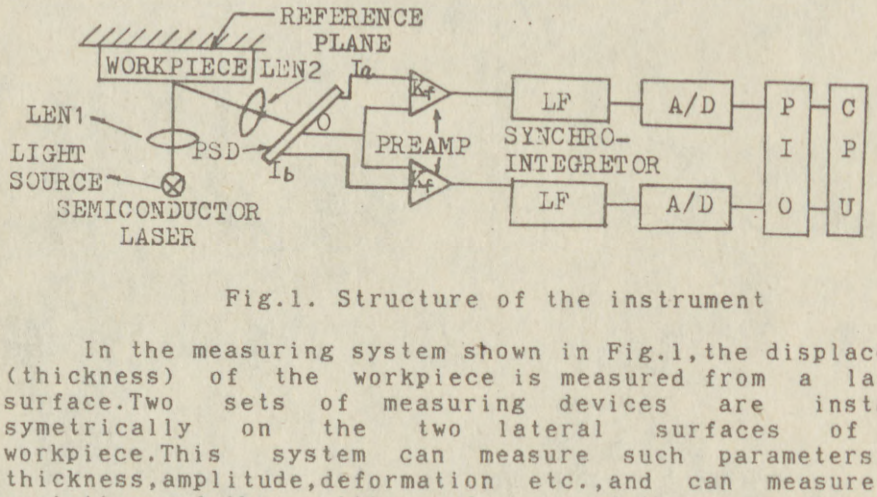


Fig.1. Structure of the instrument

In the measuring system shown in Fig.1,the displacement (thickness) of the workpiece is measured from a lateral surface.Two sets of measuring devices are installed symetrically on the two lateral surfaces of the workpiece.This system can measure such parameters as thickness,amplitude,deformation etc.,and can measure the variations of the position and shape of the measured body.So it is suitable for measuring the hot body (i.e. steel),soft body(i.e. paper) and it can compensate the defects of other methods.

To get stable light source (namely,stable wave length,phase and intensity) and increase the measurement resolution,a semiconductor laser is adopted as the light source in this instrument.An approximately infrared light of deterministic wave length is emitted from the semiconductor laser which is drived by special power supply.Then the beam

of light is focused by LEN 1 and is incident on the measured body.The reflected light is focused by LEN 2 and is incident on the photosensitive surface of the Position Sensitive Detector (PSD).Converted by PSD,the photoproduced currents I_a ,I_b are generated at the output.The use of the preamplifier is to amply the weak currents (about 100 uA) and convert them to voltages.The use of the synchro-integretor is to eliminated the noise and disturbance components from the signals,and to increase the signal-to-noise ratio.The analogue to digital converter with 12-bit resolution can convert the analogue signal to digital signal in high accuracy.As the unit of data processing and the control center,the single-chip computer 8031 performs to process data,transmit the output signals and display.The output signals may be sent to the main control center in order to compare,adjust and control the production process and to process the production in high accuracy.

3.The Characteristics of the Optoelectric PSD and Its Operating Principle

The semiconductor optoelectric Position Sensitive Detector (PSD) is an optoelectric composite device,its main characteristics are listed as follows[1] :

(1).As shown in the spectral response characteristics of PSD,it is in the highest sensitivity (0.6) when the wave length of the incident light is approximately 900 nm,and the sensitivity is constant to temperature when the wave length of the incident light is smaller than 950 nm.

(2).Fast Response.

The equivalent time constant of PSD is = R C (R : the output resistance of the equivalent circuit; C :the junction capacitance),and the junction capacitance decreases when the reverse bias voltage decreases.The reverse bias voltage is determined as 10 V to get response time of 4 to 5 microseconds.

(3).The linearity of the measured displacement is ± 1 % in the one-third range of the illuminated surface.

(4).The high position resolution is about 0.2 um.

(5).The output signal varies only with the gravity center of the light point.

The operating principle of PSD is shown in Fig.2 :

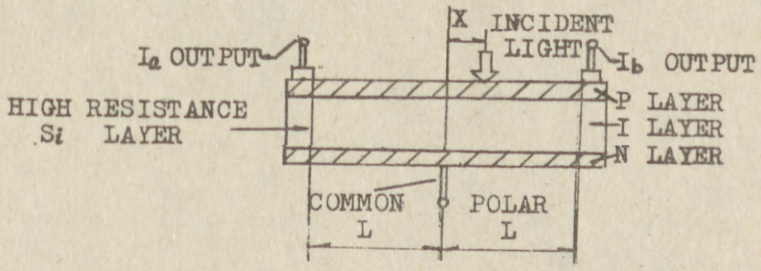


Fig.2 Diagram of PSD's Structure

When light is incident on the different position of the PSD's photosensitive surface, the PSD's output has different I_a, I_b. If the resistance of the PSD's resistance layer is consistent everywhere, then I_a, I_b are in inverse proportion to the displacement from the incident point to the output polar. Therefore, we have the equations :

$$I_a = I_0(L-x)/2L \qquad (1)$$

$$I_b = I_0(L+x)/2L \qquad (2)$$

Where I_0 represents the overall photoproduced current (namely, $I_0 = I_a + I_b$), I_a and I_b represent the output currents, and L represents the length from the electrical zero-point of PSD to its two polars.

From Eq.(1) and Eq.(2), it follows that :

$$(I_a - I_b)/(I_a + I_b) = x/L \qquad (3)$$

The right of Eq.(3) is the operating factor of the output current, and it is in linear relationship to the zero-point position x. When the value of $(I_a - I_b) / (I_a + I_b)$ is measured, the light-point position is determined. By calibration, the displacement, thickness and amplitude of the workpiece can be displayed.

Eq.(3) is the theoretical fundament to determine the diagram of the operating principle of this measurement system (shown in Fig.1).

4. Analysis of Signal Transmission and Processing Circuits

The light signal is emitted from the semiconductor laser which is drived by the square wave with the frequency of 4K Hertz. So the output light signal is the pulse light of 4K Hertz. After it is reflected, it is incident on the photosensitive surface of PSD, then the photoproduced current signals I_a, I_b (about 100 uA) are generated at the output at the same frequency from the two polars of PSD. It is an important technology of the transmission and processing of the weak signals. On one hand, the signal is amplified at deterministic power without distortion; On the other hand, the disturbance to the measuring signals should be eliminated to increase the measuring resolution and dynamic performance of this measurement system. So it is necessary to give further analysis for the problems such as the preamplifier and synchro-integretor circuit, A/D conversion etc. .

(1). The Preamplifier and Synchro-integretor Circuit

To facilitate the transmission and processing of the weak signals I_a, I_b from PSD, the current to voltage conversion and amplifier circuit is designed behind the PSD. Its principle is shown in Fig.3. Because the signals I_a, I_b are produced simultaneously, and both of them determine the light point position. It is necessary to design two-channel circuits which are consistent in parameters, and then the two-channel signals can be amplified at the same power without distortion.

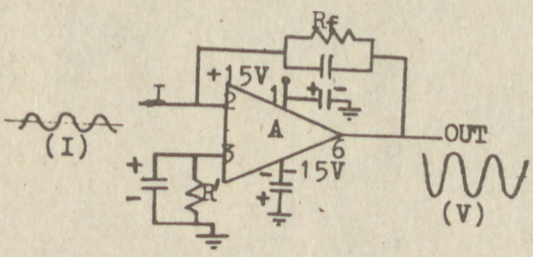


Fig.3. I/V preamplifier

The amplified signals have both the periodic component x(t) of L_a, L_b and the disturbance component a(t) due to background light, heterogeneous light, dark current of PSD and noise etc. .If the disturbance signals were not eliminated (shown in Fig.4(b)), the measuring signals would be disturbed greatly and the work of sequent signal processing couldn't be processed. Therefore, the synchro-integretor and correlation[2] processing circuits are installed behind the preamplifier. Then the measured periodic signal x(t) is reserved, and the random disturbance signal a(t) is eliminated. The operating principle is shown in Fig.4(c) and Fig.4(d).

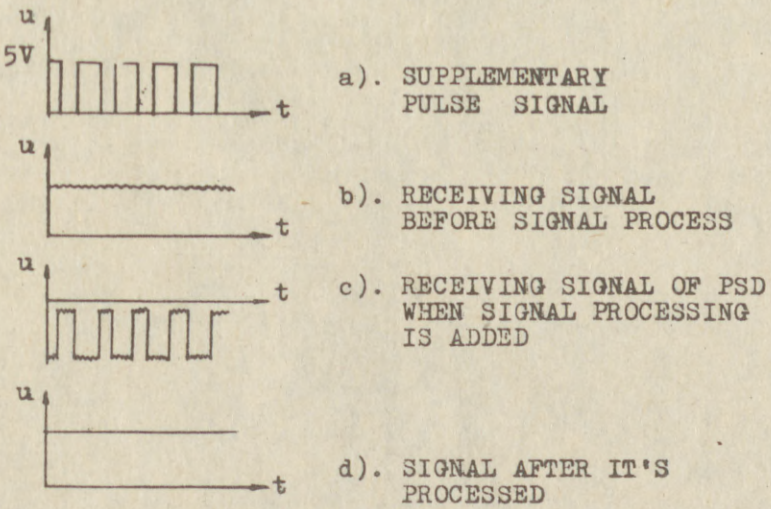


Fig.4. Results of Signal Processing

(2). Some Problems About A/D Conversion

In order to increase the resolution and speed of the data processing system, a 12-bit A/D converter (AD1211) is adopted in this measurement system. It is a successive approximation A/D converter with low power consumption and medium conversion speed. When this converter is working, the external reference voltage and clock are needed. The block diagram of this circuit is shown in Fig.5.

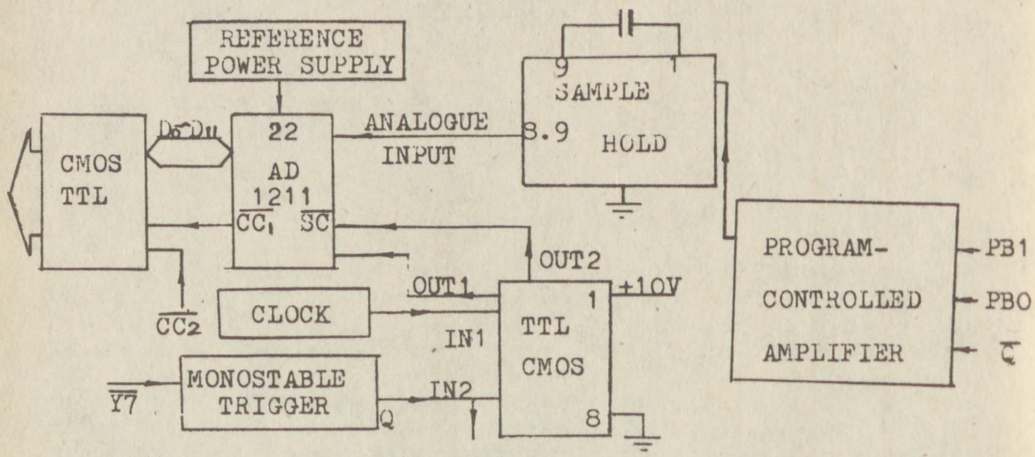


Fig.5 Block Diagram of the A/D Conversion Principle

The high-resolution and high-stability reference voltage is supplied by the specially designed reference power supply,and the diagram of the circuit is shown in Fig.6.The high-stability,low temperature drift and low-noise components should be selected for this circuit.The capacitors with the value of 100p,0.3u,4.7u are adopted at the output of this circuit to eliminate all the alternating current components and the disturbance components.Then the standard reference voltage (10.2395V) is got and transmitted to AD1211.

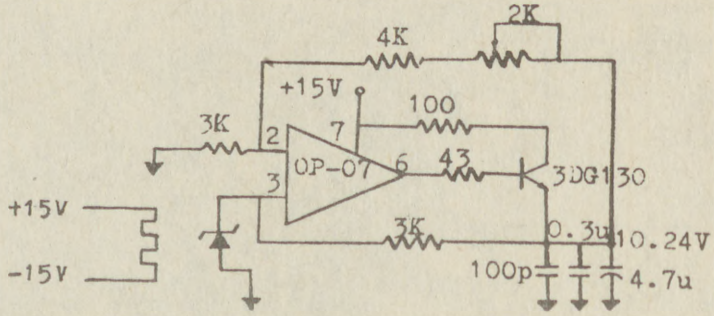


Fig.6 Diagram of the Reference Power Supply

When the A/D conversion circuit is adjusted,attention should be paid to the problems as follows :

[1].All the power supplies to the analogue components should be added with filtering capacitors in order to eliminate disturbance.

[2].The digital ground and the ananlogue ground should be exactly discriminated,namely,all the analogue grounds are connected together,and all the digital grounds are connected together,then the digital ground and the analogue ground are connected at an appreciate point.

[3].All the components should be exactly selected to ensure high stability and high resolution.To the dual-signal circuit,components with approximately equal parameters should be selected to get the same power,non-error amplification and transmission.

[4].Low temperature drift,low-noise amplifier is selected to get stable amplification.

[5].All the signal transmission lines should be shielded to prevent disturbance.

[6].High stability is required to the reference voltage with no alternating components.

5.Measurement and Calibration

Only some functions and results of the resolution calibration are introduced in the following text due to the many functions of this instrument.

(1). Data Acquisition and Processing Speed

The data acquisition speed is defined as the reciprocal of the time to acquire one-point data.To our converter,the time including the initiating pulse time,conversion time and holding time is about 160 us.The acquisition speed is therefore more than 6KHz.

Data acquisition and processing speed :The sum of the data acquisition time and processing time.To our system,it may attain to 3KHz which is proved by the practical measurement.

(2). Operating Frequency of the Instrument

The modulation frequency used in the sychro-integretor is 4K Hz.The cut-off frequency of the low-pass modem is 500 Hz,which limits the operating frequency of the instrument.If the modulation frequency is increased to 30K Hz,the operating frequency can be increased to 3K Hz and can meet the requirements for the measurement of wider frequency range.

(3). Calibration of Thickness Measurement

The comparison stardard is the 0-grade gage block with thickness of δ_1= 1.000mm, δ_2= 1.005mm.Correcting the zero-plane to the reference plane,placing the two gage block respectively,we get two groups of output average values $\bar{y}_1$, $\bar{y}_2$ .Then the output value K of unit displacement can be calculated by the following equation:

$$K=(\bar{y}_2-\bar{y}_1)/(\delta_2-\delta_1) \qquad (4)$$

Then we adjust the calibration determiner in the software to the value of K, in order to make the value of $\bar{y}_2-\bar{y}_1$ correspond to the difference of the thickness , ($\delta_2-\delta_1$ =0.005mm).So the output displays as 5 um.

(4). Resolution Calibration of the Instrument (Linearity)

Some groups of standard voltages V1,V2 of direct signals and analogue position signals of the job are input to the instrument.Some groups of values Y_1 ,($\bar{Y}_1$),Y_2,($\bar{Y}_2$) are measured,then the curve of Input versus Output (The Linearity of the Instrument) shown in Fig.7 can be drawn.

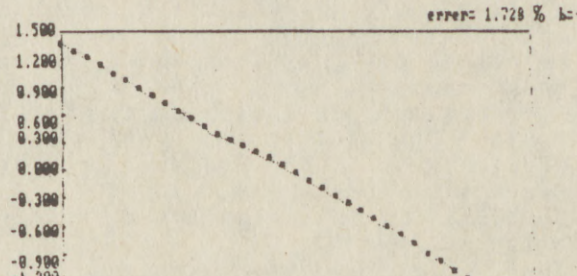


Fig.7(a). Measurement range: 0.3 - 3.5 mm

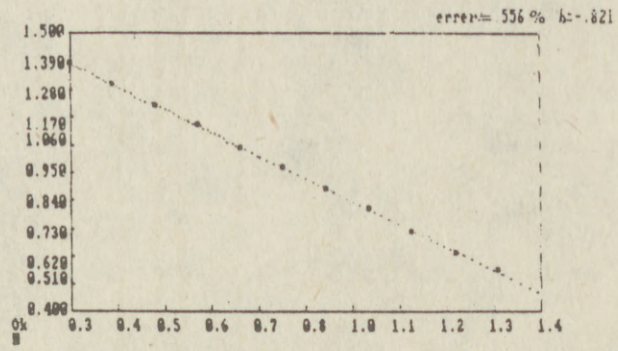


Fig.7(b). Measurement range: 0.3 - 1.4 mm

Fig.7. THE LINEARITY OF THE INSTRUMENT

To the wider measurement range,the linearity (0.7996) of the instrument is relatively low (shown in Fig.7(a)).To the smaller measurement range,the linearity (0.821) is better (shown in Fig.7(b)).

References

[1] Shimokobe, A.,Osada H. and Gotoh K., Precision Engineering, 7(1985), No.4, 195-200.

[2] Li Shengli and Jin Taiyi. " A Non-contact Method to Measurement Micro-displacement and Analysis of the Accuracy " Journal of China University of Science and Technology Vol.18.(Svm Nob2) (1988). 47-52.

TURNING CENTERS PROGRAMMING BY GTIPROG/EC SYSTEM

Dr. M.Berta, Dr. I.Cser, M.Juhasz
Institute of Industrial Technology - Hungary

The GTIPROG/EC system is a new member of the GTIPROG system family developed on the CAE Head Department of the Institute of Industrial Technology. It helps the scheduling of cutting operations (turning, drilling, milling) of the rotational workpieces machined on turning centers and helps the producing of the NC part-programmes as well. The system can be used on IBM PC XT/AT compatible computers.

The high proportion of the rotational-symmetrical workpieces in the engineering industry manufacturing and the fact that other cutting operation also have to be executed beside of turning in case of more than 80 percents to produce these workpieces have accelerated the producing and application of the turning centers and establishment rotational workpieces machining cells built around these machine-tools. The experiences till now account favourable results (increasing of the productivity and quality, decreasing of the work-in-proces materials, assurance the conditions of unmanned manufacturing and so on) regarded to apply turning centers.

Technology applied on turning centers has more different characteristics compared to conventional NC and CNC lathes:

1/ High level automation of the main and auxiliary functions.- automatic change of the workpieces, tools, chucks and jigs; control of the linked robot; automatic measuring and tool-wear compensation and so on.

2/ Considerable concentration of the operations - which decreases the number of clamps and non-cutting times; increases the accuracy and quality and so on.

3/ Two spindles and/or two slides configuration - which influences the division of the machining process into operations and the executive sequences of the operations.

We took peculiarities above mentioned into consideration when we improved the GTIPROG/E system - has been developed for programming NC and CNC lathes on the CAE Head Department of the Institute of Industrial Technology - to make it suitable for programming turning centers as well (version: GTIPROG/EC).

1. The GTIPROG/E system

The GTIPROG/E system can be used for planning of the turning operations and for producing NC programmes of the rotational workpieces (shafts and discs). The processor-postprocessor

articulation and the database of the system quarantee the easy adaptation of it to the user environment. Interactive database service (handling) program helps to create and to make up-to-date the database.

The input data of the system - the base of the operation planning consist of the part-program and database data (machine-, tool-, material- and technological data).

The main groups of the part-program data:

- General data:

  Identifications and strings data connected with the workpiece material, machine-tool and control equipment; the workpiece material condition; general surface roughness and finishing allowance; clamps data; home and tool-change positions of the slides; technological commands for the machine operator.

- Unmachined (blank) and finished workpiece contours definition:

  The contours definitions (descriptions) are performed by geometrical main elements (dia, plane, cone, torus), transitional elements (bevel, round) and secondary elements (groove, under-cut, thread) according to determined rules (workpiece cross-section in the first plane- quarter, start point, going round direction, sequence of elements). Beside of measurements tolerances, finishing allowances and surface roughness can also be definited by elements.

- Operation-element definitions:

  The operation-elements are definited by the type of operation, the serial number of the clamp and the position of the operation on the contour. Descriptional sequence of operations means at the same time their executional sequence as well.

The system in the course of part-program processing:

- performs sintactic and semantic checking of the part-program, decoding of the alfa-numeric identifications and processes the chain-measurements and tolerances;

- creates blank-, roughed and finished workpiece contours;

- determines geometrical and machining characteristics of the allowance formations linked to the operation elements;

- automatically selects tools and schedules tool-arrangement plan (taking the operations sequence and machine-tool characteristics into consideration);

- determines the cutting parameters (cutting speed or number of revolutions, cutting depth and feed);

- schedules the tool-paths needed to execute the operation elements and processes the individual tool-paths commands;
- calculates the workpiece machining time and produces NC program and documentations for the manufacturing;
- displays (onto the screen) and/or drawes the contours, the allowance formations and the tool-paths for checking.

2. Development goals to improve GTIPROG/EC system

The technological possibilities of the turning centers are determined by constructional characteristics of these machine-tools basically from these characteristics by the number of spindles and slides, the number of controlled axis, the caracteristics of driven tools and their tool-holders. In our development goals we strove to solve the next problems:

- enlarging the operation-elements assortment with special operations can be executed on turning centers;
- programming of the 3 or more axises machining;
- enlarging the furnishing of the system;
- handling of the supervisory and quality assurance functions;
- developing informational connections with other computerized systems.

2.1. Englarging the operation-elements assortment

On the turning centers different drilling (outside of the workpiece rotational axis) and milling operations can be executed as: centre drilling, drilling, sinking, reaming, taping, slot and plane milling and so on.

The types of these secondary operations can be determined by the type of the carrier surface (dia, plane, cone), the feed direction of the tool (radial, axial, tangential) and the clamp position of the tool (Fig.1.)

2.1.1. Determination of the drilling and milling operations.

Machining workpieces on turning centers the larger proportion of the cutting operations consist of turning operations too, so we have kept the contour description concepcion of the blank and finished workpieces (Chapter 1.). The holes, slots and planes (produced by milling) placed on the geometrical main elements (dia, face) are handled as secondary elements (for instance as grooves) and their determinations are done according to this: after determination of the carrier main element and the transition elements (placed on the main element) follows the determination of the secondary elements. Holes can also be

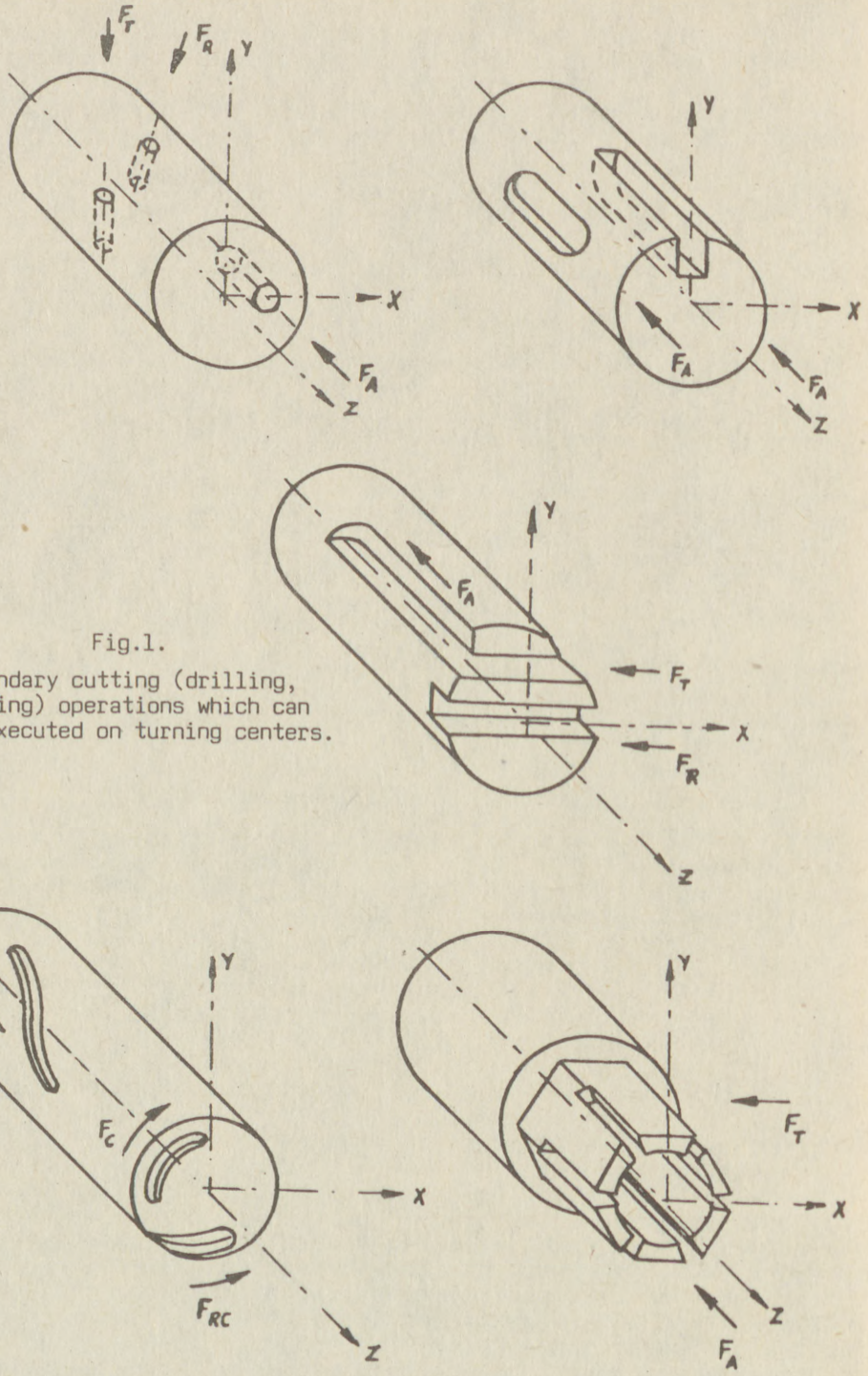


Fig.1.
Secondary cutting (drilling, milling) operations which can be executed on turning centers.

determined on planes which are machined previously by milling.

The drilling and milling operations are divided into two groups:

- typical secondary operations which can be determined exactly by typical geometrical parameters (drilling, simple milling as slot milling and so on);

- individual secondary operations to which belong complex geometry and which can be executed by complex and simultaneous moves of the workpiece and the tool.

For the geometrical definitions of the typical drilling and milling operations the following informations are used:

- type of the operation (drilling, reaming, slot milling etc.);
- identification, type and geometrical data of the carrier element;
- data of the reference point which determine the place of the operation on the carrier element (length, diameter, angle);
- geometrical data of the operation regarded to the reference point (for example: width, length and depth of the slot);
- technological characteristics of the operation (for instance: the slot is opened or closed).

2.1.2. Processing of the drilling and milling operations.

Processing of the typical secondary operations are performed as like as turning operations, as we enlarged the assortment of tool-paths cycles scheduling modules with some new ones. Calling sequence of tool-paths scheduling modules is determined by the prescribed machining sequence.

Programming of milling operations to which belong complex geometry (closed or opened contours built up by lines and circles) or drilling operations which have discrete spational positions can be solved by programming of individual tool-move commands.

2.1.3. The problem of turning placed behind the shoulder

Because of possibility of the machining only in one clamp is necessary to solve problem of turning placed behind the shoulder. The GTIPROG/EC system offers two possibilities for the programmer (who can decide in possession of the tooling data to select the more suitable variation):

- determination of a long turning operation which has enlarged function (Fig.2);

- determination of the so called "inverz" long turning operation (Fig.3.).

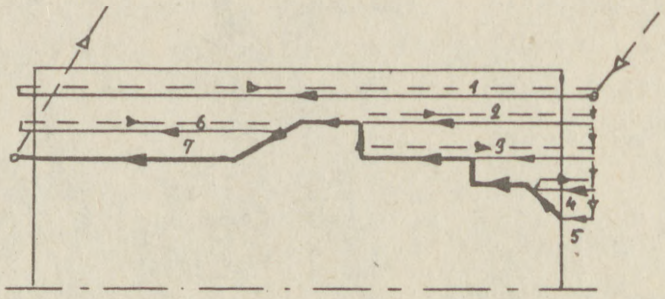


Fig. 2.
Long turning operation vith enlarged function

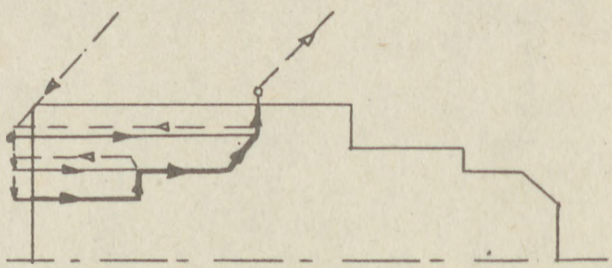


Fig. 3.
"Inverz" long turning operations

Processing of the secondary drilling and milling operations and the solution of the turning placed behind the shoulder can be regarded as solved problems and they are represented by the added system running results (Fig. 4., 5., 6.). But the solution of the next problems compose the task of the further developing efforts.

2.2. Problems of the multi-tools machining

Technological analisys of the present turning centers constructions requires to solve the next problems:

- combining of turning operations (for example: simultaneously cutting of the external and internal surfaces; contraction of the turning before and behind the shoulder etc.);

- machining of the symmetrical hole systems.

The multi-tools machining requires the change or enlarging of the program module as well which computates automatically the cutting parameters.

2.3. Planning of the supervisory and quality assurance function:

In the developing work aimed to schedule the supervisory and quality assurance functions we take the next points of wiev into consideration [3] :

- before machining: measurement controll of the blank workpieces; checking identifications and measurements of the tools,
- under machining: supervision of the clamping force, cutting force and momment, effect, vibration and chip area shape; in-process measuring; tool life control; tool-wear compensation; tool break observation and tool change derived from tool break,
- after machning: checking of the measurement-, geometrical and locational tolerances.

2.4. Englarging of the system furnishings

In our deverloping goals we intend to deal with the next questions:

- interactive contour description;
- interactive scheduling and displaying of the allowance formations;
- grafical simulation of the machining process (grafical visulization of the clamping instruments, tools and workpieces);
- interactive planning and displaying of the tool-arrangement;
- supporting compilation of the operation plan (operation sheet) with figures.

2.5. Informational connections with other computerized systems

We intend to build informational connections with CAD, CAPP and/or CIM systems equally. As a result the building of the GTIPROG/EC system into constructional and production planning computerized systems [4] :

- the application sphere of the given system will be enlarged (for example in case of a CAD system);
- the NC programming tasks of the given system can be solved (for instance in case of a CAPP system).

```
* * *     P A R T   P R O G R A M   DATA     * * *

GENERAL STRING DATA

     Name of the programer.....................:BERTA M

     Date.....................................:1989.05.15

     Workpiece name............................:FEDEL

     Workpiece drawing number..................:14-462D02-11

     :

GENERAL DATA

     Standard material identification.........:C45

     General surface roughness (RA)............:5

     :

DATA BY CLAMPS

     Material condition code...................:2       2

     Stability of the clamp....................:1       1

     Cooling...................................:1       1

     :

UNMACHINED WORKPIECE DESCRIPTION

     E5=H;ZO

     E10=D;D200

     :

WORKPIECE DESCRIPTION

     A5=H;ZO

     A10=E;EL.5

     :

SEQENCES AND DEFINITIONS OF THE OPERATIONS

     M5=FUR;BEF1;F16

     M10=NH;A70;A50

     M15=NK;A75;A85
```

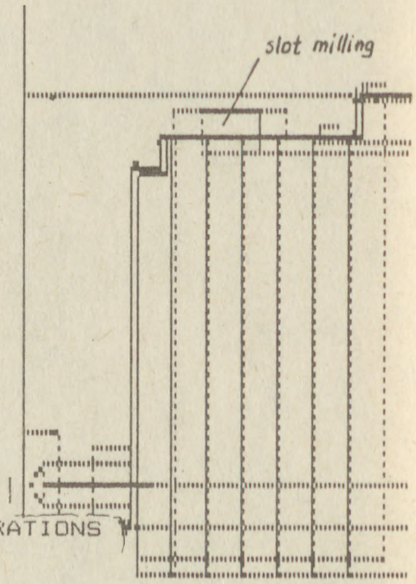


Fig. 4-5.
Input data and tool-paths

IBM PC & comp. ********** ********** EPA 320MC/HUNOR 731-PEC ********** GTIPROG E **********

WORKPIECE : FEDEL 14-462D02-11

LIST-FILE NAME : LST\LISTA.DOC

PART PROGR. NAME : HUNOR\TD0001.DOC

DATE : 02-14-1990 17:48:37

CLAMP SER. NUMBER: 2

T O O L - A R R E N G E M E N T P L A N

TOOL NUMBER	TOOL POSITION	CORECTION	TOOL LENGTH	TOOL OVRHANG	DRILL TIP DIAM.	RAD.
2101101	1	1	112.00	-90		.4
2361001	11	2	112.00	-90		.4
1301000	2	3	140.00	63		.8
2411050	3	4	95.00	-90		
5216080	4	6	166.00	0	5.8	
5613016	5	7	117.00	0	6.00	
6412033	6	9	105.00	0	8.00	
5216050	7	10	166.00	0	6.5	
5424019	8	11	169.00	0	11.00	

CUTTING TIME = 14.81 MIN.
NON CUTTING TIME = 15.07 MIN.
MACHINIG TIME = 29.88 MIN.

N C-P R O G R A M S E N T E N C E S

```
N5 G51 X204 Z45.5 V85 SM500 T101 M3 M8 M40 M96
N10 G1 X75.376 F.37
N15 G0 X76.376 Z46
N20 G41 X204 Z40.5
N25 G1 X75.376
N30 G0 X76.376 Z41
N35 G41 X204 Z35.5
N40 G1 X75.376
N45 G0 X76.376 Z36
N50 G41 X204 Z30.5
N55 G1 X75.376
```

Fig. 6.

Results of the postprocesszor running

References

[1] Dr M. Berta, Dr I. Cser, M. Juhasz: GTIPROG/E microcomputer programming system for NC lathes - "Automation of small-and middle batches production' 83" conference. Esztergom 1983. Page: 59-68.

[2] Dr M. Berta, Dr B. Futo, M. Juhasz, Gy. Voloncs: Improvement of the GTIPROG/E system for programming NC lathes - GTT XI. Automation. 1988/2. Page: 62-75.

[3] Dr S. Nagy: Developent of the cutting technology scheduling systems for programming supervisory and quality assurance functions - "Engineering Weeks of Borsod". Miskolc 1988.

[4] Dr S. Nagy, Gy. Voloncs: Development of CAP/CAPP systems for rotational workpieces - "Engineering Weeks of Borsod". Miskolc 1988.

DYNAMIC JOB SHOP SCHEDULING BY NEURAL NETWORK

Yukinori KAKAZU* and Norihiko TAKATORI†

* Department of Precision Engineering,
Faculty of Engineering, Hokkaido University,
North 13, West 8, Sapporo 060, JAPAN

†Hokkaido College of Arts and Sciences,
582-1 Bunkyodai-Midorimachi, Ebetsu 069, JAPAN

This paper presents a new approach to the job shop scheduling problem. The proposed method is theoretically based on the Hopfield-type neural network. The basic idea of the method is as follows: We can set the analogy between the field of the job shop scheduling system and the neural network system. The criterion of the scheduling is set, and then transformed into the energy function of the network. The solution is obtained when the energy of the network reaches equilibrium. In this paper the idea is formulated and implemented for the computer simulation. The results of the numerical experiments are shown.

1. INTRODUCTION

A scheduling problem is one of the important matters in the production engineering. Many researchers have been studying the problem for years and presented several solutions, which were based on branch and bound method, dispatching rules, production rules of knowledge engineering, etc. The common solution to the problem haven't, however, been established yet.

The difficulty of the establishment comes from the fact that the scheduling problem is one of the combinatorial optimization problems. In the combinatorial problems, it is almost impossible to provide the general means for the selection of the optimal solution among all feasible solutions. Therefore, it is thought that most of the conventional methods would aim at reduction of the number of the combinations.

This paper presents a new approach to the job shop scheduling problem. The problem is formulated with the frame of neural network. The basic idea of the method is as follows: We can set the analogy between the field of job shop scheduling system and the neural network system. The criterion of the scheduling is set, and then transformed into the energy function of the network so that the equilibrium of the energy corresponds to a machine allocation. Thus the solution is obtained by mapping inversely the state of the network in equilibrium. Namely, the combinatorial problem is transformed into the problem of continuous function. The concept is shown in Figure 1.

In this paper, the job shop scheduling problem is formulated using the Hopfield-type neural network. The proposed method is implemented for the computer simulation. The results of the numerical experiments are shown and the characteristics of the method are discussed.

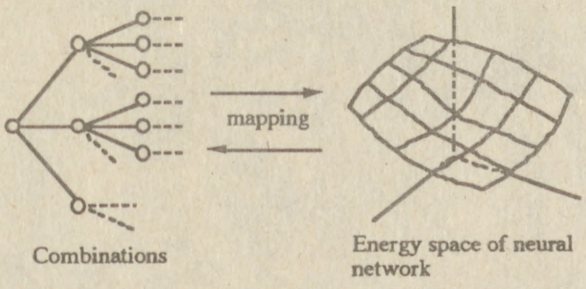


Figure 1. Concept of the proposed method.

2. DEFINITION OF A SUBJECT

2.1 SCHEDULING PROBLEM

A scheduling problem is to determine the processing order of Nj jobs on Nm machines and to timetable them in order to minimize (or maximize) a given measure of performance. A job shop scheduling problem is the case that the order of each job may be different..

In general, the scheduling problems are divided into two types, static and dynamic. Problems in which the number of jobs is known and the jobs arrive at the same time at a shop not working are called static. Problems in which jobs arrives randomly at a working shop are called dynamic. Both types will be discussed later in detail.

2.2 ASSUMPTIONS

In this paper, the following are assumed.

(1) Each job is composed of operations except assembly.
(2) All machines are always available, never break down.
(3) No machine can process more than one operation at the same time.
(4) Once an operation is started, it is not interrupted by the other operations until its finish.
(5) Processing time of each operation is constant.

3. JOB ASSIGNMENT PROBLEM

3.1 DESCRIPTION OF THE PROBLEM

In this chapter, we focus on the static problem defined as follows:

DEFINITION When the processing times and the tools for operations are given, the problem is to determine the assignment of operations to machines so that the machine load balance is optimal. We call it a 'job assignment problem'.

The next assumptions are added to the ones of section 2.2.

(1) Any machine can process any operation.
(2) The following are known; the maximum number of tools attachable to a machine, the standard processing times and the tools for operations.
(3) The occurrence probability of each job is given as the ratio of constitution against the total.

The purpose of this 'job assignment' is to prevent concentrating jobs on specific machines. So the variance of the mean total processing time on each machine is regarded as the performance measure. The assignment is planned so that the frequent operations are processed on the more machines.

3.2 DERIVATION OF CONSTRAINTS

Suppose that Nj types of jobs are processed at the shop of Nm machines and that job i is composed of Noi operations (i=1,..., Nj). The parameters used are defined as follows:

- Ce_k is the number of the machines which process operation k.
- P_i is the occurrence probability of job i.
- At_{ij} is the type of operation j of job i, in other words, the tool which is used for processing operation j of job i.
- Mt_{ij} is the processing time of operation j of job i.
- Ne is the number of the operation types.
- Cm_m is the number of the tools applicable to machine m.

Let C be the expected value of the occurrence of operations. Thus:

$$C = \sum_{i=1}^{Nj} P_i \times No_i \quad . \tag{1}$$

Let Fq_k be the occurrence of operation of $At_{ij}=k$, so:

$$Fq_k = \sum_{At_{ij}=k} \frac{P_i}{C} \quad . \tag{2}$$

Therefore, Let Ld_k be the mean processing time of operation k,

$$Ld_k = \sum_{At_{ij}=k} Mt_{ij} \times \frac{P_i}{C} \quad . \tag{3}$$

Let Nt denote the total number of tools. Since the maximum of tools applicable to machine m is $\min(Cm_m, Ne)$,

$$Nt = \sum_{m=1}^{Nm} \min(Cm_m, Ne) \quad . \tag{4}$$

Using them, Ce_k is determined by the next algorithm.

ALGORITHM A

Step 1. Set $Ce_k = 1$ for all k.
Step 2. Iterate Step 3. to Step 5. for $Ne+1$ to Nt.
Step 3. List operations in descending order of Fq_k/Ce_k.
Step 4. Fetch the first element of the list, and let k denote it.
Step 5. Examine whether it is possible to increase Ce_k or not by ALGORITHM B.
(i) if possible, set $Ce_k = Ce_k + 1$.
(ii) if not, remove the element from the list, and go to 4.

ALGORITHM B

Let k' be the operation concerned.
Step 1. If $Ce_{k'} > Nm$, go to Step 9.
Step 2. List operations, except k', in descending order of Ce_k.
Step 3. Fetch the first element of the list, and let k denote it.
Step 4. List machines in descending order of Cm_m.
Step 5. If $Ce_k \leq Ce_{k'}$, go to Step 8.
Step 6. Set $Cm_m = Cm_m - 1$ at the first to Ce_kth element of the machine list.
Step 7. Remove the element from the operation list, and go to 3.
Step 8. Let m be the $Ce_{k'}+1$st element of the machine list.
(i) if $Cm_m \geq 1$, it is possible to increase $Ce_{k'}$.
(ii) if $Cm_m = 0$, it is not possible.
Step 9. Stop.

3.3 DESCRIPTION BY NETWORK

A neural network consists of 'neurons'. The variable V_{km}, which describes the relation between operation k and machine m, is used as the neuron for the process scheduling(Figure 2). V_{km} takes the value as shown below:

$$V_{km} = \begin{cases} 1 & | \quad k \text{ is processed on } m \\ 0 & | \quad k \text{ is not processed on } m \end{cases} \quad . \tag{5}$$

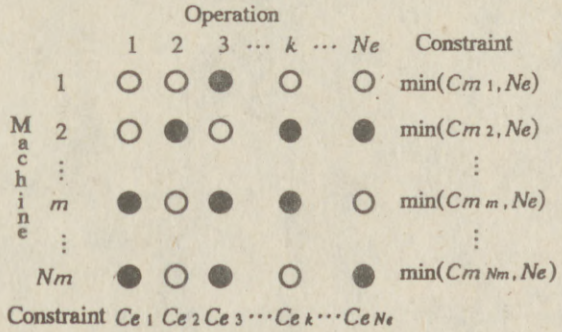


Figure 2. Configuration of neural network for job assignment problems.

In order that the state of the neurons is valid as a solution when the network is in equilibrium, the number of neurons taking the value 1 is constrained for the rows and the columns as follows:

$$\sum_{k=1}^{Ne} V_{km} = \min(Cm_m, Ne) \quad , \tag{6}$$

$$\sum_{m=1}^{Nm} V_{km} = Ce_k \quad . \tag{7}$$

The following functions are introduced which satisfy (6) and (7) respectively in the equilibrium.

$$E_1 = \sum_{m=1}^{Nm} \left[\min(Cm_m, Ne) - \sum_{k=1}^{Ne} V_{km} \right]^2 \quad , \tag{8}$$

$$E_2 = \sum_{k=1}^{Ne} \left[Ce_k - \sum_{m=1}^{Nm} V_{km} \right]^2 \quad . \tag{9}$$

Let Z_m be the mean total processing time on machine m in the equilibrium, then:

$$Z_m = \sum_{k=1}^{Ne} \frac{Ld_k}{Ce_k} V_{km} \quad . \tag{10}$$

Since the operations are processed at the same efficiency on any machine,

$$\sum_{m=1}^{Nm} Z_m = \text{Const} \quad . \tag{11}$$

Let Z_{mean} denote the average of Z_m, then:

$$Z_{mean} = \text{Const} \quad . \tag{12}$$

The variance of the mean total processing time is as follows:

$$\sigma = \sum_{m=1}^{Nm} (Z_{mean} - Z_m)^2 = \sum_{m=1}^{Nm} Z_{mean}^2 - 2Z_{mean} \sum_{m=1}^{Nm} Z_m + \sum_{m=1}^{Nm} Z_m^2 \quad . \tag{13}$$

The first and the second term are constant, so the function E_3 is defined as below:

$$E_3 = \sum_{m=1}^{Nm} \left[\sum_{k=1}^{Ne} \frac{Ld_k}{Ce_k} V_{km} \right]^2 \quad . \tag{14}$$

From these, the objective function is defined by the expression (15).

$$E = \frac{C_1}{2} E_1 + \frac{C_2}{2} E_2 + \frac{C_3}{2} E_3 \quad , \tag{15}$$

where C_1, C_2, C_3 are positive constants. The energy function of the Hopfield-type network is

$$E = -\frac{1}{2} \sum_{k,m} \sum_{k',m'} T_{kmk'm'} V_{km} V_{k'm'} - \sum_{k,m} I_{km} V_{km} \quad . \tag{16}$$

Comparing (15) with (16), synapse weight and bias can be described as follows:

$$T_{kmk'm'} = -C_1 \delta_{mm'} - C_2 \delta_{kk'} - C_3 \frac{Ld_k}{Ce_k} \frac{Ld_{k'}}{Ce_{k'}} \delta_{mm'} \quad , \tag{17}$$

$$I_{km} = C_1 \min(Cm_m, Ne) + C_2 Ce_k \quad , \tag{18}$$

where $\delta_{xx'}$ is Kronecker's delta.

4. DYNAMIC JOB SHOP SCHEDULING PROBLEM

4.1 DESCRIPTION OF THE PROBLEM

The assumptions added to section 2.2 are as shown below:

(1) Jobs arrive according to Poisson distribution.

(2) Arrangement time is considered as setup time. Transportation time is ignored.

(3) The capacity of buffer for works is infinite.
(4) The following is given; which types of operations can be processed on a machine.

In this paper, the due date of jobs is considered as the measure of performance. The target is to make a schedule so that the due date would be satisfied.

4.2 EVALUATOR FOR 'WAITING' AND 'ALLOCATING'

Suppose that Nj jobs will be allocated to Nm machines. The variable V_{im} is used for representing the relation between job i and machine m. And V_{iwait} is also introduced to present the waiting of job i. These take the value as shown below respectively:

$$V_{im} = \begin{cases} 1 & | \quad i \text{ is allocated on } m \\ 0 & | \quad i \text{ is not allocated on } m \end{cases}. \tag{19}$$

$$V_{iwait} = \begin{cases} 1 & | \quad i \text{ is waiting} \\ 0 & | \quad i \text{ is allocated} \end{cases}. \tag{20}$$

Firstly, consider the evaluator for waiting, A_{iwait}. The following definitions are used.

Di is the due date of job i.
t is the present time.
Opi is the operation number of next processing.
Lti is the minimum time by which job i can be allocated.

In order to define A_{iwait}, consider the quantity X_{iwait} defined by the next expression.

$$X_{iwait} = \frac{\left(D_i - \sum_{j=Op_i}^{No_i} Mt_{ij} - t \right) - Lt_i}{\sum_{j=Op_i}^{No_i} Mt_{ij}} \tag{21}$$

From the definition, the denominator denotes the remaining processing time of job i, and the first term of the numerator represents the slack time.

The expression (21) means that the greater X_{iwait} is, the longer the time by the due date of i is. Such a job should be in waiting in the solution. Therefore, A_{iwait} is defined by expression (22) so that it is small when X_{iwait} is great.

$$A_{iwait} = \frac{1}{2} \cdot \left\{ 1 - \tanh\left(\frac{X_{iwait} - 1}{Cd - 1} \right) \right\}, \tag{22}$$

where Cd is a constant for due date.

Secondly, consider the evaluator for allocating job i on machine m, A_{im}. Similarly to X_{iwait}, the quantity X_{im} is defined as follows:

$$X_{im} = \frac{D_i - \sum_{j=Op_i}^{No_i} Mt_{ij} - t}{\sum_{j=Op_i}^{No_i} Mt_{ij}} \tag{23}$$

Different from A_{iwait}, it should be small when X_{im} is small. So, let A^1_{im} be this evaluator, it is defined by the next expression.

$$A^1_{im} = \frac{1}{2} \cdot \left\{ 1 + \tanh\left(\frac{X_{im} - 1}{Cd - 1} \right) \right\} \tag{24}$$

In order to take the setup time into account, the following term A^2_{im} is added.

$$A_{im}^2 = \frac{Rt(Wop_m, At_{ij})}{A_{iwait}}, \tag{25}$$

where $RT(Wop_m, At_{ij})$ is the setup time for exchanging the current operation Wop_m for the other type At_{ij}.

Consequently, the evaluator A_{im} is defined as follows:

$$A_{im} = A_{im}^1 + \mu A_{im}^2, \tag{26}$$

where μ is a weight for the second term.

4.3 DESCRIPTION BY NETWORK

The network for the dynamic job shop scheduling is constructed with the variable V_{im} as neurons (figure 3). For convenience, the variable for waiting is represented with the subscript 'Nm+1'. The network is constrained for the rows and the columns as follows:

$$\sum_{i=1}^{Nj} V_{im} = H_m, \tag{27}$$

$$\sum_{m=1}^{Nm+1} V_{im} = 1, \tag{28}$$

where H_m is the number of the neurons of 1 for the mth row. H_m is calculated by the next algorithm.

ALGORITHM C

Step 1. Set $H_m = 0$ for all m.

Step 2. Iterate Step 3. for m=1 to Nm.

Step 3. Iterate Step 4. for i=1 to Nj.

Step 4. Examine whether it is possible to process operation j of job i on machine m or not. If possible, set $H_m = 1$.

Step 5. Stop.

So, H_{Nm+1} is described as follows:

$$H_{Nm+1} = Nj - \sum_{m=1}^{Nm} H_m. \tag{29}$$

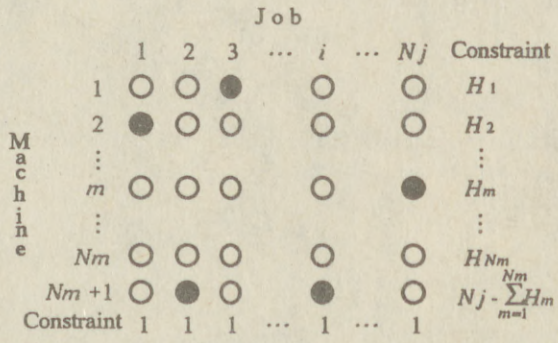


Figure 3. Configuration of neural network for dynamic job shop scheduling problems.

The function F_1 and F_2 are defined by the expression (30) and (31) respectively.

$$F_1 = \sum_{m=1}^{Nm+1} \left[H_m - \sum_{i=1}^{Nj} V_{im} \right]^2, \tag{30}$$

$$F_2 = \sum_{i=1}^{Nj} \left(1 - \sum_{m=1}^{Nm+1} V_{im} \right)^2 . \tag{31}$$

And from section 4.2,

$$F_3 = \sum_{m=1}^{Nm+1} \sum_{i=1}^{Nj} (A_{im} V_{im})^2 . \tag{32}$$

The objective function is defined by the next expression.

$$F = \frac{C_1}{2} F_1 + \frac{C_2}{2} F_2 + \frac{C_3}{2} F_3 . \tag{33}$$

Thus synapse weight and bias is

$$T_{imi'm'} = -C_1 \delta_{mm'} - C_2 \delta_{ii'} - C_3 A_{im} A_{i'm'} , \tag{34}$$

$$I_{im} = C_1 H_m + C_2 . \tag{35}$$

In solving the problem, there are two cases that the value of neuron is restricted. One is that $V_{i^*m^*}=1$ when job i^* is being processed on machine m^*. Therefore, the bias is set as follows:

$$I_{i^*m^*} = \infty . \tag{36}$$

Another is that $V_{i''m''}=0$ when it is impossible to process job j'' at machine m''. In this case,

$$I_{i''m''} = -\infty . \tag{37}$$

5. EXPERIMENTS

The computer simulation is done to verify the proposed method. HITAC M-682H of Hokkaido University Computing Center is used. The program is written in FORTRAN.

5.1 SIMULATION OF JOB ASSIGNMENT PROBLEM

The parameters of the experiment are as follows.

Number of types of jobs :	$Nj=10$.
Number of machines :	$Nm=3$.
Number of types of operations :	$Ne=8$.
Number of operations which a job consists of :	$No_i=4$ ($i=1, \ldots, 10$).
Number of operations to be processed at a machine :	$Cm_1=6$, $Cm_2=4$, $Cm_3=4$.

The information of jobs is presented in Table 1; the processing times and the types of the operations composing the jobs, and the occurrence probabilities of the jobs. Before calculating the assignment, the number of machines to process operations is calculated for each operation, and shown in Table 2.

The conditions of the network are as follows.

Coefficients of objective function :	$C_1=80.0$, $C_2=80.0$, $C_3=25.0$.
Initial value of neurons :	Random values in [0,1] .
Number of transitions of neuron state :	20 times.
Function of transition :	Step function.

The energy of the network at each state and a result of assignment are shown in Figure 4.

5.2 SIMULATION OF DYNAMIC JOB SHOP SCHEDULING PROBLEM

Nj, Nm, Ne, No_i, Cm_m and the information of jobs are the same as of section 5.1. The following parameters are added.

Average interval of job occurrence :	8.5.
Number of total jobs :	150.

Due date D_i of job i is determined by the next expression.

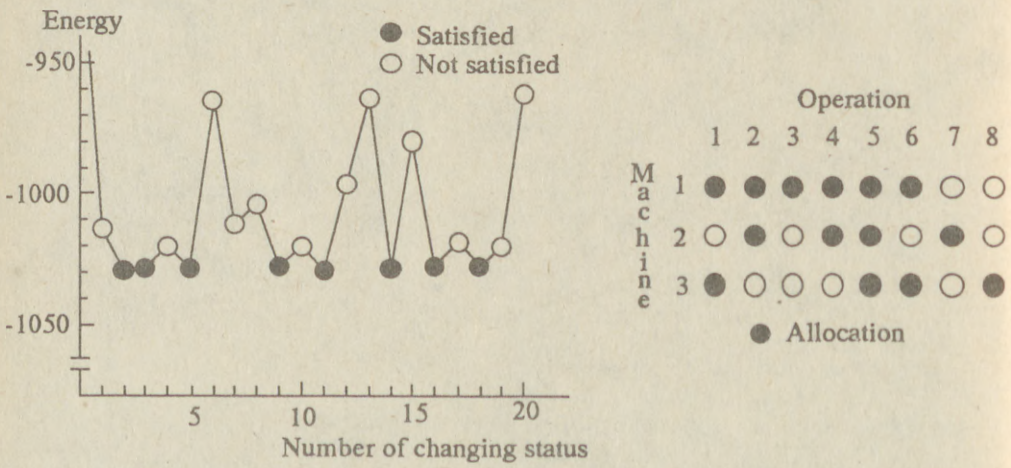
$$D_i = \left(\sum_{j=1}^{No_i} Mt_{ij} \right) \times RN , \tag{38}$$

Table 1. Test data (the processing times and the types of operations, and the occurrence probabilities of jobs).

	Operation(processing time / type) 1	2	3	4	Occurrence probability
Job 1	5/1	4/2	6/3	3/4	0.10
2	3/5	6/6	8/7	3/8	0.20
3	5/1	4/5	5/1	6/6	0.20
4	4/2	3/5	7/3	3/5	0.15
5	6/1	3/4	6/3	4/5	0.05
6	4/2	3/4	3/5	7/3	0.05
7	4/1	3/5	4/4	9/7	0.05
8	4/2	6/6	4/1	3/4	0.10
9	5/6	4/5	6/1	4/5	0.05
10	4/2	3/4	3/8	5/6	0.05

Table 2. Results of calculations for operations.

k	Fq_k	Ce_k	Ld_k	Ld_k/Ce_k
1	0.19	2	0.93	0.46
2	0.11	2	0.45	0.23
3	0.09	1	0.58	0.58
4	0.10	2	0.31	0.16
5	0.24	3	0.80	0.27
6	0.15	2	0.88	0.44
7	0.06	1	0.51	0.51
8	0.06	1	0.19	0.19



(1) The energy of the network (2) A solution of the problem

Figure 4. Results of the job assignment simulation.

where RN is a random number of $2.0 \leq RN \leq 4.0$. RN occurs when a job is ordered.

The conditions of network are as follows:

Coefficients of objective function : C_1=80.0, C_2=80.0, C_3={20.0, 25.0, 30.0, 35.0}.

Initial value of neurons : Random values in (0, 1).

Number of transitions of neuron state : 4 times of setting initial value of neurons for each C_3. 10 times of changing state of neurons for each initial state.

The scheduling by dispatching rules is also simulated. The rules used are as follows:

DDATE (Due Date).

OPNDD (Operation Due Date).

DDATE+3PRTM (PRTM is the rule of the order of the shortest setup time. 3 is weight.).

OPNDD+3PRTM.

SPT (Shortest Processing Time).

The results of scheduling are shown in Figure 5. The abscissa shows the percentage of flow time to due date. More than 100 percent means tardiness of job. The ordinate represents the number of jobs. The total tardiness, the maximum tardiness, the average length of job queue and CPU time are presented in Table 3.

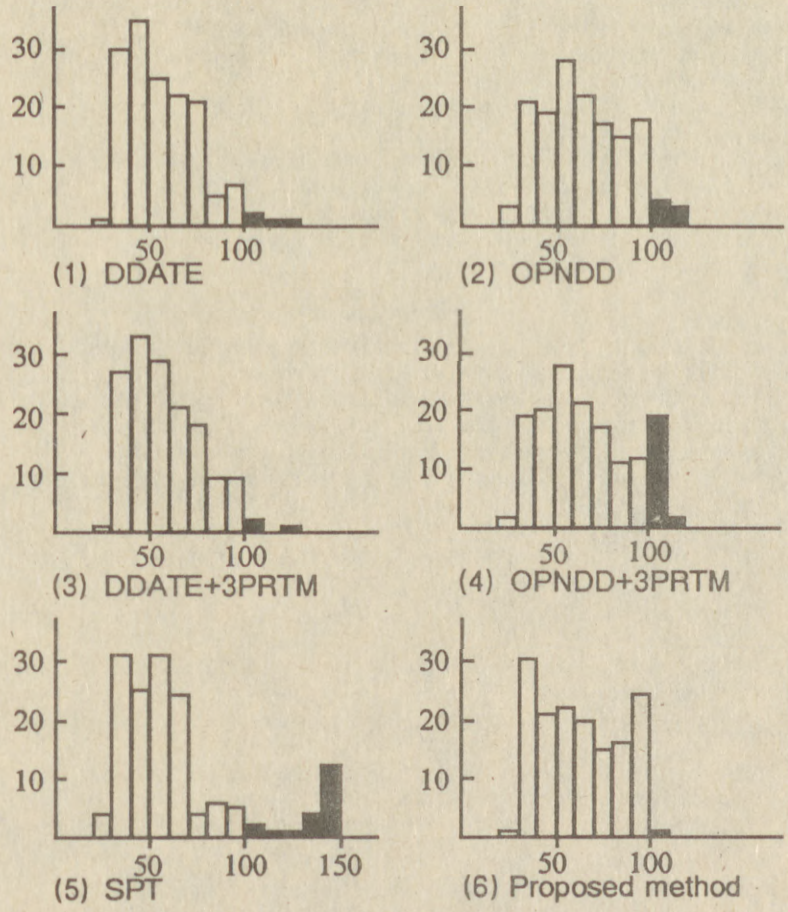


Figure 5. The tardiness in the scheduling by the proposed method and by the dispatching rules.

Table 3. Results of dynamic job shop scheduling.

	Total tardiness	Max. tardiness	Average length of job queue	CPU time [sec]
DDATE	23	10	4.22	0.13
OPNDD	30	7	4.70	0.13
DDATE+3PRTM	12	10	4.29	0.13
OPNDD+3PRTM	77	6	4.89	0.15
SPT	864	268	4.92	0.13
Proposed method	1	1	4.57	73.53

6. DISCUSSION

The merits of the proposed method are as follows:
(1) The proposed method doesn't have to deal with the combinations directly because the scheduling problem is solved in the energy space of the neural network.
(2) When more than one machines is idle, the scheduling can be done in which they are treated equally and simultaneously.
(3) This is the method in which 'waiting' evaluates explicitly.

The demerits are below:
(1) It is difficult to introduce the heuristics because the scheduling is evaluated numerically.
(2) In the case of multi-criteria, they have to be represented by weighted sum. Moreover, it is difficult to change the criterion according to the condition.
(3) The problems of the Hopfield-type neural network, e.g. local minima, cost of computation, etc., influence the accuracy of the method.

7. CONCLUSION

In this paper, the scheduling problem is reformulated with the frame of neural network.
(1) The neural network was introduced to the scheduling problem.
(2) This enabled the combinatorial problem be considered in the energy space of the network.
(3) Based on this idea, the method was proposed which was for job assignment problems and dynamic job shop scheduling problems by the Hopfield-type neural network.
(4) The method was implemented and the results of numerical experiments were shown.

REFERENCES

[1] Conway, R.W., Maxwell, W.L. and Miller, L.W., "Theory of Scheduling", Addison-Wesley (1967).
[2] French, S., "Sequencing and Scheduling ; An Introduction to the Mathematics of the Job-Shop", John Wiley & sons (1982).
[3] Bellman, R., Esogbue, A.O. and Nabeshima, I., "Mathematical Aspect of Scheduling & Applications", Pregamon Press (1982).
[4] Hitomi, K., "Production / Manufacturing Systems Engineering" (in Japanese), Kyoritsu Shuppan (1983).
[5] Hopfield, J. and Tank, W.D., "Neural Computation of Decisions in Optimization Problems", Biological Cybernetics, No.52 (1985), pp.141-152.
[6] Asoh, H., "Neural Network Information Processing" (in Japanese), Sangyo Tosho (1988).

STUDY ON AUTOMATIC TEACHING BY LEARNING —OFFLINE TEACHING FOR INDUSTRIAL ROBOTS—

Mitsuo Kamimura, Senior Engineer
Sadao Fujii, Director

Fujitsu Limited, 1015 Kamikodanaka
Nakahara-ku, Kawasaki 211, JAPAN

Yukinori Kakazu, Professor

Department of Precision Engineering,
Faculty of Engineering, Hokkaido University,
North 13, West 8, Sapporo 060, JAPAN

ABSTRACT

With the introduction of high-precision industrial robots, their use in complicated assembly now done manually is expected to increase. To make teaching easier, we developed offline teaching using robot simulators for automatic positioning based on sensor feedback.

This report describes our study of automatic teaching. If teaching requires precise positioning, sensors are attached to the robot, enabling it to detect arm positioning.

1. INTRODUCTION

The use of robots is being examined in a variety of fields. In assembly, the labor for teaching robots increases with work complexity and a growing need for highly precise positioning.

Robots teaching must meet the following minimum requirements:
(a) Teaching time and labor must be minimized
(b) Teaching must be simple and safe, without the need for special training.

Teaching is categorized as follows:
- Online teaching
  Work data relating a robot to an object is generated in manual operation.
- Offline teaching
  Work data is generated in a robot language in advance by a computer and programmed into the robot.

Problems arise in differences between the real world where a robot operates and the virtual world of the computer. This report presents a way to solve such problems using sensor feedback.

2. PROBLEMS WITH OFFLINE TEACHING

Assume actual three-dimensional operation (Figure 2) in which a 6-degree-of-freedom, jointed robot (Figure 1) positions a spherical end effector and an object at three points.

Problem

The data necessary for this work is generated offline from numerical data based on a drawing. A computer can determine points P_1, P_2, and P_3 precisely. When values are used in the real world, however, data on operation is not detailed and precise because it is difficult to fit the robot and object coordinate system used in calculation in the computer onto those in the real world.

Corrective Action

One object is positioned precisely by online teaching to compensate for the difference between the real and virtual coordinate systems. Robot position P_1 is determined by teaching the positioning at object 1 manually. Robot positions P_2 and P_3 at objects 2 and 3 are given by

$$P_2 = P_1 + R_{12} \quad \text{--- (1)}$$

$$P_3 = P_1 + R_{23} \quad \text{--- (2)}$$

where R_{12} is a vector representing the relative position of object 1 and R_{23} is a vector representing the relative position of objects 2 and 3.

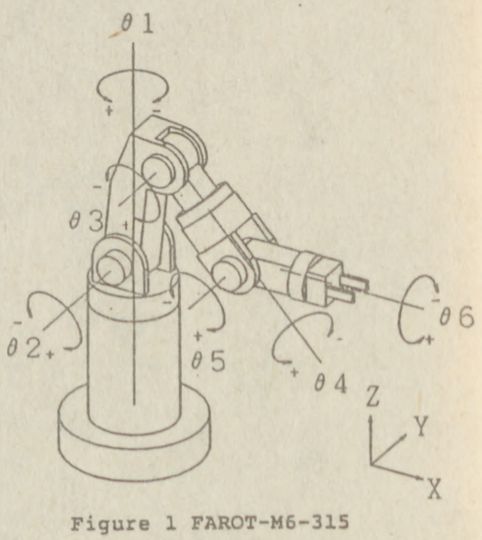


Figure 1 FAROT-M6-315

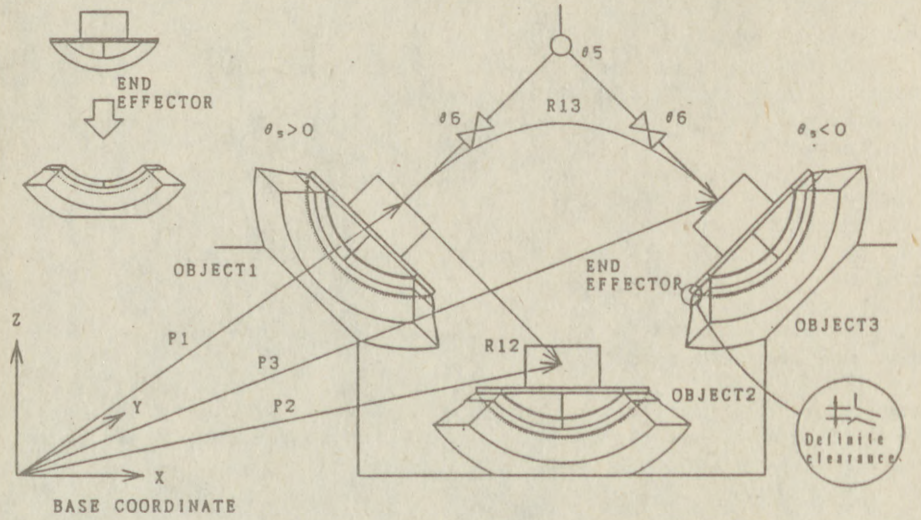


Figure 2 Three-dimensional work model

In an experiment based on data generated using equations 1 and 2, the positioning error was about 1 mm at object 2 and about 2 mm at object 3. Possible causes for this, other than the difference between coordinates include the following:

① Eccentricity of the rotary shaft or arm length errors due to machining or assembly

② Robot positioning at object 3 differing in the type of solution from that when the robot was positioned at object 1, i.e., angle $\theta 5$ of the fifth joint changing from positive to negative

These errors affect the conversion of P_2 and P_3 to joint angles, thus changing the robot's end position.

To fit the real and virtual worlds, offline teaching must overcome three problems:

① Errors in the robot
Errors such as eccentricity of the rotary shaft, in setting of the origin, or in arm length. These errors, which affect the precision of the absolute position of a robot, occur if an end effector or an object has not been manufactured as designed.

② Difference in shape between robots
This difference occurs when multiple products, such as robots, end effectors, and objects of the same type are manufactured.

③ Environment error
Robot or object installation location error

3. AUTOMATIC TEACHING BY SENSOR-BASED LEARNING

To solve the problems of offline teaching, we paid attention to the positional relationship between the end effector and object. By positioning, we mean to place a positional relationship in a specific state. This enables a robot to learn the positioning of an end effector and object in advance, and reproduces the states to position the robot. Sensors are used for learning. An end effector and object model are placed in the final position, and the object is measured with sensors. After that, positioning is performed using offline teaching data in the field. The position of the base point is found so that the value of each sensor is the value at that time, and positioning is automatic. This deals only with the final positional relationship between the robot and object. Thus, this method is not affected by errors in the robot, the difference in shape between robots of the same type, or errors in robot or object location.

Automatic teaching is done using data generated offline and by applying this method to points where precise positioning is required.

3.1 Calculating Robot Location and Positioning

To define the operation position of a 6-degree-of-freedom, jointed robot, the position and posture of the robot in the hand coordinate system must be defined for the robot's base coordinate system using six values, $XYZ\alpha\beta\gamma$ (XYZ are for position, $\alpha\beta\gamma$ are for direction). At least six input values are required to determine the above six unknown values. Six sensors are attached to a robot and sensor values are used as input in robot positioning. Each sensor measures the distance to an object.

Each sensor value at the target (positioning) position and each sensor read is E_i (i = 1 to 6) and S_i (i = 1 to 6). To reach the target value, each sensor must be displaced by

$$\Delta E_i = E_i - S_i \quad (i = 1 \text{ to } 6) \qquad \text{--- (3)}$$

This is detailed as follows:

(a) Rectangular parallelopiped

Figure 3 shows the sensor contact locations on a rectangular parallelopiped. Equations 4 to 9 give the approximate relationship between the displacement (ΔE_i) of each sensor, the differential changes (Δx, Δy, Δz) in location along the axes of the robot, and the differential changes ($\Delta\alpha$, $\Delta\beta$, $\Delta\gamma$) in direction around the axes. r_{x1}, r_{y1}, and r_{z1} are the radiuses of gyration around the axes (Figure 4).

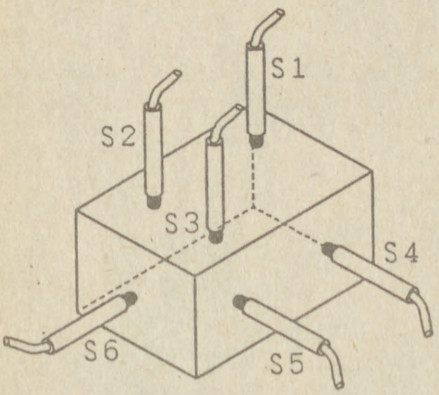


Figure 3 Sensor contact positions (rectangular parallelopiped)

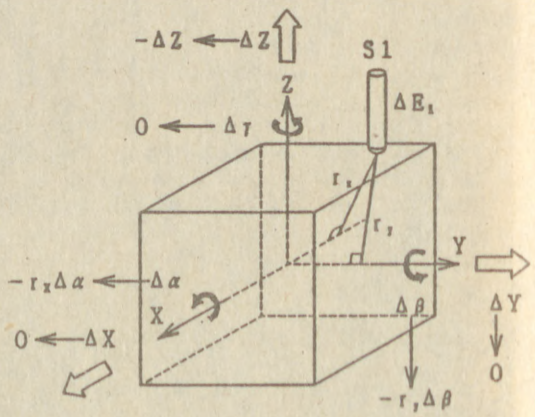


Figure 4 Sensor displacement

$$\Delta E_1 = -\Delta z - r_{x1}\Delta\alpha - r_{y1}\Delta\beta \qquad \text{--- (4)}$$
$$\Delta E_2 = -\Delta z + r_{x1}\Delta\alpha - r_{y1}\Delta\beta \qquad \text{--- (5)}$$
$$\Delta E_3 = -\Delta z + r_{x1}\Delta\alpha + r_{y1}\Delta\beta \qquad \text{--- (6)}$$
$$\Delta E_4 = -\Delta x + r_{z1}\Delta\gamma \qquad \text{--- (7)}$$
$$\Delta E_5 = -\Delta x - r_{z1}\Delta\gamma \qquad \text{--- (8)}$$
$$\Delta E_6 = \Delta y \qquad \text{--- (9)}$$

The differential changes in the location and direction of the robot subtracted from measured sensor values are given by equations 10 to 15 as follows:

$$\Delta x = (-\Delta E_4 - \Delta E_5)/2 \qquad \text{--- (10)}$$
$$\Delta y = \Delta E_6 \qquad \text{--- (11)}$$
$$\Delta z = (-\Delta E_1 - \Delta E_2)/2 \qquad \text{--- (12)}$$
$$\Delta\alpha = (-\Delta E_2 - \Delta E_1)/2r_{x1} \qquad \text{--- (13)}$$
$$\Delta\beta = (-\Delta E_3 - \Delta E_2)/2r_{y1} \qquad \text{--- (14)}$$
$$\Delta\gamma = (-\Delta E_4 - \Delta E_5)/2r_{z1} \qquad \text{--- (15)}$$

(b) Spherical body

Figure 5 shows the six sensor contact locations on a spherical body. Each sensor is inclined by 45 degrees so that it contacts the spherical surface at an angle of about 90 degrees.

As in a rectangular parallelopiped, equations 16 to 22 give the approximate relationship between the displacement of each sensor and the differential changes in the location and direction of the robot. r_x, r_y, and r_z are the radiuses of gyration around the axes. It is assumed that the robot rotates in the center of the sphere (Figure 5).

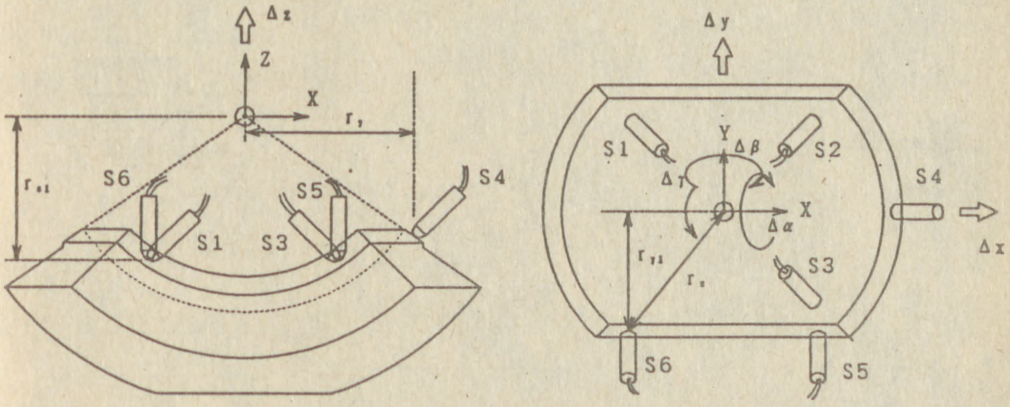


Figure 5 Sensor contact position (spherical body)

$$\Delta E_1 = -(\Delta x + \Delta y + \Delta z)/\sqrt{2} \quad \text{--- (16)}$$
$$\Delta E_2 = (\Delta x - \Delta y - \Delta z)/\sqrt{2} \quad \text{--- (17)}$$
$$\Delta E_3 = (\Delta x + \Delta y - \Delta z)/\sqrt{2} \quad \text{--- (18)}$$
$$\Delta E_4 = -(\Delta y + \Delta z)/\sqrt{2} - r_y\Delta\beta \quad \text{--- (19)}$$
$$\Delta E_5 = (-\Delta x + \Delta y + \Delta z)/\sqrt{2} - r_x\Delta\alpha - r_z\Delta\gamma/\sqrt{2} \quad \text{--- (20)}$$
$$\Delta E_6 = (\Delta x + \Delta y + \Delta z)/\sqrt{2} - r_x\Delta\alpha - r_z\Delta\gamma/\sqrt{2} \quad \text{--- (21)}$$

where $r_x = \sqrt{(r_{y1}^2 + r_{z1}^2)}$

Differential changes in the location and direction of the robot subtracted from measured sensor values are given by equations 23 to 28 as follows:

$$\Delta x = \sqrt{2}(\Delta E_2 - \Delta E_1)/2 \quad \text{--- (23)}$$
$$\Delta y = \sqrt{2}(\Delta E_3 - \Delta E_2)/2 \quad \text{--- (24)}$$
$$\Delta z = -\sqrt{2}(\Delta E_1 - \Delta E_3)/2 \quad \text{--- (25)}$$
$$\Delta\alpha = (\Delta E_5 + \Delta E_6 + \sqrt{2}(\Delta y + \Delta z))/2r_x \quad \text{--- (26)}$$
$$\Delta\beta = (\Delta E_4 - (\Delta x - \Delta z)/\sqrt{2})/r_y \quad \text{--- (27)}$$
$$\Delta\gamma = (-\Delta x + \sqrt{2}(\Delta E_5 - \Delta E_6)/2)/r_z \quad \text{--- (28)}$$

3.2 Positioning

Equations 8 to 13 for a rectangular parallelopiped and equations 20 to 25 for a spherical body are approximate. Therefore, if the differential changes given by equations 10 to 15 and 23 to 28 are input to a robot, sensor values do not converge (when $\alpha = 1.0$ in Figure 6). It is also difficult to reduce ΔE_i to zero because of the measurement error due to the measuring device. Therefore, the robot is moved gradually to the target position by multiplying the sensor displacement to the position by α (convergence coefficient, $0 < \alpha < 1.0$) as in equation 29. This operation is repeated until equation 30 holds for threshold value H.

$$\Delta E_i = \Delta E_i \times \alpha \quad (i = 1 \text{ to } 6) \qquad \text{--- (29)}$$

$$|\Delta E_i| \leq H \quad (i = 1 \text{ to } 6) \qquad \text{--- (30)}$$

A position at which equation 30 holds for the values measured by the six sensors is treated as the target location. Figure 7 shows the processing flow.

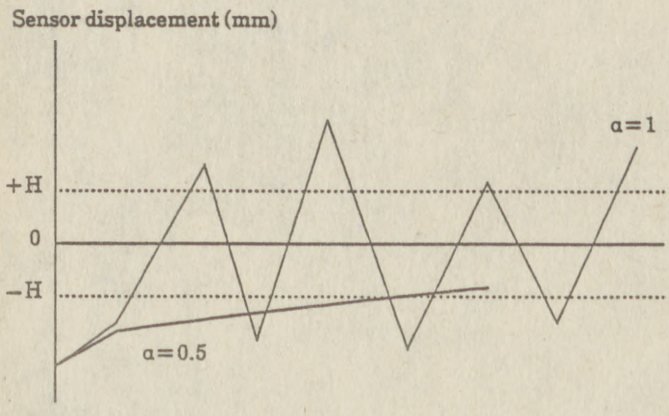


Figure 6 Displacement of sensor value

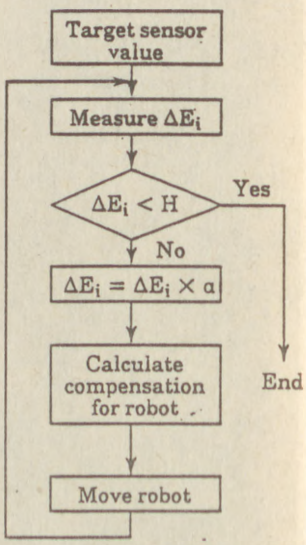


Figure 7 Processing flow

4. EXPERIMENTS AND RESULTS

To prove the effectiveness of this method, we did the experiments below.

System configuration

We used the FAROT-M6-315 6-degree-of-freedom, jointed robot (Figure 1), a differential detector (resolving power: 1 μm), and a personal computer. The computer compares the value measured by the sensor with the target value. Based on the result, the computer compensates for the location and posture of the robot to move it to the target location. Figure 8 shows connections between devices.

Operation

Experiments were made for two different types of operation. Marking lines were provided as references on the end effector and objects used in the experiment.

(1) Operation 1 aligns the marking lines on the end effector (rectangular parallelopiped) with the corresponding lines on each of four blocks in different locations so that there is a definite clearance between the end effector and the block (Figure 9).

(2) Operation 2 converts the end effector and objects into spherical bodies and positions them like a rectangular parallelopiped (Figure 2).

Figures 3 and 5 show the contact locations of the six sensors.

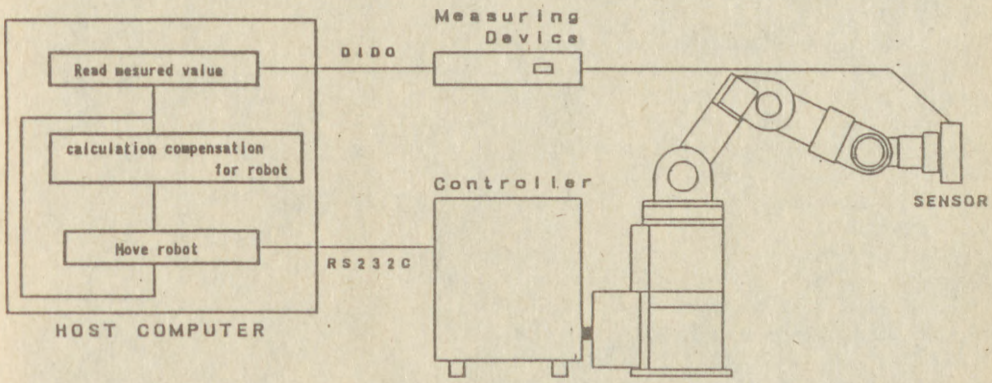


Figure 8 System configuration

Experiment 1: Measuring the number of convergences
To measure the number of convergences, object 2 was positioned automatically in operation 2 while changing the threshold value and the convergence coefficient. Tables 1 and 2 list the results. In the experiments below, the convergence coefficient was set at 0.75, at which the number of times convergences occurs is minimized, and the threshold value to 0.02 mm.

Table 1 Threshold value and number of convergences

Threshold value	Average number of convergences	Average convergence time
0.05 mm	6	12 s
0.02 mm	10	20 s
0.01 mm	18	35 s

Table 2 Convergence coefficient and number of convergences

Convergence coefficient	Average number of convergences
1.0	Divergence
0.75	10
0.5	15
0.25	24

Experiment 2: Measuring positioning time and error

To evaluate positioning data, we generated positioning data by online teaching, i.e., it was generated offline and corrected manually.

After that, we measured sensor values at positioning locations. In measurement, online teaching data for object 1 was used as a reference. We moved the robot to other objects to perform automatic positioning. Table 3 lists the results of a comparison between this method and online teaching. Table 4 lists the slippage between marking lines in operation 2. Figure 10 shows the end effector positioning locations for objects 2 and 3 (end effectors indicated by dotted lines, 50 .times enlarged slippage).

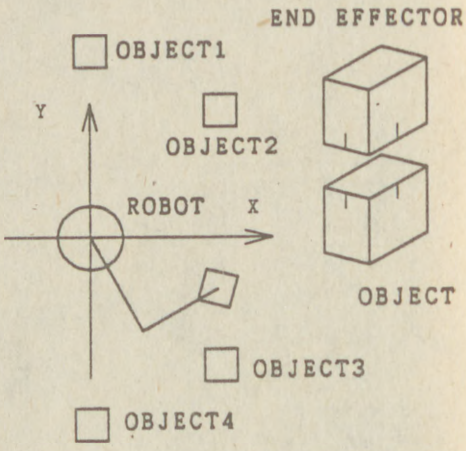


Figure 9 Work model

Table 3 Results

	Operation 1		Operation 2	
	Online teaching	This method	Online teaching	This method
Time for teaching	30 min	20 s	180 min	20 s
Difference	—	0.06 mm	—	0.10 mm

Table 4 Slippage between marking lines (operation 2)

Object	X	Y	Z	α	β	γ
1	0.0	0.0	0.0	0.0	0.0	0.0
2	−0.029	0.043	0.013	0.01	−0.009	0.0
3	0.101	−0.098	0.018	−0.117	−0.094	0.072

Unit: XYZ: mm; αβγ: degree

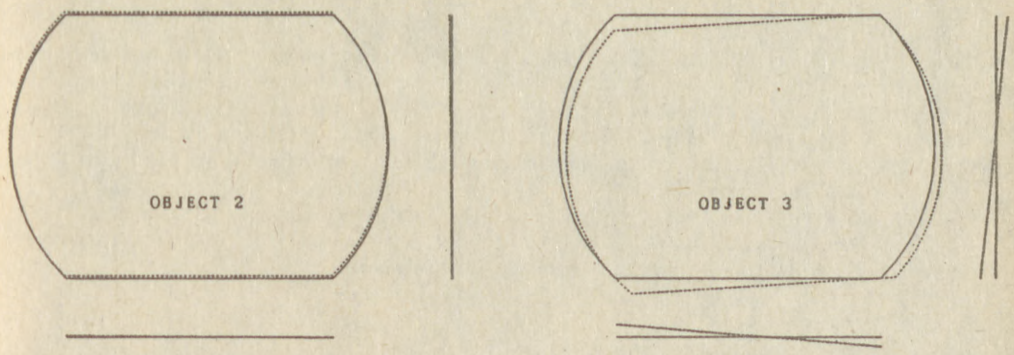


Figure 10 Slippage of end effector

Experiment 3: Measuring repeatable accuracy
To measure the repeatable accuracy of the robot end location, we repeated automatic positioning for object 2 in operations 1 and 2. Table 5 lists results.

Table 5 Repeatable accuracy

	Operation 1	Operation 2
Repeatable accuracy	±0.03 mm	±0.04 mm

Experiment 4: Effect of changing the solution type
We generated data for object 2 in operation 2 while changing the type of solution for robot posture. Changing the type of solution had no effect on the slippage between marking lines, but it caused a robot slippage of about 0.2 mm.

5. DISCUSSION

To prove the effectiveness of our method, we did experiments using simple two-dimensional operation and complex three-dimensional operation.

① Our method greatly reduced the time needed for teaching. (Experiment 2) If one end effector location and one object location are determined, teaching is not required for objects of the same shape. Therefore, this is effective in processing multiple objects of the same shape.

② There was a great difference in data generation time in online teaching for two-dimensional operation (rectangular parallelopiped) and three-dimensional operation (spherical body). Our method practically eliminated the difference. (Experiment 2)

This is because our method, which pays attention to the positional relationship between an object and an end effector, is not effected by the complexity of the shape of the object.

③ Equations 10 to 22 and 23 to 25 indicate that, when the threshold value (±0.02 mm) set in the experiment is used, the slippage between marking lines will be ±0.02 mm for a rectangular parallelopiped and about ±0.03 mm for a spherical body. Thus, the repeatable accuracy data (±0.03 mm and ±0.04 mm) obtained in experiment 3 is satisfactory for the robot positioning accuracy.

④ For object 3 in operation 2, great slippage occurred (Table 4, Figure 10). When the slippage is substituted in equations 16 to 21, they give about 0.1 mm as the displacement of each sensor.

Possible causes are:
- Error due to the threshold value
- The contact sensor was bent when it came into contact with an object.
- Error due to the measuring device
- Differences in shapes of objects 3 and 1 (reference)

⑤ In experiment 4, changing the type of solution causes no slippage when the robot has no error. The possible cause of the slippage of about 0.2 mm is an error in the robot, such as the eccentricity of the rotary shaft of the fourth, fifth, or sixth joint. It was confirmed that errors in a robot can be ignored when this method is used.

⑥ The degree of automation is raised with the improved collection and storage of reference data for each operation.

6. CONCLUSION

This report presented a method that uses sensors in automatic positioning to enable a robot to recognize the location and posture of an object. Experiments confirmed the effectiveness of the method:

- This method reduces the time for teaching.
- Work can be done in a definite time, whether it is simple or complicated.
- This method is makes it easy to replace or repair a robot if an accident occurs.
- Data can be easily generated when multiple robots are to do the same work.

The following problems remain

- A model is required for online teaching and for learning reference data.
- A measuring hand provided with sensors must be replaced with an actual hand during actual work. This causes errors.

REFERENCES

1) R. P. Paul: Robot Manipulators: Mathematics, Programming, and Control. MIT Press (1981)
2) H. Wada: Teaching System for Coordinated Two-Arm Controller, Proceedings of the International Symposium and Exposition on Robots, pp. 983-997

PART-MIX ALLOCATION BETWEEN AUTOMATED AND CONVENTIONAL MANUFACTURING: IMPROVED SOLUTION BOUNDS

M. Sinan Kayalıgil
Industrial Engineering Department
METU , Turkey 06531

1. Introduction

Manufacturing firms acquiring automation face a number of managerial problems. Among the most critical of these issues three have attracted considerable interest: (a) whether automation in one form or another is justified (e.g. Canada [2], Miltenburg [11], Wabalickis [15], Keller *et al.* [9]), (b) patterns of acquisition through time (e.g. Klincewicz and Luss [10],Gaimon [4]), (c) how best to utilise automated facilities together with the less capable (i.e.,less flexible) productive capacities (e.g. Hutchinson *et al.* [6] ,Avonts *et al.*[1], Gupta *et al.* [5]). Work in areas (a) and (b) have mostly been concentrated on overall evaluations whereas operational aspects (e.g., part-machine grouping, processing capacities, system performance) are emphasised more in studies that address problems in (c).

It is considered that most existing manufacturing firms acquiring automation are at a position to decide upon how best to utilise the *combined* capability of their existing (assumed here as conventional) and newly acquired capacities. Gaimon [4] , Gupta *et al.* [5] ,Avonts *et al.*[1] and Kayalıgil [8] point out that automated (or flexible) and conventional (or inflexible, dedicated) facilities are to operate in a coordinated manner to achieve higher system performance.

Our motivation is mainly to support the decision making on the introduction of automation by identifying its relative contribution. The combined operation of automated and conventional systems is analysed via a simple model. However, distinguishing features of flexibility and processing rate differences are captured to a certain extent.

We propose improved lower bounds on optimal solutions suggested in an earlier version of the work reported here, Kayalıgil [8].

2. The Model

The production facility is assumed to be supplying a MRP environment.
Hence, demand occurs for similar part types in different proportions within every "time bucket". Finished items are transferred to succeeding departments immediately as they get through.

Conventional facilities are set up each time product types change. Hence, to reduce switchovers lot sizing becomes critical. Since the conventional shop (CS) is assumed to be set up for a single product each time, it can be taken as a single stage production for approximate evaluation.

Automated production (AS), on the other hand, has the capability to carry out multiproduct

manufacturing without major switchovers due to its inherent process flexibility. Items in the AS are produced in unit sized lots .Total costs calculated for every facility unifies the completion time and inventory carrying performances. The sum of AS and CS costs reveals the relative benefit of a specific part mix allocation.

2.1. Total Cost of CS Operation

Let there be N total number of part types and,
J_C : set of part types manufactured in CS,
in all the following $j \varepsilon J_C$
P : number of part types to be produced in CS ($P <= N$), D_j : demand for part type j, H_j : unit holding cost of item j in the CS, C_j : unit time cost of item j in the CS, t_j : unit processing time of item j (at the slowest machine) in the CS , s_j : set up time for item j in the CS, f_{ij} : flow time of the i th item produced of type j, $i=1,2,....,D_j$, k_j : number of set ups for item j in CS.
Then total cost of operation for the CS becomes:

$$C_C(J_C) = \sum_{j \varepsilon J_C} \sum_{i=1}^{D_j} H_j f_{ij} + \sum_{j \varepsilon J_C} C_j (k_j s_j + t_j D_j) \qquad (1)$$

Individual flow times, f_{ij}, depend on the lot sizing and sequencing decisions given the part mix allocation to CS.

2.2. Total Cost of AS Operation

Let,
J_A : Set of part types manufactured in CS,
in all the following $j \varepsilon J_A$
S : number of part types to be produced in AS ($S <= N$), M : number of stations in the AS, h_{ij} : unit holding cost of item j waiting for process at station i, $i=1,2,...S$, c_j : unit time cost for item j in the AS, where

$$c_j = C_J' + U_j (D_j/2) \qquad (2)$$

C_J' : unit time cost of utilizing AS by item j, U_j : unit time cost of holding unprocessed item j (prior to entry), X_j : average production rate of item j in AS, l_{ij}:average work-in-process inventory of item j carried at stage $i,i=1,2,..,S$

Then total cost of operation for the AS becomes:

$$C_A(J_A) = \sum_{j \varepsilon J_A} c_j (D_j/X_j) + \sum_{j \varepsilon J_A} D_j/X_j \sum_{i=1}^{S} h_{ij} l_{ij} \qquad (3)$$

Equation (2) can be justified by visualising the declining amount of unprocessed type j items ($j \varepsilon J_A$) through time at the average rate of X_j. $D_j/2$ then becomes the time average of the amount carried at a unit cost of U_j.

3. Cost Optimization with Given Part Mix Allocations

Given a part mix allocation to the CS and AS as J_C and J_A, respectively the total cost becomes the sum of two separate functions :

$$C(J_C,J_A) = C_C(J_C) + C_A(J_A) \qquad (4)$$

Minimisation of $C(J_C,J_A)$ can be achieved via minimizing $C_C(J_C)$ and $C_A(J_A)$ separately. The minimisation of $C_C(J_C)$ involves optimizing over a feasible set of item flow times $\{f_{ij}\}$, which is determined by the number of set ups for each item k_j, and by the sequence of lots.

Dobson *et al.*[3] show that the first expression in (1) can be minimized by a single set up for each item and a particular index sequencing like the well known "covert" rule for minimising weighted mean flow time in single stage manufacturing. However, since $k_j=1$ for all $j\varepsilon J_C$ yields the minimum that the second expression in (1) can attain, the overall minimum will be achieved taking the approach in Dobson *et al.* [3].

The proposed rule requires the lots for relevant part types to be sequenced such that

$$\frac{s_{[1]} + t_{[1]}\, D_{[1]}}{D_{[1]}\, H_{[1]}} < \frac{s_{[2]} + t_{[2]}\, D_{[2]}}{D_{[2]}\, H_{[2]}} < \cdots\cdots\cdots < \frac{s_{[P]} + t_{[P]}\, D_{[P]}}{D_{[P]}\, H_{[P]}} \qquad (5)$$

where [i] indicates the ith part type in the sequence. This rule is quite advantageous when used in a search procedure over different part types, since relative positions of part types stay the same in any such combination.

Minimisation of $C_A(J_A)$ requires the determination of average production rates and average in-process inventory levels, X_j and l_{ij}, respectively for all $j\varepsilon J_A$ being simultaneously manufactured in the AS.

AS is taken as a closed system of network of queues and the steady state values of AS performance are calculated.

3.1 Mean Value Analysis (MVA)

Reiser and Lavenberg [12] proposed an iterative procedure to calculate mean throughput rates and queue sizes in a closed network of queues with exponential service times and multiple classes of customers. In order to relieve the excessive computational requirements with large numbers of classes, various approaches have been proposed to obtain approximate results via MVA (e.g. Schweitzer [13], Zahorjan *et al.* [16]).

Suri and Hildebrandt [14] demonstrated how approximate MVA can be applied to the analysis of automated multiproduct manufacturing systems.

Adopting the notation of Suri and Hildebrandt [14] let,
i : index of a station of the automated system, $i=1,2,\ldots,M$, j_r : index of a specific routing for part type j, $j=1,2,\ldots,S$, N_{jr} : total number of type j parts on route r circulating in the closed network, $T(i,j_r)$: mean service time at station i on route j_r,

$V(i,j_r)$: mean number of visits of a type j part on route r to station i, $R(i,j_r)$: mean time spent by a type j part on route r at station i in the steady state, $X(j_r)$: mean throughput rate on route r for part type j

Average production rate of part type j is the sum of mean rates over all the routes applicable. Therefore,

$$X_j = \sum_r X(j_r) \qquad \text{for all } j \varepsilon J_A \qquad (6)$$

Every part spends a waiting (if queue is not empty) and a processing time at every station it visits on its route. Hence, deducting the process time $T(i,j_r)$,from the mean total waiting period at a station $R(i,j_r)$, the mean waiting time in front of station i on route r is found for the part type j.

Then, the well known Little's Law (i.e.,$L=\lambda.W$) reveals that

$$I(i,j_r) = V(i,j_r) \cdot X(j_r) \cdot (R(i,j_r) - T(i,j_r))$$

where $I(i,j_r)$ is the average work-in-process inventory level over time at station i on route j_r. In order to find the total average WIP carried for every part type j at station i , $I(i,j_r)$ values need to be accumulated over all applicable routes visiting station i

$$I_{ij} = \sum_r I(i,j_r) \qquad \text{for all } i=1,2,\ldots,M \text{ and } j \varepsilon J_A \qquad (7)$$

Equations (6) and (7) supply the necessary performance measures for the AS to compute relevant operation cost $C_A(J_A)$, given an allocation J_A.

3.2 Cost Minimizing Route Allocations In AS

Mean values of throughput rates and work-in-process inventory levels depend on the number of each part type allocated to a route, N_{jr}. These allocations in turn affect resulting operation cost.

Given a part-mix allocation J_A for automated manufacturing, optimal allocation to routes is performed by Complex Search method proposed by Box as a modification of the Nelder and Mead's Simplex Method (both in Jacoby *et al.* [7]).

4. Optimal Part Mix Allocations

Part allocation between automated and conventional manufacturing systems AS and CS is implicitly enumerated by a tree search. A level of the tree represents part mixes consisting of identical number of part types produced in the automated facilities. Each node in the tree corresponds to a particular part-mix for the automated manufacturing.

Let J denote the set of all parts to be produced with N parts in total. In any particular solution, set J is partitioned into two subsets, J_A and J_S for the automated and conventional manufacturing,respectively. Hence, $J = J_A \cup J_S$.

There are 2^N-1 nodes in the tree over the N levels as a whole.

Every part mix allocation considered in the tree search is evaluated in terms of its total costs, and if found better than any other solution until then, that solution is made the incumbent.

In order to curtail the nonpromising part mix allocations and to arrive at the optimal allocation without going into the total enumeration of all possible solutions, two additional schemes are proposed. They both have demonstrated significant savings in our experimental runs.

4.1 Lower Bounds on Total Costs

Optimal cost of automated production , $C_A^*(J_A)$ is a nondecreasing function as new part types are added to the existing part mix. This is somewhat justified (but not proven yet) since manufactured parts interact more with one another (i.e., block each other more) with extra part types .

Hence it is taken that,

$$C_A^*(J_A \cup J_B) \geq C_A^*(J_A) + C_A^*(J_B) \qquad (8)$$

Moreover, extra cost due to the interaction of part types in J_A with those in J_B (or vice versa) can be added to the lower bound. Let us take J_A as {a,b} and J_B as {c,d,e}.

Then the extra cost of interaction $C_I^*(J_A|JB))$ becomes :

$$\begin{aligned} C_I^*(J_A|J_B) &\geq C_A^*(\{a,b,c\}) - C_A^*(\{a,b\}) - C_A^*(\{c\}) \\ &\quad + C_A^*(\{a,b,c,d\}) - C_A^*(\{a,b,c\}) - C_A^*(\{d\}) \\ &= C_A^*(\{a,b,c,d\}) - C_A^*(\{a,b\}) - C_A^*(\{c\}) - C_A^*(\{d\}) \end{aligned} \qquad (9)$$

This inequality states that extra cost of interaction will be at least as large as the sum of interaction costs resulting from appending elements of J_B to J_A in an accumulated manner. Similarly, another lower limit to the extra cost of interaction can be obtained by calculating $C_I^*(J_B|J_A)$.

Hence the lower bound in (8) can be improved through the effect of interactions as:

$$C_A^*(J_A \cup J_B) \geq C_A^*(J_A) + C_A^*(J_B) + \text{Max.}\{ C_I^*(J_A|J_B),\ C_I^*(J_B|J_A)\} \qquad (10)$$

For a given automated manufacturing part mix J we would like a lower bound on the optimal cost as high as possible.

$$LB(J) = \max_{J_A, J_B = J - J_A} \{ C_A^*(J_A) + C_A^*(J_B) + \text{Max.}\{ C_I^*(J_A|J_B),\ C_I^*(J_B|J_A)\} \} \qquad (11)$$

Equation (11) requires optimal solutions to all part mixes that are subsets of J to be evaluated prior to branching to J . Hence, a breadth-first type branching is needed throughout the tree search.

4.2. Sort Heuristic for Node Selection and Branching

The node to branch from represents a part mix for AS manufacturing. The node selection rule applied is to branch from the node with the lowest total cost or the least lower bound. The tree search procedure branches to a new node by releasing a part from CS and appending that to the AS mix. If part types are released from the CS mix such that the released is the part type causing the largest saving for CS manufacturing among the existing CS part mix, chances of arriving at an improved solution will be enhanced.

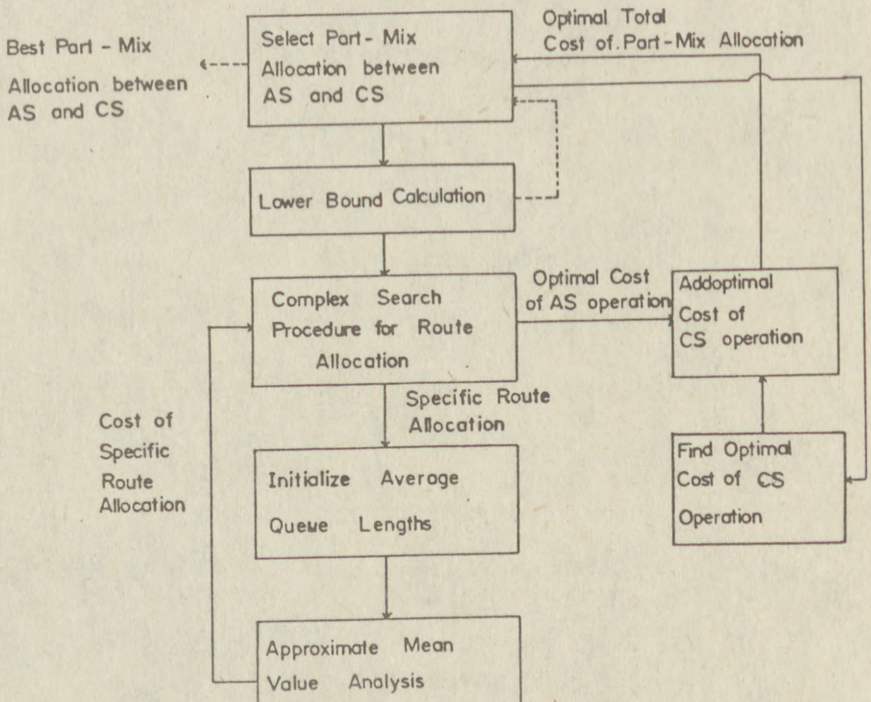
Examining the index sequencing (5) reveals that a part type in an earlier position of the optimal sequence will reduce total CS manufacturing costs higher than the release of any other part later in the sequence. The sort heuristic for branching is to branch to part types in the same order as they are sequenced by (5).

Figure 1 illustrates the operational flow of the tree search in connection with the approximate MVA and the Complex Search procedures.

5. Experimental Runs

Experimental runs are carried out to demonstrate how the potential benefits of introducing automation in combination with a given conventional system are identified using the proposed approach.
Throughout the experimental runs CS characteristics are held constant. Changing the unit time cost of operating AS relative to CS , the dependence of part mix allocations to unit cost differentials are analysed. Effects of flexibility as determined by the proposed approach are identified by introducing routing alternatives in the AS .

Figure 1. Operational Flow of the Overall Procedure



The combined system (CS and AS) is assumed to produce 5 part types within the allowed time (during which no new orders arrive). Demand for the parts are assumed independent and uniformly distributed all with mean 50. Three of the 5 part types have lower variance (U[30,70] is used) than the remaining two part types for which U[5,95] is used in generating demands.

Processing rate in the slowest CS machine is assumed less than the slowest stage in AS processing. This is justified since otherwise there could be little incentive to allocate some production to the AS for the unit costs assumed.

Data for the CS manufacturing is as follow: s_j = 20 time unit, t_1, t_2, t_3 = 12 time units, t_4 = 6 time units, t_5 = 4 time units, H_j = 0.002 units/item-time, C_j = 0.1 units/time

Table 1. Data for AS Manufacturing
Mean Processing Times (time units)

		Flexible Configuration Stations				Inflexible Configuration Stations			
Route No.	Part	1	2	3	4	1	2	3	4
1	1	1	2	3	-	1	2	3	-
2	1	-	3	2	1				
3	1	-	-	-	8				
4	2	2	5	-	-	2	5	-	-
5	2	-	5	-	2				
6	3	5	2	-	-	5	2	-	-
7	3	5	-	-	2				
8	4	3	3	3	3	3	3	3	3
9	4	-	-	5	5				
10	5	1	1	1	-	1	1	1	-

Parameter Sets

Set 1 : c_j = 0.2 units/time

Set 2 : c_j = 0.5 units/time

Set 3 : c_j = 0.8 units/time

Table 1 displays the data for the experimented automated system parameters. Three sets of unit time cost for AS as shown in the table are examined.

5.1 Results

The statistics of experimental runs are based on 10 randomly generated demand vectors implemented in two configurations (flexible and inflexible) and three sets of unit time AS costs. Thus in total 60 instances have been solved.

Table 2 displays C^* and s which are the average and sample standard deviation of optimal costs respectively.

C^* increases, as expected, with the unit cost of AS. Although increases in unit costs are 150% and 300% of the lowest unit AS cost (i.e., 0.2) , the increases in the average optimal costs are 50% and 78% respectively in the flexible configuration combined with the CS. For the inflexible configuration the corresponding percentage increases are 46% and 63%.

The inflexible configuration yields optimal costs 15%, 12% and 6% above the optimal costs in the flexible configuration for consecutive parameter sets, respectively.

Optimal total costs of all AS manufacturing illustrates the benefits of using the two facilities (AS and CS) in combination. Optimal total costs go up dramatically to the point where an automated system is not justified (with respect to savings in operational costs alone) compared to the all CS manufacturing as unit costs increase . Only if unit costs are more than those of CS by 100% will it be beneficial to use all AS instead of all CS manufacturing for the assumed increase in processing rates.

Table 2. Comparison of Average and Standard Deviations in Optimal Costs

	Flexible		Inflexible	
	Combined	All AS	Combined	All AS
Set 1 (c_j=0.2)	C^*=338 s = 69	C^*=486 s = 92	C^*=391 s = 90	C^*=670 s = 134
Set 2 (c_j=0.5)	C^*=511 s =109	C^*=1185 s = 223	C^*=571 s =124	C^*=1644 s = 334
Set 3 (c_j=0.8)	C^*=603 s = 141	C^*=1892 s = 348	C^*=641 s = 145	C^*=2597 s = 520

Optimal Total cost of All Conventional Manufacturing

C^*_A= 804
s = 179

Table 3 supplies part mix allocation frequencies to the AS under different parameter settings and flexibility.

Table 3. Part Mix Allocation Frequencies

	Flexible		Inflexible	
Parameter	Part Mix	Frequency	Part Mix	Frequency
Set1 (c_j=0.2)	(1,2,3)	6	(1,3)	5
	(1,3)	3	(1,3,5)	2
	(2,3)	1	(2,3)	2
			(1,2)	1
Set 2 (c_j=0.5)	(1,3)	10	(1,3)	5
			(1)	3
			(1,5)	1
			(5)	1
Set 3 (c_j=0.8)	(1)	8	(1)	7
	(1,5)	1	(5)	3
	(1,3)	1		

Item 4 never appears in the allocation to AS since its processing in CS is relatively faster than others. Items 1 and 3 are selected most frequently since their processing on automated stations create less congestion than other combinations. It could be stated that flexibility causes a more robust (less varying) allocation in the face of demand variability.

Table 4 compares average flow times of the most frequently allocated items (i.e., items 1 and 3).

Table 4. Comparison of Average Flow Times for most Frequently Allocated Items

	Flexible		Inflexible	
Parameter	Item 1	Item 3	Item 1	Item 3
Set 1 (c_j=0.2)	5.5	5.8	4.7	7.5
Set 2 (c_j=0.5)	2.9	5.7	3.8	7.3
Set 3 (c_j=0.8)	2.4	5.4	3.1	-

With the exception of parameter Set 1 flexible configuration leads to lower average flow times. Even in parameter Set 1 average flow time for item 3 is considerably less than its corresponding value for the inflexible configuration. The flexible configuration causes shorter average flow times than the slowest station for item 1 in two cases (2.9 and 2.4 as opposed to 3 in parameter sets 2 and 3).

Optimal allocations resulting from the proposed procedure are tested by means of simulation experiments. Solutions corresponding to Set 1 parameters for the flexible and inflexible configurations are implemented via a simulation program coded in GPSS. Experimental runs are carried out until the completion of 1000 items of each part type allocated to the AS to reach the steady state. Once the system reaches the steady state 3 runs are replicated with the generated demand vectors for every allocation. Table 5 displays mean % deviations in completion times (C^*) and work-in-process inventory levels (WIP) for the most frequently allocated mixes in the two configurations. The results indicate that even with limited sample sizes the deviations are within acceptable limits for an overall evaluation.

Table 5. Comparison of Mean % Deviation of Solution Results from Simulation Results

	Flexible			Inflexible		
	C^*	WIP		C^*	WIP
Part	Mean Δ%	Mean Δ%	Part	Mean Δ%	Mean Δ%
1	1.3	7.4	1	7.8	8.6
2	-5	14	3	1	16
3	0.3	2			

6. Conclusion

Evaluating investment proposals in acquiring automation is complicated by operational aspects of both the AS and CS if one wants to evaluate the combined facilities. However, this is an involved task and one should not avoid this necessary level of detail .

Many interesting characteristics of the proposed AS can be understood . In this regard, no "typical" set of system parameters exists general to all such firms since every case is unique in such automation acquisition decisions. Nevertheless, the methodology is more general and far reaching than solutions obtained with any specific set of parameters.

Acknowlegement : The author is indebted to Ms. Demet Ceylan for her help with coding and running the simulation experiments.

References

1. AVONTS,L.H.,GELDERS,L.F. and Van WASSENHOVE,L.N., Allocating Work Between an FMS and a Conventional Jobshop: A Case Study, *European Journal of Operations Research*, **33**, 1988,p.245-256

2. CANADA,J.R., Annotated Bibliography on Justification of Computer-Integrated Manufacturing Systems, *The Engineering Economist*, **31**, No.2, 1986,p.137-150

3. DOBSON, G.,KARMARKAR, U.S. and RUMMEL,J.,Batching to Minimize Flow Times on One Machine, *Management Science*, **33**, 1987,p.784-799

4. GAIMON,C., 1985, The Dynamic Optimal Acquisition of Automation, *Annals of Operations Research*, **3**, p.59-79

5. GUPTA,D., BUZACOTT,J.A. and GERCHAK,Y., Economic Analysis of Investment Decisions in Flexible Manufacturing Systems,Department of Management Sciences, University of Waterloo, CANADA, 1988

6. HUTCHINSON, G.K. and HOLLAND,J.R., The Economic Value of Flexible Automation, *Journal of Manufacturing Systems*, **1**,No.2, 1982, p.215-227

7. JACOBY,S.L.S., KOWALIK,J.S. and PIZZO,J.T., *Iterative Methods for Nonlinear Optimization Problems*,(New Jersey:Printice-Hall), 1972

8. KAYALIGİL,M.S., Part Mix Allocation Between Automated and Conventional Manufacturing,Technical Report,89-10, METU-IE,1989

9. KELLER,G. and NOORI,H., Justifying New Technology Acquisition Through Its Impact on the Cost of Running an Inventory Policy, *IIE Transactions*, **20**, No.3, 1988, p.284-291

10. KLINCEWICZ,J.G. and LUSS,H., 1985, Optimal Timing Decisions for the Introduction of New Technologies,*European Journal of Operations Research*, **20**, p.211-220

11. MILTENBURG,G.J. and KRINSKY,I., Evaluating Flexible Manufacturing Systems, *IIE Transactions*, **19**, No.2, 1987,p.222-233

12. REISER,M. and LAVENBERG,S.S., Mean-value Analysis of Closed Multichain Queueing Networks, *Journal of the Association for Computing Machinery*, **27**, No.2, 1980,p.313-323

13. SCHWEITZER,P., Approximate Analysis of Multiclass Closed Networks of Queues, *Proceedings of the International Conference on Stochastic Control and Optimization*, Amsterdam, The Netherlands ,1979

14. SURI,R. and HILDEBRANT, Modelling Flexible Manufacturing Systems Using Mean-Value Analysis, *Journal of Manufacturing Systems*, **3**, No.1, 1984,p. 27-38

15. WABALICKIS,R.N., Justification of FMS with the Analytic Hierarchy Process, *Journal of Manufacturing Systems*, **7**, No.3, 1988,p.175-182

16. ZAHORJAN,J., EAGER,D.L. and SWEILLAM,H.M, Accuracy, Speed, and Convergence of Approximate Mean Value Analysis, *Performance Evaluation*, **8**, 1988,p.255-270

CAQ in flexible prefabrication of concrete elements

Klöpper, Karla
Technical University "Otto von Guericke" Magdeburg, DDR

1. Introduction

The goal in the prefabricating process of concrete elements consists in producing parts of buildings with a high degree of flexibility and with best quality /1,2/.
This aim requires to use computers in all parts of the process that means for planning, manufacturing, controlling and checking. This paper deals with computer aided quality assurance (CAQ).

2. Parts of the CAQ-System

All parts of the production process contribute to the quality of the products (fig. 1) and a high degree of quality assurance is of necessity in all these parts:
- prefabricating of reinforcement
- concrete preparation
- preparing of mouldings
- placing reinforcement
- concrteting area and vibration
- hardening and removal area.

In modern factories relevant parameters (fig. 1) of this process are controlled, checked and recorded. In some cases signals appear on the monitor when a value nears or exeeds a critical region.

2.1. Prefabricating reinforcement

The aims of this part of the process consist in producing reinforcement with high quality of accurate shape and dimension. In the computer aided manufacturing of reinforcement it is possible to make an optimization of steel consumption /3/. It is also possible to print lists which contain the main data of reinforcement.
The accurate dimensions of reinforcement are of interest in point of view of covering it by concrete.

2.2. Concrete preparation

Most control equipments of concrete preparing stations consist of modular systems of hardware and software /4/.
These plants are flexible and assure the required quality of concrete. A special problem consists in the accurate measuring of moisture content of aggregates /5/.Therefore di-

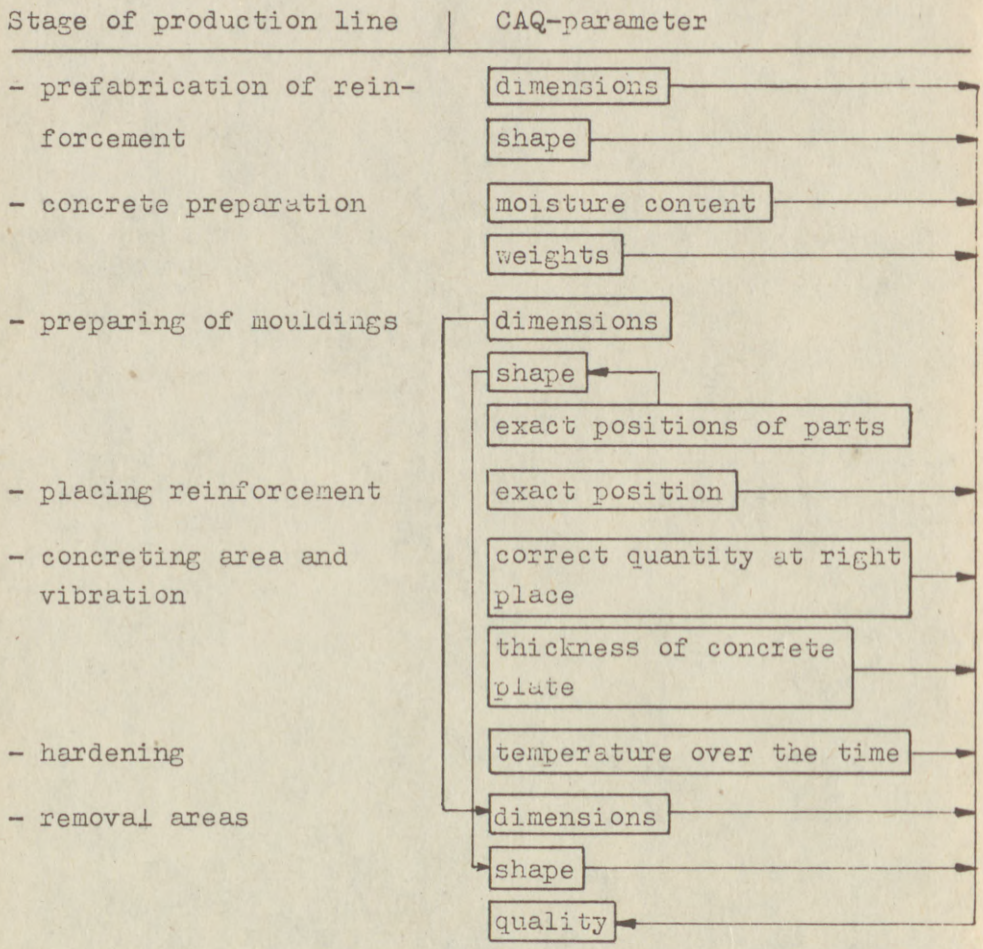


Fig. 1: Connection between CAQ-parameters

rect and indirect values are measured and used to assure the quality by means of computers.
The following functions are of interest:
- electronic precision at any stage of concrete production
- exact batching of all parts
- checking of all relevant parameters
- recording of all relevant data.

Beside this conventinal checks are made that means that samples are taken like specifications (DIN 1048, TGL 33433) dictate, tests are made and the results are also recorded.

2.3. Preparing of mouldings

As a flexible production shall be realized at shuttering station must be the possibility of flexible positioning the parts parts of the mould including the blockouts. In the CAQ-system at this part of production line checks of accurate positioning are made. In the case of fully automated operation /6,7/ the control computer receives the geometric data of elements from the central master computer. Whenn the pallet has been positioned under the machine which has the functions: magazining, cleaning, plotting, the computer causes the programmable controller to collect the transverse bulkheads, place them in the magazine and to clean the pallet. After this slab edges are marked out in the oppotite direction and when necessary bulkheads are removed. The control computer waits for the signal to start tracing. The signal comes from the PC as soon as cleaning process is finished. "This is the last possibility to intervene in the production process via function keys at the terminal"/6/. A waitung period of 20 seconds was added on order to make it possible to check wether the contours have been correctly traced. Then follows a part in the production line where longitudinal moulds and block-outs are placed manually. After this a next check is provided. This is important because mistakes in positioning of parts of the moulds lead to useless elements.

2.4. Placing reinforcement

In this part of the process reinforcement is placed partly automatically and partly manually. The pallet drive must have in this area a position measuring unit for accurate positioning because this influences the accurate position of reinforcement. The process computer outputs the production data in an optimal sequence to minimize the positioning movements of the pallet /6/. After all stations (automatic and manual) are ready a next check is provided. The accurate position of reinforcement must be guaranteed because mistakes in thickness of covering concrtte can cause failure.

2.5. Concreting area and vibration

This part of process is automated in modern factories. "Casting the concrete in the correct quantity and at the right place requires an exact control of concrete beeing poured in accordance with the slab geometry involved as well as taking account of the induvidual flow behaviour of the concrete. Dealing effiently with concrete presupposes communication with master computer, mixer and bucket conveyor."/6/ The next step is vibration of concrete. In the research work at the University "Otto von Guericke" Magdeburg we deal with such problems /8,9,10/. The main problem consists in the fact that there is no concrete inherent parameter which can be used for direct automatic control of vibration. Therefore mostly time is used as an indirect parameter for controlling the vibration process. The accurate value for special concrete depends on the special properties of the concrete which is placed in the mould.
At the end of this station concrete thickness is controlled for exactness.

2.6. Hardening and removal area

In the most factories which produce concrete elements curing chambers are used to shorten the hardening period. In these curing chambers the main parameters like temperature are controlled automatically, The relevant values are recorded.
In the most cases removal areas consist of partly manual stations. When geometrical shape shall be checked then a system can be used which was developed at the Technical University "Otto von Guericke" Magdeburg /11/. A robot combined with a CCD-camera checks the shape of the elements and it is controlled by computer. The program is comfortable and the user can easy learn to work with this software.
A protocol is printed. When the measuring robot is integrated into the system it can be realized that all relevant data also can occure at this minutes.

3. Prospects

In the international scale in the next years a lot of buildings must be erected or renewed. Possibilities are to be found to do this work in such a way that buildingd can be accepted from the point of view of aesthetics, usefullness and efficiency in the phase of erection and in the phase of use. One way to meet these goals consists in a flexible prefabrication of concrete elements /12/. Parts of the production process are fully automated and research work is going on to automate further parts. In this development CAQ must have its right position. /13/

Lite
/1/
/2/
/3/
/4/
/5/
/6/
/7/
/8/
/9/
/10/

Literature

/1/ Klöpper, K.
Prefabrication of concrete walls with the aim of higher flexibility; Proceedings of CIB-Symposium, 22. - 25.5.89 in Magdeburg/ Berlin

/2/ Trettin,Th.
CAM-solution to a flexible automation of prefabrication process in the building industry; Proceedings of CIB-Symposium, 22.-25.5.89 in Magdeburg/Berlin

/3/ Schnittlängenoptimierung mit Micro-Processor, Firmenschrift der Firma Peddinghaus, BRD

/4/ Klöpper,K.
Automatisierungsschritte bei der Umrüstung von Betonaufbereitungsanlagen; Proceedings 10. IBAUSIL, 9.-13.5.88 Weimar

/5/ Morgeneier, K.-D.
Erfahrungen und Ergebnisse bei der Feuchtemessung von Zementzuschlagstoffen; Proceedings 10.IBAUSIL, 9.-13.5.88 Weimar

/6/ Krömer,R.
CAD-CAM-Konzept in der Elemente-Produktion am Beispiel des österreichischen Fertigteilwerkes Katzenberger Betonwerk + Fertigteil-Technik 55(1989)1, Wiesbaden,BRD

/7/ Wernicke, J.
Automatisches Betonwerk: Der Schalungsroboter schließt den Kreis
Betonwerk + Fertigteil-Technik 54(1988) 6, Wiesbaden,BRD

/8/ Arnold,W.
Dynamische Untersuchungen zur Vibrationsverdichtung, insbesondere von Frischbeton - 1983 Magdeburg; Techn. Hochschule, Wissenschaftlicher Rat, Dissertation B

/9/ Arnold,W.; Helm,M.; Killmey,H.
Zur Bewegung der Materialteilchen bei der Vibrationsverdichtung von Frischbeton;
betontechnik, Berlin 7(1985)6

/10/Arnold,W.
Grundsätzliches zu dynamischen Untersuchungen der Vibrationstechnik; Proceedings der Internationalen Fachtagung Baumaschinen, 17.-19.11.1987, Magdeburg

/11/ Bischoff,W.
Automatisierung von Maschinen und Prozessen im Bauwesen
Ansätze und Lösungswege
Wissenschaftliche Zeitschrift der Technischen Universität "Otto von Guericke" Magdeburg
Sonderheft CAD/CAM Juni 1990

/12/ Ehmer,H.
Rechnerintegrierte Fertigung (CIM) im Fertigteilwerk;
Beton + Fertigteil-Technik 54(1988) 11, Wiesbaden,BRD

/13/ Ulrich,P.
Rechnerintegrierter automatischer Betrieb
VEB Berlag Technik, Berlin 1990

Mutual effects in "Materials handling - logistics infrastructure"

Prof.Imre KNOLL, Ph.D.-University of Agr.Techn.Sciences
Gödöllő. Hungary.

1. Production-,materials handling- and logistics effectiveness

The Institute of Materials Handling and Logistics working within the scope of the University of Agr.Techn.Sciences in Gödöllő, cooperating with one of the labour comissions of the European Logistics Association /ELA/ led by me studied the measures needed in production process on the basis of modern logistics survey. Also the analysis of material supply ensuring the continuity of production belongs to here where the "just-in-time" principle was kept in view. The comprehensive logistics philosophy demands the optimal forming of distribution of end-products and the accounting of infrastructural factors /IS/ influencing the whole T-F process fundamentally, as well. /It should be noticed that T means the place of the beginning of the production and F is the end of the movement of products that can either be procurement, or processing or consumption immediately./

Materials handling as suborder of production has been scientifically formulated for decades. But the analysis of the interrelations of the 3 factors stressed in the headline needs the unambiguos definition of the concept of logistics being in the process of formation now in practice

The point in question is here the way of looking at things and activity scope respectively that comprehensively deals with the complex system of "supply of raw materials - production - sales".- There are four "resources" needed to its realization namely: materials, energy, live labour and information.

In that way logistics are the totality of activities connected with optimal and suitably programmed /that is organized/streaming, leading and evaluation inside the given production and distribution system or among them.

The essence of this organization is to forward the produced goods to the given destination in wanted quality, in due time and under minimal costs.- The operational leading is carried out by the logistics center consisting of some multilateral specialists and belonging directly to the leader of manufacturing factories.

2. Infrastructure and East-West connections

I want to accentuate on the widely analysed past of our

researches in this publication that explores the interrelations among the materials handling and the IS factors and logistics measures, respectively.

As the final aim of all these is the reduction of costs of the produced goods and the formation of the production-distribution process without waiting, therefore was primarily the factor R of the efficiency of material handling examined that influences the majority of further steps /included transportation as well/.

The aim of the efficiency polygonal diagram /Fig.1./ is to show even visually the linkage of factors playing determining part in material handling and distribution process, as well. It was proved that the efficiency R of the complete process depends on the road length L, and applied transportation speed /v/. The transportation time /T_o/ is determined from the previous two factors, and the measures taken to preserve the quality of the goods handled /Z/ are just influencing factors /namely deterioration is a negative factor!/.- An important parameter is the reloading factor "a " and the handling costs /K/ based on all these. Thus: t

$$R = f/L,v,T_o,a_t,K/$$

In addition to materials handling and logistics in our examined topic as a third basic factor were examined the infrastructure and its components, as well.

As an economic category it is a collective noun of such economic system of conditions, the elements of that don't directly participate in production process but they can indirectly influence the production and its development possibilities significantly. /Reckoning among them: network of roads, storage, market, and network of public utilities, etc./

The IS should be always judged according to the role playing part in the examined producing process and its dynamic technical-economic system of effect should be analysed.

Even the interrelations standing in the center of our interest can be followed well, if the connections of the 3 main fields to be discussed in a bloc-diagram /Fig.2./ are summarized. According to my opinion one of the keys is the employement of East-West connections the more effective development of connections of IS in Hungary, therefore I'd like to introduce shortly the sketched IS fields and the necessary research steps.

Freight transport necessary to the distribution of goods

a/ the character of the applied means:
- bay air, on roads, railway, waterways,
- the technical-economic parameters of means

b/ the roads used by the means, and their character, development, maintenance, operation,
- the distance taken by the means;

c/ the organization of the activity of means:
1. making the cyclical time of transportation optimal;
2. increasing the utilization factor of vehicles;
3. minimalizing the specific transport costs.

The role of storage and warehousing in the process of "production - consumption":

a/ what building structure /storing technology/ do we need? /e.g. cooling storage; automatized high warehouse/;

b/ what sort of organizational chain should it join? /It determines the storing transit times, the turn of stock, stockpiling./

An example for the mutual effects of logistics: if we have the so called "just-in-time" method of production, the storing capacity may be minimal!

The regulating role of the market:

a/ the territorial localization, the regional or overconcentrated location of the buyer's market /wholesale and retail trade/;

b/ the formation of building structure related to the above mentioned; mainly the connecting characters of materials handling and transportation as well as the mutual effects of their means /unit loads and their loading means/.

Stream of information:

a/ the necessary hardware and software /telephone, telefax, computer,etc., as well as the organizational and other programs/ must be available;

b/ the role and further education of man;

c/ data bank;

d/ mutual effect mainly with value analysis of logistics.

3. The Conclusions to be drawn from interrelationships

Our researches and analyses are unanimously proved that each factor detailed in the preceding can significantly influence the economic characters of dinamics of production -directly or indirectly- and through that of integrated multilateral information of the produced goods.

When this examination was preliminary carried out orientated on the market, the interrelations of factors were forming according to fig.3.

Also here it is unambiguous that the starting point should be meant by production, let it be means or organizational method and infrastructural element, respectively it should be subordinated to this.

But if it is concentrated on storing as an another basic fact of IS, it should be given extraordinary attention to connections according to Fig.4.

The multilateral examination of mentioned costs constituted our task as well. Only two analysis will be given as an example as follows.

If e.g. the storing questions sketched in Fig.3. and appearing as IS element, it can be made several absolute and specific value with the help of technical and economic factors. These were used during our research work realized in practice when the different characteristics of granaries were compared with evaluating numbers /Fig.5./

The four scenarios and the nine factors constitute a decision-making model with which an optimum solution can be selected, relying on the merit points already defined.

The Fig.6. belonging to these shows the relationships, where the change of goods-distribution expenses of the many times analysed K specific factor is examined, and even with the help of applying logistics methods as a function of the always improving organization.

The value of K is influenced by expenses of upkeep ratio /1/ that shows a definite decrease with the increase of the organization of the process.- As the curve of logistic organization costs /2/ is due the effect of mentioned factors, of increasing character, our goal is the searching of the minimum of the resulting curve /3/ with the summarizing of the two curves. This gives -as a matter of fact- the most favourable goods-distribution costs, and the value of R_{opt} of organization, respectively.

However there is no doubt that besides the indicated two factors even several points of view should be considered /e.g. necessity for living labour, use of vehicles,etc./, if the comprehensive effects of organization are surveyed. Only the superposition of all these inside the given technologie will create the most optimal values of organization.

4. Alterations and tasks of the immediate hence

It is an indisputable fact that the present dynamic changes of the home economic life are closely connected with the 3 discussed topics in serious developing. It should specially reckoned -among others- with such IS sugges-

tions in the international system of transportation and distribution of goods that from even economic point of view mean the increased storage demand of definite kinds of goods. As you can see in Fig.1. the negative effects of this, however increase concerning the a, multiple factor of materials handling. That is the increasing quantity of reloading works act a negative effect upon the production costs.

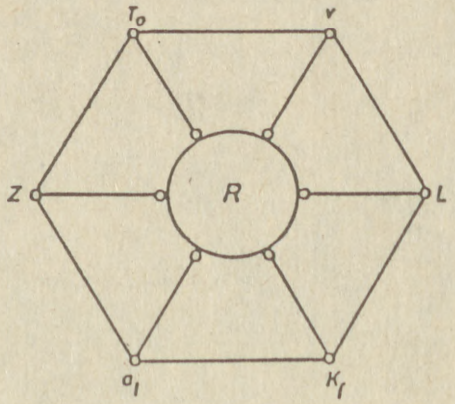
As another factor of IS is demanded specially by the branch of agriculture that in the future should be taken care of the following in an increased degree: maintenance and renewing, establishment of subsidiary roads leading to national roads and inside the factories /investment-, financial-, council- and other problems all together/.

And in the field of distribution it should be chiefly investigated the possibility of transporting goods of agricultural produce on waterways even if it needs only harbours of smaller capacity, ships /boats/ and machinery handling materials with them as well.- Here also should be investigated the questions of tariff effect on production cost of transporting.

And as an important IS problem, the changes of the tariff between national roads and railways should be worked out for a longer period in a satisfying arrangement. It is namely incorrect that the relatively often unexpected tariff modifications during the last years influence the investition of means and their utilization in a radically negative or positive direction, however in random.

The agreements among economic branches should precede the establishment of central and regional storages and that of buying up or market centres, as all these have an effect on the IS questions of settlements, as well.

And in the logistics centres it should be taken care of that fact that the materials handling, distribution of goods and the modern and concentrated organization of the IS-elements should contribute to the optimal nivelling of development of production and of its costs.



T_o - turning time
v - speed of movement of goods
L - length of the route
K_f - specific costs of movement of goods
a_t - multiple factor of movement of goods
Z - quality saving factor

Figure 1.
The polygon diagram of the efficiency of materials handling

PRODUC-TION

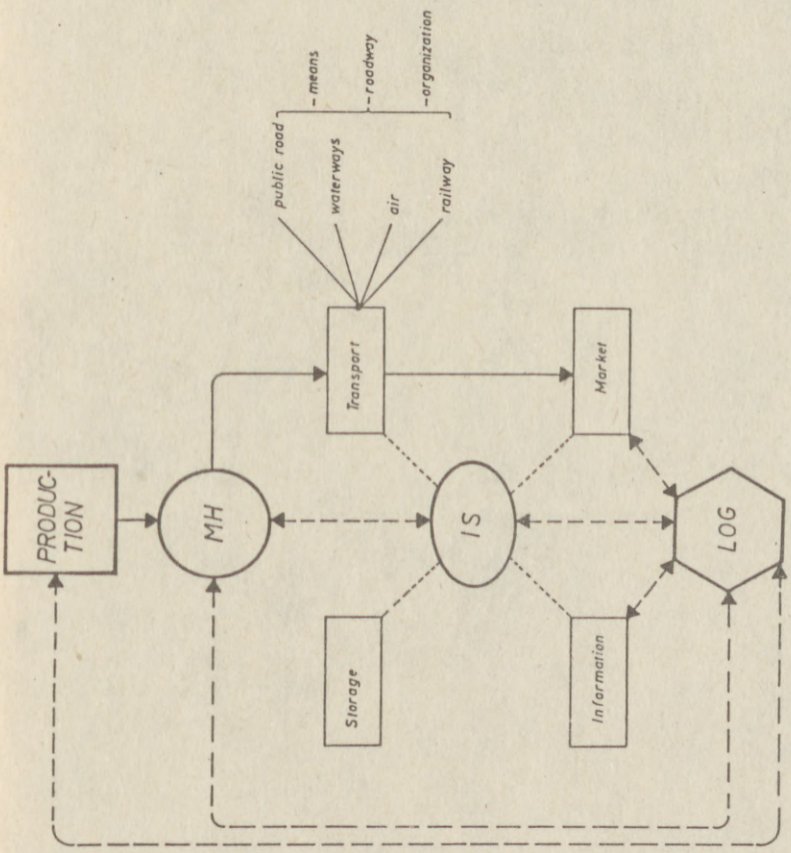


Figure 2.

Interrelations of materials handling, infrastructure and logistics

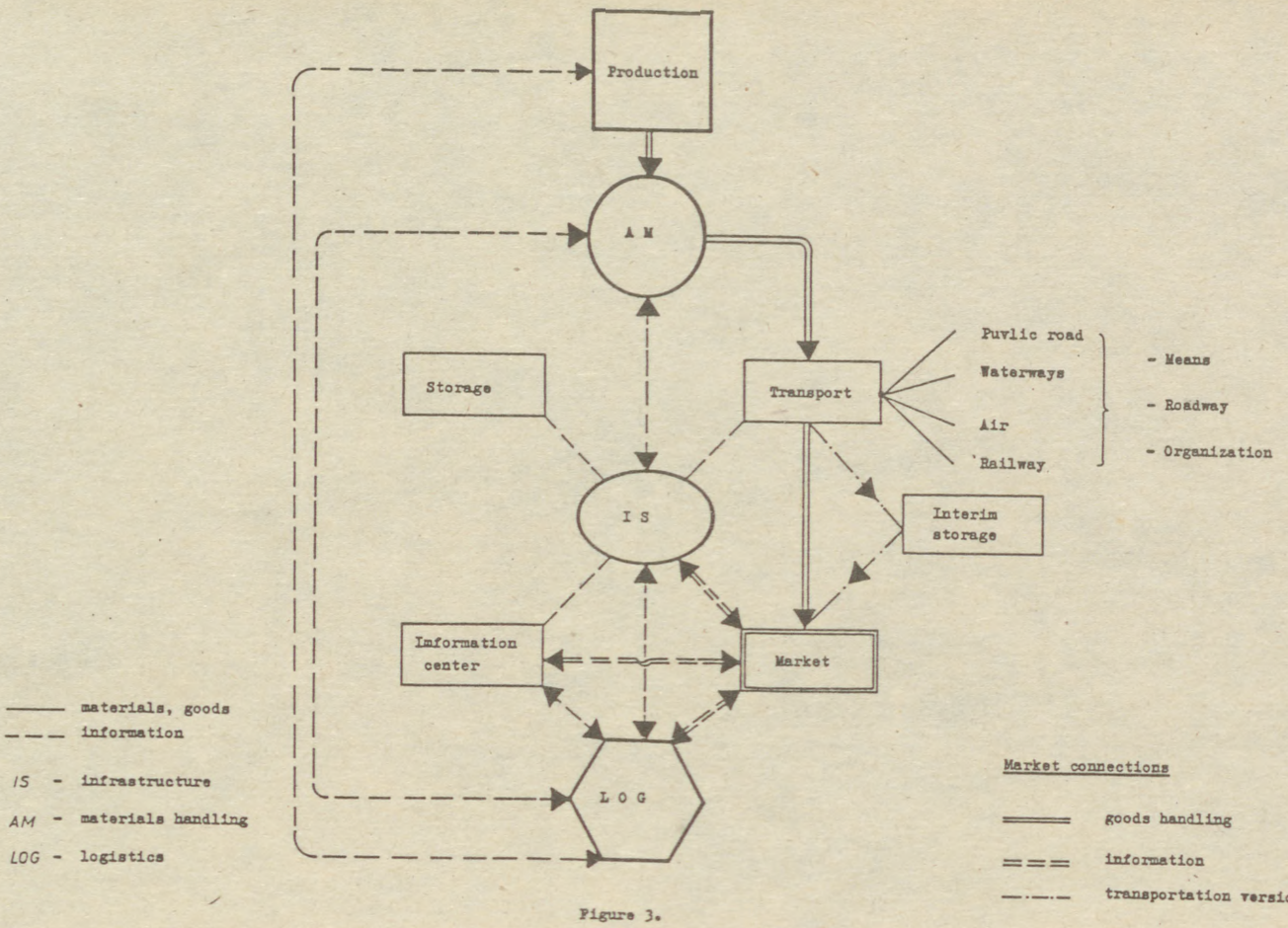


Figure 3.

The stressed role of the "market"

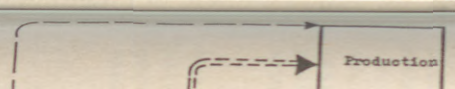


Figure 3.

The stressed role of the "market"

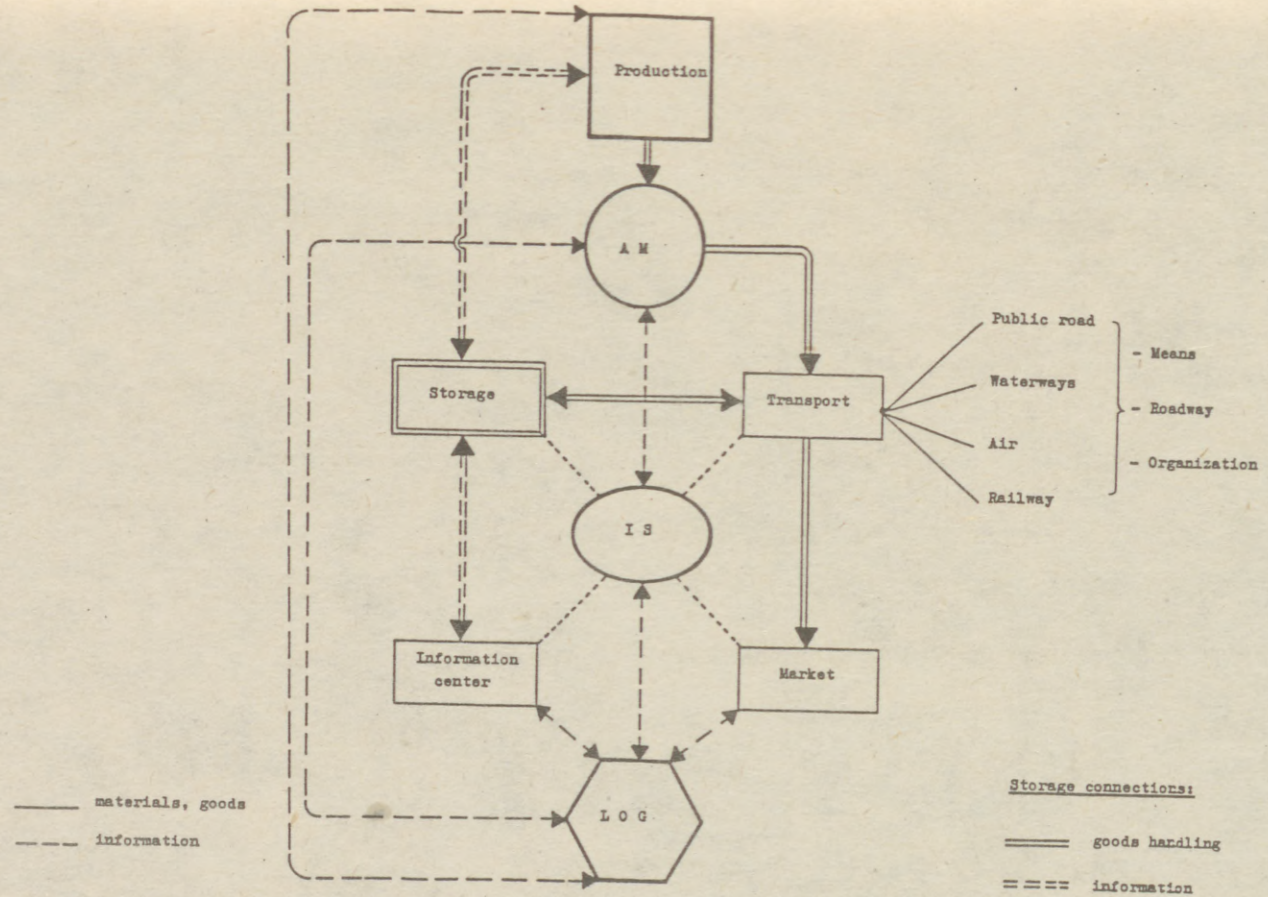


Figure 4.

The stressed role of "storage"

Features \ Types of storage facilities	Storage sheds	Flat stores	Metal silos	Reinforced concrete silos
Total specific project costs HUF/ton	8	6	4	3
Specific energy requirement, kWh/ton	8	4	3	3
Specific operating costs, HUF/ton/year	8	5	4	3
Specific maintenance costs, HUF/ton/year	9	6	4	7
Specific ventilation costs, HUF/ton/year	5	3	7	9
Rate of mechanisation	1	8	10	8
Environmental considerations	2	4	6	8
Useful life	3	6	7	9
Utility, versatility	7	10	3	3

Values:

o - 3 unfavourable, ie. high specific costs

4 - 6 medium

7 -10 favourable, ie. low specific costs.

Fig. 5.

Evaluation of grain storage facilities

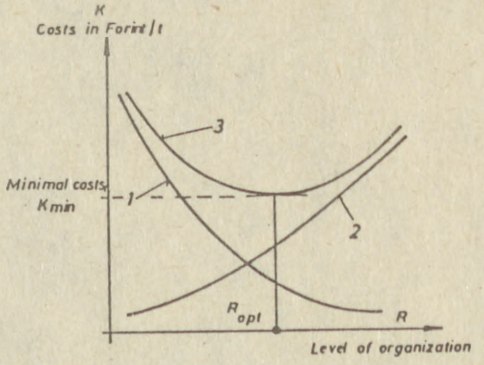


Figure 6.

The effect of logistics-organization costs on the formation of specific costs

ROBOT CONTROLLER HARDWARE FOR ARTIFICAL INTELLIGECE APPLICATIONS

Csaba Krajcsovics, TU of Budapest, Hungary
Dr. Gusztáv Arz, TU of Budapest, Hungary

In recent times the number of automation tasks requires control machines with human intelligence, increases rapidly.

One can often meet specific problems, in which the working environment, or the system itself is not exactly known .On the other hand there are a lot of systems, too complex for human experts to deal with.

In both cases recent controlling devices can not be used.

These devices operate only in environments where all the parameters, all the behaviors are well known and can be modeled mathematically. The human expert is the one, who must create the model, find the control algorithm, design the system. It seems necessary to create an artificial intelligence, with greater capabilities than the human brain's, but with all the advantages of human thinking, for substituting the human in this field too.

The difference between the recent controlling systems,and the future ones can be measured by the level of intelligence. Intelligence means problem solving capability, which is a quantitative characteristic, qualifying the efficiency of the reactions of a decision-making system.

All decision-making systems must have :

1. A control device, with
   - a model, which describes the reactions of the environment, and the control device in case of spećial events
   - information about the past, and recent state of the environment, and control device, enough to make decisions
   - an algorithm, to make a decision with the help of the two capabilities listed before
   - list of intervening actions to choose from
   - devices with enough capabilities for efficient intervening
2. An environment to be controlled, with a required goal state
3. Disturbing environmental effects

The level of intelligence is proportional to
- the quantity of information gathered, stored, processed, (about the past and recent states)
- the quality of the information storage system (objects, and their relations)
- the efficiency of the decision-making algorithm
- the efficiency of intervening

Recent systems (such as PID controllers) use these methods too. They have a fixed model of their environment, with previously selected (by a human) attributes, and quantities. The future systems will have dynamically changing model, self selected information input, and intervening output.

These tasks need new hardware, and software designs.

It seems possible to copy the human brain's informatical structures, and their processing methods. These HAI (Human Artificial Intelligence) systems will probably be based more on situation analysis, than algorithms like the computers of the present. They will collect, store, transfer, process great quantities of information. Therefore they must have more, different information sources (sensors), high capacity information storage devices, quick information transferring paths.

The huge amount of information needs special structures for efficient processing. It seems to be necessary, to create functional (more or less) independent groups of information. The future HAI hardwares need independent, parallel processing facilities, with well organized, flexible communication structures.

This paper describes a control hardware, designed at the Department of Manufacture Engineering TU of Budapest. It was planned with the help of the principles of HAI systems.

The controller was made for robotical tasks, it drives a microrobot, based on a MIT construction.[1]

1. The features of the microrobot are :

The microrobot is a six-degree-of freedom robot with a small working envelope and high accuracy.

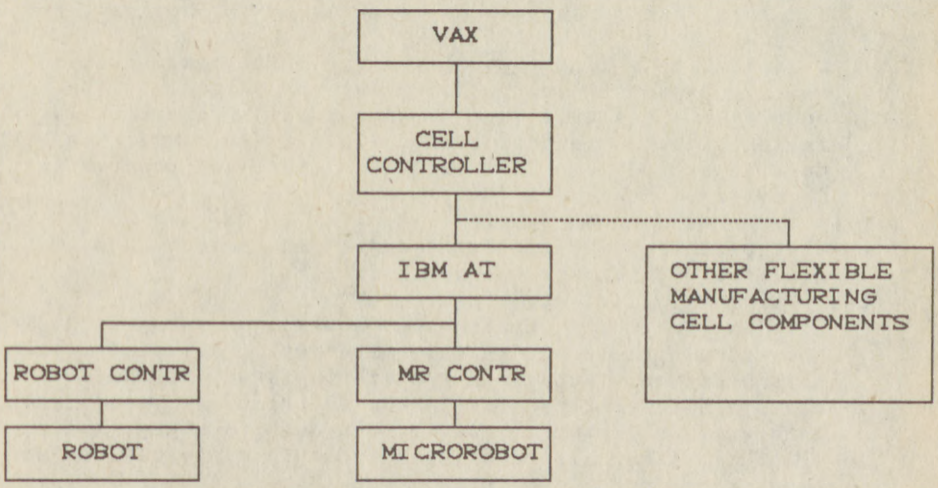
It is placed between the end plate, and the effector of an industrial robot. The basic robot moves the microrobot, and the effector to the desired place with its maximum accuracy, then the microrobot measures its absolute position, and corrects the errors.

The two robots are integrated in a flexible manufacturing cell for assembly tasks.
The microrobot provides :

- improved repeatability of an industrial robot
- an active compliance system for assembly tasks
- measuring device for assembly tasks
- practical device for testing assembling algorithms
- placed on a fix basis, works as a fine motion microrobot

2. The structure of the controller [2] :

The informatical structure of the system is hierarchical.



The VAX and the cell controller coordinates the tasks of the flexible manufacturing cell, organizes the interactions of the machines and robots, the ways of material handling.

The PC-AT receives tasks from the VAX, communicates with the robot controller, checks command executability, loads the necessary program and data into the microrobot controller, traces the execution, in case of error stores fault state, determines possible cause, re-load program for microrobot controller, sends reports to VAX.

The microrobot controller gets commands from the IBM-AT, controls, supplies sensors, and motors, checks system state, makes primitive diagnostics.

3. The detailed description of the controller tasks :

3.1. Autonomous process driving

The PC-AT works only as a commander, and diagnostican, therefore the microrobot is not driven by the PC-AT

directly. It sends only the command, but the execution method, scheduling, is worked out by the controller. In the case of normal operation the link between the PC-AT and the controller breaks off. Connections are reassigned if error occurred. The PC-AT reads all the state registers, analyses the situation, and makes decisions.

3.2. Simple command execution

To trigger a command's execution, a state register has to be written. The register is read and the command is executed by various interface cards. It can be a simple command (motor stop), setting a parameter (set speed), or a complex movement (move axis to position). It is possible for interface cards to send commands to another card too.

3.3. Sensor interfacing

Digital, and analog input lines are built into the card, to receive pressure, and position sensor signals. The card couples the electric signals, amplifies, filters them. The analog signals are digitized by 12 bit A/D converters. The data is stored on the card for further processing if necessary.

3.4. Sensor and motor supply

The specific power supply needed by the sensors and motors are also provided by the controller.

3.5. Parameter limit checking

All devices have their own working envelope. Overrun corresponds to error, in case of a well designed system. This event must appear in a state register. All cards check their own parameters. If overrun occurred, it is signaled in a state register.Serious errors interrupt the execution of other tasks. All cards have built-in circuits to avoid hardware damages. The errors are responded immediately, without using the inner bus.

3.6. Parameter level checking, and signaling

The cards are supplied with special programmable checking hardware for tracing the signals received. If a signal reaches a preprogrammed value, it had to be reported for other processes.

3.7. Error detecting

Various types of hardware error can occur during execution. (motor overload, overheating, sensor malfunction) A part of these errors can be detected by monitoring built-in sensors, other types can be recognized by specific values of other sensor data. These events must be reported for other processes.

3.8. Subroutine execution

Some tasks can be grouped for execution always in the same order. (Six force sensor measurement cycles) In this case the controller asks only for a subroutine execution, instead of commanding the sensors separately.

3.9. Data archiving

For further processing the unprocessed and processed measurement data is stored on a high capacity winchester

drive. With the help of this information all the history of the execution can be read and processed.

3.10. IBM-AT interfacing

The controller has the interface circuits to communicate through the bus. The IBM-AT can read all the state registers of the controller for diagnosing. On error the IBM-AT bus IT system is activated.

3.11. Inner bus arbitting

The inner bus is compatible with the IBM-AT bus so the IBM-PC extended cards can be used. To reach higher transfer speed the specific cards uses other features of the inner bus also built into the bus arbiter.

4. Robot controller sensors

Two types of positioning sensors are built in the controller. Incremental encoders placed on the driving motors and PSD diodes mounted on the microrobot body itself. Six-degree-of freedom force sensors drives the active compliance system.

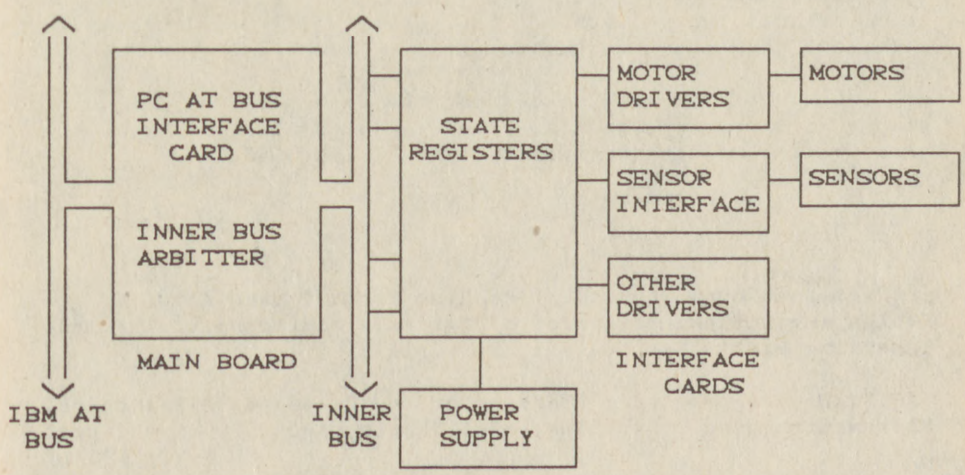
5. Robot driving

The actuators are driven by hydraulic cylinders. The valves of the hydraulic system set by stepping motors will provide a fine and even motion and a high accuracy.

Certain measures will be taken to eliminate the so called stick slip motion.

6.Hardware description of the controller :

The controller consists of two main parts. The main board, and several interface cards. The controller's main board is placed in a normal IBM-AT-slot. It has an interface for the AT bus, state registers for commands, and sensor data, power supply.



The controller is built up from MSI, and LSI components. (TEXAS 74XXX, INTEL 8XXX series) The main board contains the IBM—AT coupling circuits, address decoders, inner bus timing devices, IBM-AT communication registers, signaling circuits (Interrupt requests).

The IBM-AT communicates with the controller through I/O ports.

All the cards work independently, executing its own processing program. Each card is responsible for one specific sensor, or motor. Most of the card parameters are stored in RAM memories so the controlling software can change the way of execution easily. The motor speeds, the data sampling frequencies can be modified independently.

The cards communicate through the state registers only. The state registers' addresses can be changed by software, enabling dinamical configuration of the information structure.

Following cards are under development for the controller :
- incremental encoder interface card
- PSD sensor interface card
- position diagnostic card
- piezo pressure sensor interface card
- force diagnostic card
- stepping motor interface card
- winchester disk interface card
- subroutine driver card

Other types of interface cards, further signals of the flexible cell can be integrated into the informatical structure. The controller's main board is able to control other devices too, (lathes, robotcars) only the necessary interface cards have to be designed.

Because of the modular design, the system can be built up step by step. Installing more interface cards, the capabilities of the controller could be improved.

REFERENCES

[1] International Journal of Machine Tools & Manufacturing : Design and Implementation of a Five Axis Micromanipulator for Inserting Parts Into Collets, No 4./1988

[2] Csaba Krajcsovics : Design of a PC-based Hierarchical Micromanipulator Controller, MSc. Thesis, 1989, TU of Budapest

AUTOMATION OF MATERIAL HANDLING AND TRANSPORT CONTROLLED BY DIGITAL SYSTEMS.

Dr K. Kurutz; Dr L. Kása; Dr G. Rácz.
Technical University of Budapest. HUNGARY.

The rapidly growing organization in modern manufacturing requires high technology in industrial handling. It's well known that the modern industrial production achieves extremly good quality massproduction in spite of small material stock. For reaching such results, a well organized cooperation is needed among the partner firms, the workshops and the working processes. Nowadays the conditions of such a high integrated cooperation is given by the presence of modern computers, their appearance caused revolutionary changes on all the fields of production.

In spite of the modern possibilities in the material handling, a significant backwardness can be found in our country. In most cases, engineers deal with their own separated problems of manufacturing and neglect to solve the rational production generally. Consequently, the importance of the optimal material handling and the possibilities of an optimal organization are generally recognized too late. A computer controlled system of the material handling means an advantage first of all in the integration of production processes.

Recognizing these facts, the Departments of Traffic Automation and of Material Handling Machinery of the Technical University of Budapest decided to solve this complex problem together, without any industrial background, theoretically and practically, as well. To utilize the already achieved results there are certain efforts which are unfortunately hindered by the recent recession.

The present report deals with three solved problems as follows:

A/ Control of a container yard
B/ Control of a monorail system in mass production
C/ Laboratory construction of a complex material handling model

In details:

A/ Automation on a container yard, based on a Hungarian built crane with foreign drive equipment.

1/The solution based on computers controls the following tasks:

a/ Automatic positionig within 10 mm accuracy in horizontal coordinates
b/ Registrating about 600 container data, each consisting about 150 bytes as identity number, storing coordiates, owner's name, and other transportation data
c/ Automatic control of the spreader to reach the position given by the conainer identity or by the destination data
d/ Storing place optimization and automatic choice of incoming containers from rail or road
e/ Optimization of crane routes over the yard at comissions,handling the operational and emergency stop
f/ Registration of store places, automatic invoicing, and communication with corresponding items
g/ Recording of crane tasks, events, and loads.

2/ The solution needs the following units:

a/ Passive metal codelabels along the coordinates of the spreader routes, detected by inductive sensors mounted on the crane
b/ An onboard microcomputer placed in the cabine of the crane,consisting of a keyboard, a display, a data-register and an event-recorder
c/ Mainframe computer placed in the office building, consisting of a high capacity data register and a printer unit
d/ Data-transmitter unit to assure communication between the computers

3/ The construction was designed on the basis of the following aspects and principles:

a/ The onboard computer has to be insensible to climatic conditions and has to be protected against dust and any electric influence
b/ The control unit, during its operation has to be able to recognize the failures, to eliminate them if possible, and give indications about its cause
c/ In the case of inevitable failures, the automatic control has to stop the crane. The operation can be overtaken from automatic to manual one, by any simple manual interaction
d/ For easy maintenance, the control unit consists of modular units, without moving or rotating elements. There is a

protection in the case of circuit interruption, ensuring a minimum 6 hours continous operation, and data protection for months
e/ The system was constructed to ensure further developments
f/ Under present conditions the hoisting and lowering of containers was planned manually controlled. The data transmitter unit was realized by fast infrared light beam in one or more positions of the crane

B/ The computer controlled monorail system was designed for mass-production. It was based on suspended vehicles (telphers),each driven by its own electric motor on an overhead rail system

1/ The conditions of automatization were the followings:

a/ Max. 64 vehicles, and the same amount of work sites, or stations and junctions were taken into account. Unidirectional traffic was considered
b/ At each work site an operator is employed for receiving, handling or sending machinery parts by push buttons
c/ On each of the vehicles there is a fixed combinative code, anouncing its position to the central computer, while moving at the work sites or junctions.
d/ The vehicle is connected to the three phase electric system by trolleys through contactors to enable the full- and slow speed drive or stop in any marked position
e/ Any junction can be switched by the central computer through wire connections
f/ Each vehicle is provided with an automatic collision avoiding system

2/ The construction was designed in two different versions:
a/ The technically simpler solution was based on wire connections between the work sites and the central computer. Two further trolleys control the contactors on the vehicles, following the orders of the computer. The handling of machinery parts is directed by operators at each work site by means of machinery. The combinative code on every vehicle consists entirely of passive elements, and the position of the vehicle is controlled by inductive sensors at any site, transmitting the signal to the computer by wires.
b/ The other version is based on front end type Slave processors on every vehicle which communicates on high frequency in duplex operation with the central processor. All the

stations and junctions are in serial connected to the central Master processor too. Every vehicle is able to fulfil max. 8 different orders, like stop and start with fast and slow speed, catch and leave or loading and unloading, and so on. This operation needs high frequency modem couples with effective power not higher than the necessary level. The Master processor stores data of vehicles, load, destination, speed, position and general data of the whole monorail system at any moment. It controls the junction switches and vehicle movements. All computers are provided with similar displays, keyboards and protective elements against external effects and data protection against circuit interruption.

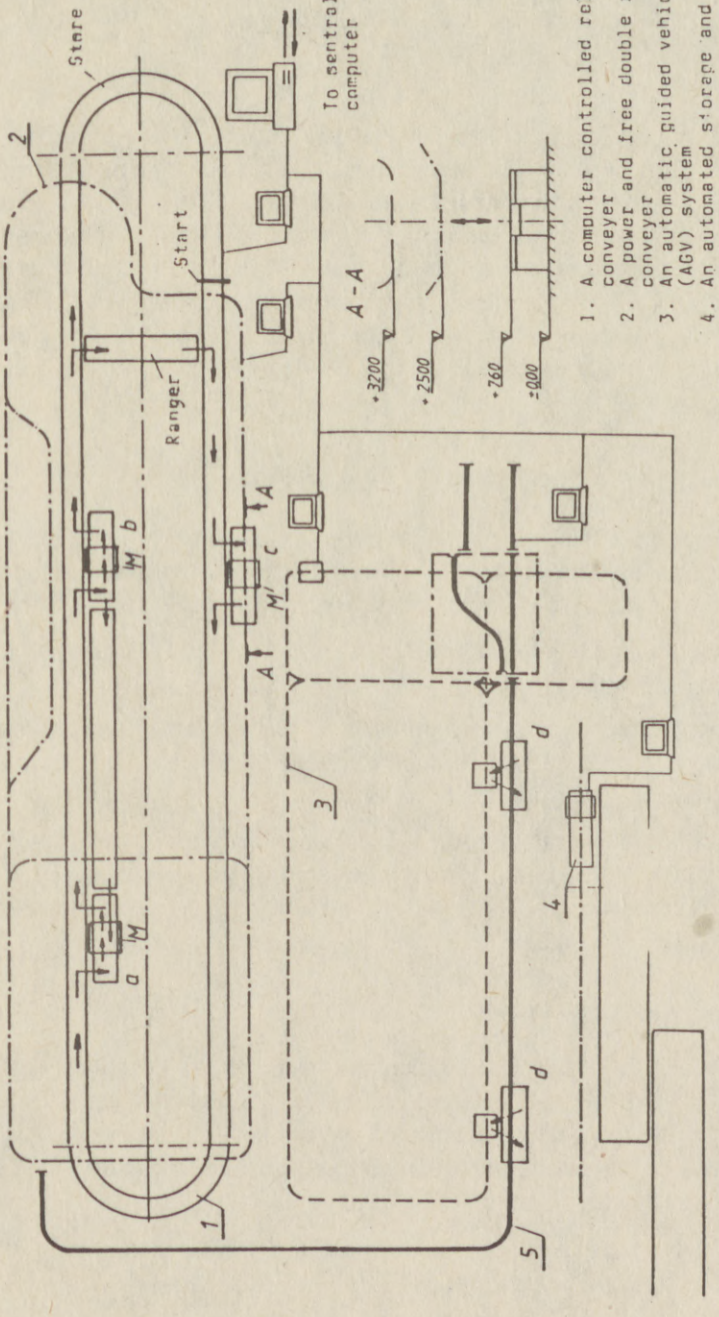
C/ A computer controlled material handling system has been designed for the laboratory of the Department of Material Handling Machinery of the Technical University, primerly for educational purposes and research work. The whole system will consist of the following items: (They can be seen on our figure)

1/ A computer controlled roller conveyer
2/ A power and free double railed conveyer
3/ An automatic guided vehicle (AGV) system
4/ An automated storage and retriaval system (AS/RS)
5/ A monorail (telpher type) system

Every unit has its own microcomputer or PLC which are connected to an IBM-AT type central computer, which coordinates the whole system. To make complete the laboratory we just designed further special equipments to transfer unit loads (paletts) from one medium to the other at the junction points. This experimental laboratory system gives a possibility for manufacturers to test their products during the design, in aspect of machinery and control problems.

The system enables a research on the reliability too, comparing theoretical and real material handling processes. The field of transferring equipment enables the students to create a real machine. The gantry type manipulator, placed on site a/ was designed by students and made in our workshop. Testing of industrial robots and AGVs are also a part of our Department's research work.

For more detailed information, contact:
Dr K. Kurutz associate professor
H 1111 Budapest, Bertalan Lajos 2
Technical University of Budapest
Dept. of Traffic Automation



1. A computer controlled roller conveyer
2. A power and free double railed conveyer
3. An automatic guided vehicle (AGV) system
4. An automated storage and retriaval system (AS/RS)
5. A monorail (telpher type) system

Fig. 1.

Paper for INTERTECHNO'90, 11-14 Sept. 1990 Budapest

PROCESSING of SHEET MATERIAL in CIM ENVIRONMENT

LEHOTZKY, József Mech.E., Prod.E., Oec.
INNOVOTECHNIK Ltd., Péter-u 4, H-1031 Budapest

A characteristic sortiment of products are made of different sheet or plate parts. The engineering work for modern sheet production is based on integrated CA technologies. The previous generation of engineering had the help of separate CAD and CAM tools without any consistency and integrated system. Today we present a new generation of CA tool sortinent which forms an integrated CAE, Computer Aided Engineering system for the production of sheet parts for CIM environment.

INTRODUCTION

A wide range of industries and products applies little or more sortiment of plain or formed sheets and plates. The sheet parts can be made of different materials such as metal, wood, paper or cardboard, textile, leather, plastic, etc.

Sheet parts of different industries and products are fabricated of definite materials e.g. a cupboard is made of wood.

A great sortiment of parts are made of plain sheets, sometimes are also folded from one piece into a box form. Such kind of part we represent with a 2D or 2 1/2 D geometric description and visualize in 3D.

Another sortiment of parts are formed into not plain sheet shapes e.g. a bow of a ship hull. Such geometrically sculptured sheet shape needs 3D - 5D geometric representation and a 3D visualization. Table 1. presents some significant products formed from sheet parts and its data for classification.

MANUFACTURING OF SHEET PARTS

To produce a defined shape and form of a sheet part and we apply a wide sort of processes. Significant one is the cutting process. To cut different materials we need a wide soriment of tools. To gain the needed part shape we let the different tools move with the help of different machine-tools, a modern is a NC one, loaded with robot.

Defined materials need significant tools, a classification shows Table 2.

There is also a great sortiment of tools and machine-tools for bending or drawing the parts to final shape. The different sheet parts in a product are connected into integrated parts with different processes, e.g. - metals with welding, - textile and leather with sewing and gluing, - wood with gluing or nailing. Modern machine-tools for sheet fabrication are numerically controlled and need a part program to control the geometry, the movement of tools with the help of a machine-tool. A loading robot need a movement program.

Application of CA tools for sheet fabrication began with the preparation of part programs. Today we apply an integrated CAE system to fulfill all the tasks of engineering preparation for manufacturing for CIM environment.

A CAE SYSTEM FOR SHEET PRODUCTION

A CAE system integrates numerous CA tools which can communicate and cowork even with the help of a computer network. These tools are the following:

- product design,
- geometrical description,
- production engineering,
- engineering administration.

In the industry for application of CA tools there is a need to begin with NC part programming. There are two directions for the development and application: - product development, - engineering preparation of production and production planning.
In the kernel there are two columns:

- a geometrical system for description and visualization,
- a DBMS to support geometrical, text and data sortiments.

CAE system means all the information are represented with CA tools with minimal or without any application or need of traditional drawings or text and data paper documents.

PROVISION TODAY

The product development with the help of CA tools and documentation presented in a standard form are not applied in all cases. If they do, we can accept e.g. an *IGES* standard protocoll form to interface them.

Geometrical description

The work in our system now begins with the *geometrical description*. Now we can present parts with 2 1/2D and *visualize* in 3D form. It means, box type 3D parts with flat or out-layable walls we can describe now. For the description we present a macro *library* for *contour fragments* and standard configurations, which helps to speed up the decription procedure with the help of a *GT*, group technology system. The *part* geometry is presented in a library. For the fast part description there is a wide sortiment of *macros* and *parametric* tools for different shapes and measures. Our geometric description language has a name GOL, (Geometric Oriented Language which won a price on COMPFAIR'89).

Bending and lay-out of box parts

There are box type and sculpturally formed space parts also. In the case of a *box* type *part* with plain or out-layable walls we can make the *plain laid-down contours*. It is typical for box forms that the edges formed by bending. The laid-down contour is presented in the part library. Our procedure calculates the *elongation* during bending to gain a correct contour for cutting. The *bending* tools are selected and defined *with* its data in this module and are represented in a *library*.

A further module for bending technology is where the machining *sequences* and *operations* are defined and connected with the applied *tools* and *presses*. All the needed bending parameters are calculated for the selection and the setting up of presses e.g. - powers, - movements, - spring-back.

Cutting of contours

Having all the needed flat part contours, they are placed in a part library. In the library we handle a further sortiment of data connected with the contour. We select a cutting tool with its contour shape and register in a library. With the cutting tool we generate a *"virtual* (an equidistant) *contour"*, for the cutting (an automatic KERF compensation). To handle the sheet sometimes we need *bridges*, further a cutting *sequence* to minimize deformation during cutting. For a smooth shape some contour form needs a *running in circle* for the stepping-in of tool. These and further data and parameters are also connected to the part contour and handled in the library. In the library there are further engineering *administration data* connected to the part, e.g. product and production No-s, material definiton.

Nesting

For the nesting a sortiment of parts is gathered into a group according to the daily production program serving JIT, just in time programming of production. The grouping will be based on identical material and sheet thickness, to be laid-on one rough sheet table. With this grouping we handle also production *priorities*.

The sheet *flat* form and measure should be an original standard, a rest measure and contour, an *undefined* topological shape (e.g. leather). In the latter case are available a *view-finder* device and a system to pick-up and process the contour by an interactive software tool, with them the inner and outher contours can be both handled.

The *nesting* procedure is an automated one, but can be handled interactively also. There we can handle different flat measurings, a lay-out of *duplication* (more flats in same time) and *mirroring* (pairing) for cutting.

The nesting and lay-out procedure handles the parts with their virtual contours and the connected data are presented in the part library.

The nesting program is capable to lay the *outher* contour of smaller parts *into* the *inner* contour of bigger one. After you accept the nesting, you can interactively connect the different cutting contours applying a defined cutting *sequence strategy*. Our CA program has a name NESTING and won a price on the fair and conferece μCAD'90.

The cutting program is processed to ESSI NC part program standard format and is postprocessed for the special NC machine-tool. Further a DNC format is available if it is a needed. Capacity, personal, tool wear and other norms can be processed from the NC part program.

The CAE system has defined *interfaces* for production planning system *(PPS)*, management resource planning (MRPII), material requirement planning *(MRP)* etc. and can handle the given normative *cost* parameters for the cost estimation procedure.

An integrated part of the CAE system is a *DBMS*, data base management system, which supports the different libraries explained above. The geometrical descriptions and the engineering administrative parts are systematically closely connected. This feature is powerful for the daily changes, which are resuled by the life of market and production processes.

SIGNIFICANT APPLICATIONS

In the introduction on Table 1 a couple of significant products and materials for the application of CAE system for sheet part production are explained for CIM environment. Till this time we have developed some software modules for industrial applications e.g.:

- "steel" constructions of different metal parts and products, such as:
  - = cranes,
  - = boilers,
  - = ventillation systems,
- ship hulls, consists of the bow and stern parts too and other box type "steel" constructions. We are working on further application programs for different industries and products, e.g.:
- cabinets for electrical and electronic systems,
- piping, for
  - = ventillation and heating,
  - = heating and boiling,
  - = pneumatics and hydraulics,
  - = cableing,
- shoe industry,
- garment industry,
- spectacle frame,
- furniture,
- packaging boxes.

This development follows an inspiration and sequence iniciated by purchasers according to the needs of the innovation of their companies.

FURTHER DEVELOPMENTS

The development of the system runs on in different directions. A significant one is the 3D - 5D presentation for sculptured sheet parts and their forming dies or masterpieces (e.g. last). A further development direction is to produce CAD systems for different product constructions and its geometrical and data descriptions, further their documentation and interfaces for further information processing.

CONCLUSION

The explained CAE system in this generation is a powerful and modern CA tool sortiment for sheet part production with personal friendly features for CIM environment.

To run this system now we need a minimal support of PPC, an IBM-AT one with 1 MBy core RAM, a mathcoprocessor, EGA display, tablet, mouse, plotter.

It needs as system software MS.DOS-3.xx operating system support. With a 32 bit computer in net environment we can speed up and make more powerful the system.

Parallel to this CAE system we are working on a PPS, a MRPII, a MRP and a material management respectively warehousing system which will be closely connected to this one and we develop a powerful CIM system for industries with products of sheetparts in definitive measure.

Some significant products, its material and geometrical presentation Table 1

Product	Significant material	Geom. descr., D			
		2	21/2	3	5
"steel" construction, cranes	steel, Al, Cu,...	+	+	+	
ship hull	steel, Al, ...	+	+	+	+
box, for electric...cabinets	steel, Cu, plastic,...	+	+		
ventillation sys., boilers,...	steel, Cu, ...	+	+	+	
box for packaging	paper, carton, plastic wood, cardboard, ...	+	+		
body of car, aeroplane, ...	stell, Al, plastic, ...	+	+	+	+
form pieces	glass, plast, steel,...	+	+	+	+
garment	textile, leather, ...	+	+	+	+
shoe	leather, textile, ...	+	+	+	+
spectacles	plast, metal, glass	+	+	+	
furniture	wood, plastic, metal	+	+	+	

Tool classification to cutted materials Table 2

Tool	Cutted material
Tool with rigid edge:	
- nibbler die	metal
- knife, blade+disc (HM, diamond...)	metal, textile, leather
Flexible tools:	
- flame, plasma	metal, glass
- laser	metal, wood, paper, plastic
- electron beam	metal, ceramics,...
- water jet	wood, paper, cardboard, textile, plastic

INTERTECHNO'90
11-14.Sept.1990
BUDAPEST

RELIABILITY in the FACTORY of the FUTURE

J. LEHOTZKY

Mech.E.,Prod.E.,Oec. Innovotechnik LTD. Budapest

SUMMARY

The FoF (Factory of the Future) is a greatly complex system, where the automation of physical and informational flows has a new quality level in comparision to the automation of the TF (Traditional Factory).

The availability and reliability problems of automation for different subsystems and production cells are discussed and realised in wide sortiment.

The reliability of complex automation in the FoF puts further problems with a new morfology and parameters, connected with:
- the physical and informational life of products and their parts with a wide mixed range of sortiment during the production,
- the functional availability and reliability problems of the highly complex and long flow chains and their mixtures,
- the role and qualities of man in the working staff for service and supervision.

INTRODUCTION

In the hero time - before WW I (World War) - at the beginning of production automation Taylor realised - at the Ford M. Co. with the help of the famous assembly line - a concept: the long mechanised (later automated) flow chain with rigid tacted fluctuation.

This was overstepped till the time of WW II with the concept of: optimal flow length with defined buffers, quality and flow control points. This concept presented a higher quality of system availability and reliability.

J.von Neumann developed the theory of correction with the help of the redundant information along the flow, today employed with wide range of practice. The automatic correction theory is based on the theory of cybernetics developed by Wiener and is connected to the redundant information theory by Neumann.

Today in the world there are some realised AF (Automated Factory)-s, they are really working and there are also ghost shifts (at night and holydays) realised in them under the control of a supervisiory staff of little number. They realise the maximum level of availability and reliability of the factory and its functioning under today's technology.

The PROBLEM

In the FoF we give an anormous amount of working potential and value into the hands of the supervisory staff compared to the TF. In the FoF we are pressed to apply more serious values of parameters with one or two decades - with decimal scale of magnitude - in the qualities, accuracy and availability than it is in the TF, with the help of the automated production flow.

These advanced tasks of qualities and precision are in contradiction with the possibilities in precision of most of our theoretical and practical tools we have today to realize an acceptable level of availability and reliability for a successful functioning.

The working elements and components of a system today have sometimes also 10-20 thousand hours running time MTBF (Mean Time Between Failures), but the whole system has very little availability and reliability depending on the length of the flow chain and MTBF & MTTR (Mean Time To Repair) values of components.

We must define the precision and the tolerance of the considered parameters, which we can measure with ppm, part pro mille. In the TF most parameters apply the precision of 1000 - 100 ppm-s, where eg. about a 100 mm long part with 1 micrometer tolerance we say 10 ppm. If it is out of steel, 1 °C temperature difference causes about 10 ppm change in length.

In the availability and reliability we often speek about the reversed parameter: how many "9"-s are wanted for it. In the above mentioned example we express a need for five "9"-s = 99,999 % value. In the TF we operate only in the range of two-tree "9"-s = 99,0 - 99,9 % !, and in the precision industries sometimes with four "9"-s = 99,99 % precision in availability and reliability.

For the realisation of FoF we need normally four "9"-s and sometimes five "9"-s = 99,999 % precision of availability and reliability of parameters to realize a reasonable stability of its functioning under the hands of the supervisory staff.

The questions are:

1./ What kind of theoretical and practical tools do we need to realize FoF?
2./ What real requirements must we set as a task complex to realise FoF with a successful implementation technology ?

Before the discussion over the availability and the reliability of a defined set, we need to define its morfological description and the sortiment of the effective parameters of it. Till now in the FoF we has defined wide range of parameters and function regions, but the whole parametrised morfology is still missing.

RELIABILITY of PRODUCT LIFE during PRODUCTION

In the FOF we need to build up a consistent automated flow system for the production of the product sortiment. The production flow - preproduction, part production and assembly - is a highly complex one, which is realised on different production places and is connected with material handling places in the flow chain of the system.

The production flow itself is not only a physical, but also an informational one [1]. On the FIG 1 I show you an example of FMS (Flexible Manufacturing System), where you can see the principle of the physical and informational life of the part sortiment produced with the help of it.

The qualities of the information sortiment of the product must contain also the reliability parameters for the automated part production and assembly contraversary of TF. To achive this level we need a complex CAD/CAM system also with AI (Artfical Intelligence) qualities for the whole informational life of the product during its fabrication.

To realise this task the kearnel criteria is: we must modell all the structures and parameters of the physical life of the product during the design and the planning period (which is the beginning of its informational life) and we need to build up the functional life of an advanced cybernetic flow chain for the realisation of the physical life of the product.

Along the chain the parts are informationally and physically passing through defined gates and this and further measuring and controlling points are connected on-line with a cybernetic backcontroll circuit, which has a "clock period" of the information flow a decade faster than the physical flow of the production itself. In the TF this is not realized because with the natural intelligence of the staff people the organisational gap between the informational and the physical life of the product is taken over during the production.

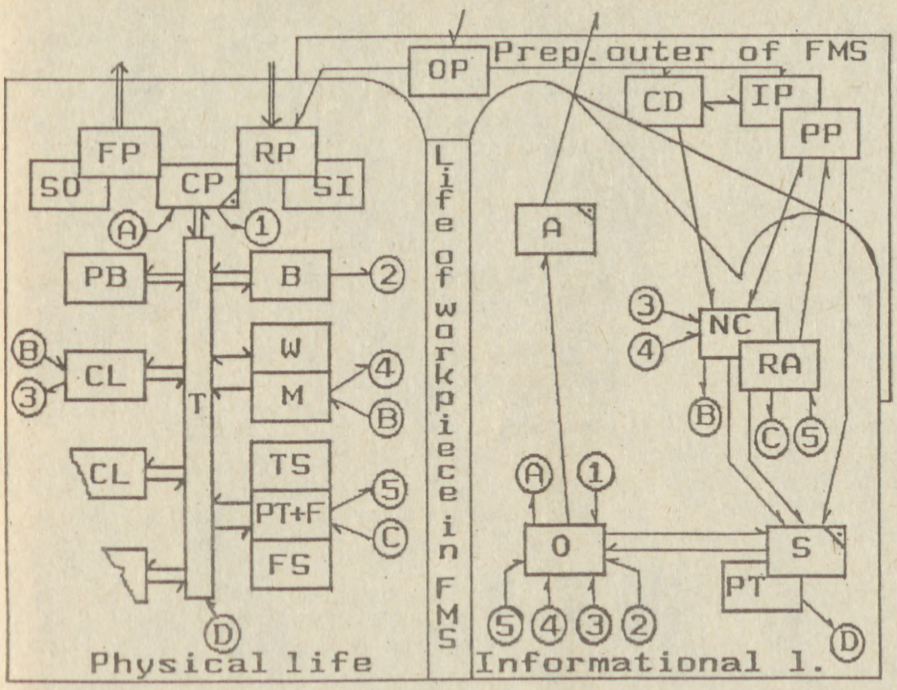


Fig 1 Life of workpiece in the FMS (for machining a defined set of gearboxes)

Abbreviations:

Physical life:

1.	SI	Store, Input
	RP	Row workPiece
2.	CP	Change of wP
3.	PB	Preparing of Batch
4.	PT&F	Preparing of Tools & Fixtures
	FS	Fixture Store
	TS	Tool Store
5.	T	Tracker
6.	CL	processing CeLl
7.	W	Washing station
	M	Measuring station
8.	B	Buffer
9.	FP	Finished wP
	SO	Store, Output

Informational life:

1.	NC	NC, Robot programming
	RA	Requirements for Appliance
2.	S	Schedule for production
	PT	Programming for Tracking
3.	O	supervision of Operation
4.	A	Administration

Prepar.outher of FMS:

0.	OP	Order of wP
	IP	Inform. Prep.
	CD	CAD Database
	PP	Prod. Plannig

⊿ gate

To achive a consistent reliability for FoF we must build up the informational life of the product and its parts, without lacks and gaps connected to the physical one with cybernetic qualities. Only after this consistancy can we define the different parameters of it and discuss in detail its theoretical and practical tools with the hope of a valuable success.

AVAILABILITY and RELIABILITY of PRODUCTION FLOW

The production flow is realised on production and material handling workplaces. They have not only their own physical availablilty and reliability, but we shall define a Production Availability and Reliability (PAR) also connected with the product requirements processed with the help of them.

In this context we need to define more levels:
- a PAR of the production workplaces themselves,
- a PAR of the connected and coworking length of the production and the material flow workplaces as subsystems,
- a PAR of a complex system of a whole workshop or factory.

The informational life of the production flow in the TF is traditionally based on "staff and paper" with its own morphology and "clock periodicity" consistent with the physical work of man (with blue and white collar).

The highly automated FoF needs a decade faster "clock periodicity" than the TF and must be based on an consistently and highly automated "paper free" information flow, connected with defined measuring and controlling points.

To build up such level of qualities we need a consistent system of cybernetic circuit chain. In this chain the physical flow periods with their check points must be connected to adequate points of information flow. On these points we need intelligent and automatic checking and supervisory functions to control back the physical flow with a satisfactory result. The informational reflex frequency needs a decade faster "clock periodicity" than the physical one has.

To realise these needs in the practice we also need redundant informations in the cybernetic circuits to keep the evaluations and the decisions further the controlling activities correct.

RELIABILITY of STAFF

A working man in the staff during the whole working year normally makes not less then 0,1 % mistake (with 99,9 %, "three nines" precision), but with a complet staff we must calculate with 1,0 % (99 %) reliability. In a factory with an existing system you can compute the reliability on the complexity and the length of the real flow chain (see the literature on this problem).

We need to realise real functioning properties and their parameters along the whole flow chain with a system reliability and its components minimal 99,99 %.

After the theory and the applied practice of the redundant information morphology we can fortunately avoid the destruction of mistakes with the help of testing and apply redundant information with the supervisory controlling steps in the cybernetic circuits assembled into the flow chain.

In connection with this we must speak about the automated supervisory and controlling functions of system coworking with the suprvisory staff. Eg. in a nuclear power station most (more then 2/3 parts) of the accidents are mischiefed by the supervisory staff and not the components and the system reliability (see eg. Chernobil).

So we need to separate man from the routined controlling and supervisory work and we must take his decisions under automated critical proving with the help of AI.

The hierarchy of critical prooving must be based on the redundand information evaluation to avoid mistakes until an acceptable low level is achived. We can do it, then the mistake values in a controlling procedure are multiplied. Eg. if an operation has 99,0 % and the proving operation process has also 99,0 % reliability, after the proving procedure we achive a 99,99 % reliability, which can be accepted.

CONCLUSION

I wanted to show in this paper the great complexity of the problem sortiment we need take over to realise successfully the problems of PAR in the FoF.

There is a wide range of problems solved, but a greater one is before us and I formuleted some questions of the working hypothesis and tasks for the furter R&D.

REFERENCES.

[1] J. Lehotzky, S. Megyik : Projecting of a Turnkey FMS and its Information System.
Compcontrol'87 Moscow

DEVELOPING CAD USAGE BY LOGICAL STEPS

G. Makszy, TUNGSRAM Co. Ltd., HUNGARY

Keywords:

- The right CAD tool for every task
- Different methodes below and above the 'critical CAD mass'
- CAD and the part-family principle
- CAD and in-house standardization
- Introduction of the CAD into a classical design environment.
- Human aspects of the CAD introduction.

Background:

TUNGSRAM's machine building branch develops and produces vacuum technical assembly automats and complete production lines on four sites all over Hungary. Our machines are built individually or in very small batches. The central drawing stock contains about three millions of drawings and 800.000 of them are still 'alive'. More than 85% of our parts can be represented on two dimensional technical drawings. Only the rest of it needs three dimensional modelling. There are several key assemblies which have special importance concerning the quality of the complete machines.

Principles:

Our main principle is 'the right tool for every task'. We do not want to use either weaker or stronger CAD system to solve our problems than are really needed. Having taken our first steps in CAD usage we realized that there is a 'critical mass' also in CAD application. For example if more than four engineers had to share a CAD workstation it would not be worth while using it interactively.

Case history:

The first project - 2D part drawing generation :

Hardware basis:

At the end of 1986 TUNGSRAM leased two ICL PERQ graphic work-stations (2MB RAM, 34 MB H/D, BW graphic screen resolution of 768*1024 dots, UNIX based operating system with multi window capability) and bought DIAD 2D CAD software (CADCENTRE Ltd., Cambridge, UK).

Decisions:

Having got acquainted with the CAD system the basic questions of CAD usage arised:

- What purpose we want to use the CAD system for ? (assembly designs or part drawings ?)
- How large should be the CAD user's group ?
- How to fit CAD into a classical design and documentation environment ?

At the beginning we had had to realize that the first two questions were depending on each other and are in close connection with the 'critical mass'. The strong macro capability of DIAD helped us to choose. We decided to form part families and develop their drawing programs. These parts were:

- Tooth gears -- cylindrical with straight toothing
  -- cylindrical with inclined toothing
  -- conical with straight toothing
  -- conical with inclined toothing
- Chain gears -- 1, 2 or 3 row's
  -- edged
  -- free running
  -- which can be mounted onto a holder
- 2d and 3d cams
- cam follower rollers
- pins for rollers
- welded arms

The basic principle of the parametrization was the upward compatibility that means if every parameter receives a non zero value than the most complex part is generated. If one or more parameters ar set to zero the generated part becomes simplier.

Realization of the project :

The realizing team :

In order to be effective the members of the realizing team were selected on voluntary basis. The team consisted of six young engineers who worked for the project in part time (one day a week) and the CAD system manager (the author of this paper) worked in full time. The team was divided into four subteams consisting of two engineers (the CAD system manager took part in two subteams). Each subteam developed an application program for a part family.

The steps of the realization :

The first step of the realization was the user's training. The part time members of the team were tought and trained to use DIAD by the CAD system manager. The training was devided into two courses. The topic of the basic course has been the interactive usage of DIAD. It took two times two hours a week for three month. During this period the CAD system manager developed the macro programs of the simple part families (cam

follower roller, pins for roller) and a lot of commonly used routines. The second training course which dealt with DIAD's macro language needed two month.

The second step of the project was the development of the macro programs began in july 1987. A year later "ready for machining" drawings were produced by the first versions of the macro programs. Even the selection of tolerances has been built into them.

The third step of the project was the introduction of computer aided draughting. To tell the truth it was not easy to convince the designers accustomed to the classical way of drawing that computer can really help them. It is very hard to understand this phenomena because the method of part drawing generation is very simple. When the designer has completed the main assembly drawing of a part of a machine the measures of the parts are already fixed. In case of a part which could be drawn by the CAD programs the designer has only to fill a form (see fig. 1.) and send it to the CAD system manager. The full time CAD users (now there are three of them) generate the drawing and send it back to the designer (see fig. 2.).

While using the application programs it turned out that the complex calculations and the data handling written in macro language are not fast enough.

The fourth step of the project was the development of the mixed language versions of the CAD application programs. The time consuming calculations, the data base handling functions and the man-machine communication was written in C language using the graphic pop-up menu capability of the PERQ workstation. These 'front programs' ask for the input data, calculate the intermediate values and put them into command files. The reshaped macro programs read the command files and generate the part drawings. The mixed language versions of the applications have become 25-30% faster. Another important advantage of the 'front programs' was that the probability of the data input errors could be reduced.

Results :

At the time being the advantages of CAD-based part drawing generation are as follows:

- considerable time spare
- decreasing number of drawing errors
- valuable step in direction of in-house standardization

The time spare is proportional to the complexity of the part. Most part drawings are ready in ten minutes after the first key-stroke. Even the most complex cam which would be drawn by a draughtsman in two days, takes only twenty minutes using CAD. Sorry to say that from financial point of view until now CAD usage is not competitive with the draughtsman's performance because the hardware is very expensive and the

saleries are low in Hungary.

In small batch machine production (like in TUNGSRAM) the in-house standardization is very important. The designers have their 'own style'which is not appropriate for the type technologies and cause a lot of troubles in production scheduling. If the CAD application can keep a tight rein on the part drawing style these problems could be avoided.

The second project - 3D CAD, FEM and kinematics :

In 1987 TUNGSRAM signed an agreement on a research and development project with the Heavy Industrial Technical University Miskolc (NME) in cooperation with OKKFT G/6 project bureau. The scientific staff of the Mechanical chair of the University developed a computer program for the analysis and synthesis of mechanisms.

In 1988 TUNGSRAM and OMFB agreed on a cooperation to install a 3D CAD-FEM system in TUNGSRAM's machine building branch. At the end of 1988 a super mini computer (TPA-11/510) and a 3D CAD program has been installed. In 1989 this system has been enlarged by the SYSTUS FEM package (FRAMASOFT, Paris F).

At the time being our subproject under development is to create a complex CAE system from 3D CAD, FEM and mechanisms design programs.

Future :

Even nowadays there is a strong need in TUNGSRAM's country side plants for using mechanical CAD. This motivated a new project namely to choose and implement a unified 2D CAD and 2.5D NC programming system all over our machine building branch.

TUNGSRAM Rt.

LÁNCKERÉK ADATLAP

(1-2-3 soros)

r = Rajzszám ..... :

LAN = Lánc tipusa ..... :
Z = Fogszám ..... :
B2 = Agy furat átmérője ..... :
Q = Retesz tűrés (P9/JS9/D10) ... :
K2 = Agy külső átmérője ..... :
S = Hány soros a lánckerék ..... :
SZEL = Agy hossz ..... :
VALL = Váll szélessége (mm) ..... :
MET = Menet táv. (0, ha nincs menet) :
MEN = Menet nagysága ..... :

Dátum :

.....
(szerkesztő)

Megjegyzés:

A lánc tipusa az MSZ 5508-70 alapján, Sárközi Zoltán "Műszaki Táblázatok és Képletek" cimű könyve 674-ik oldaláról választható ki.

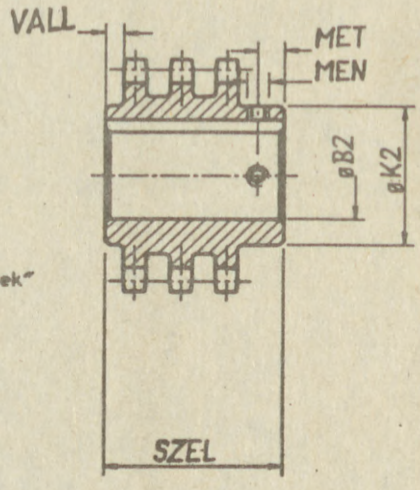


Fig. 1.

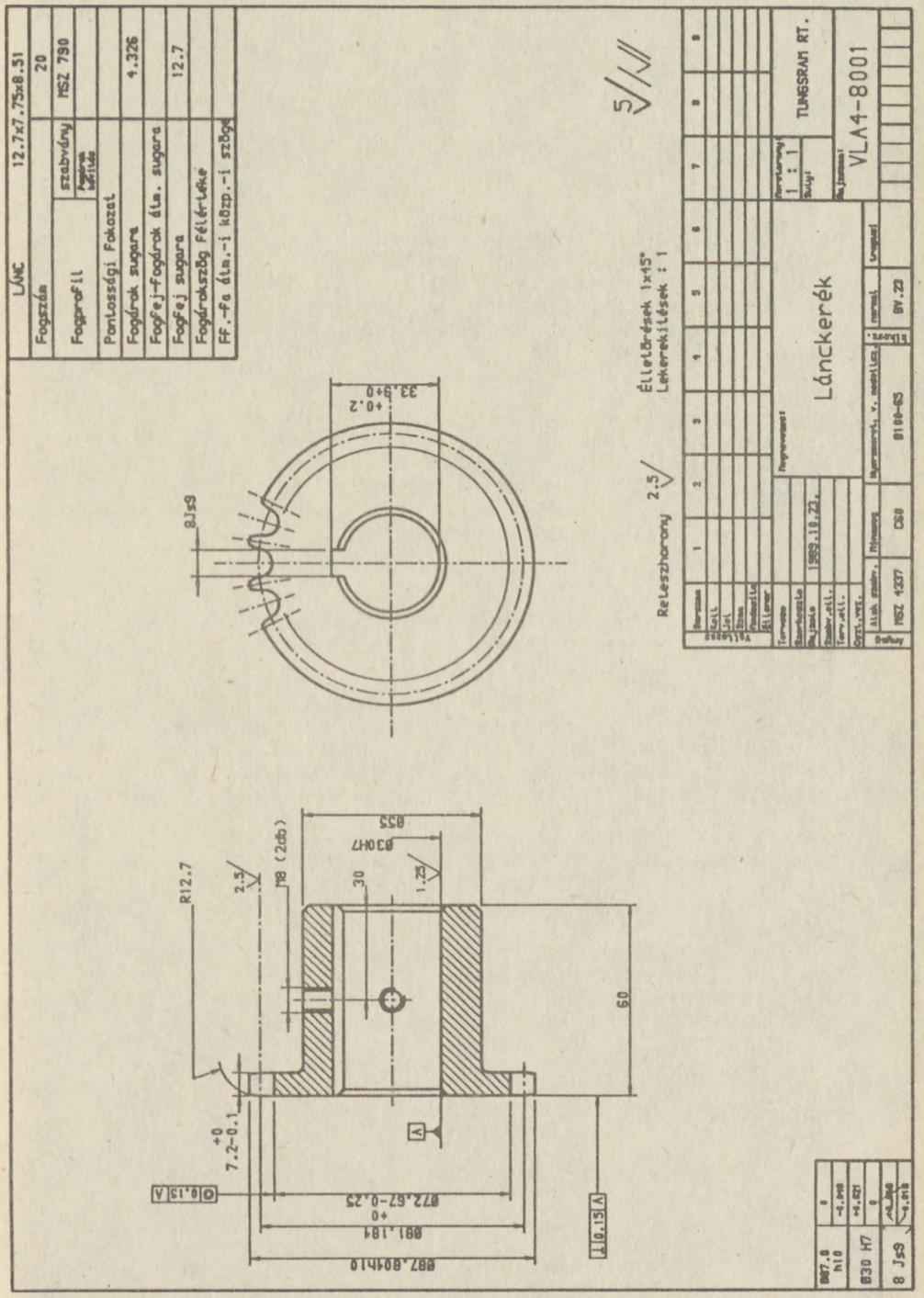

LÁNC 12.7x7.75x8.51
Fogszám 20
Fogprofil szabvány MSZ 790
Pontossági fokozat
Fogárok sugara 4.326
Fogfej-fogárok átm. sugara
Fogfej sugara 12.7
Fogárokszög félérléke
FF.-fa átm.-i közp.-i szöge
Élletörések 1x45°
Lekerekítések : 1
Reteszhorony 2.5
Lánckerék
TUNGSRAM RT.
VLA4-8001
MSZ 4337
BV.23
R12.7
M8 (2db)
Ø55
Ø30H7
Ø72.67-0.25
Ø81.184
Ø87.804h10
60
8Js9
33.3+0
+0.2
7.2+0-0.1
Ø30 H7
8 Js9

Fig. 2.

THE FIRST RESULTS WITH USING CAD IN BUS-CHASSIS DESIGN

dr MATOLCSY Mátyás
dr IVONY József

1. INTRODUCTION

Introducing the CAD technique into the field of product development /concerning both the hardwere and the softwere/ we had to face some special problems of Csepel Automotive Works. Below we mention one of these:

Csepel has more independent products /e.g. gearboxes, clutches, steering gears, trucks, bus chassis and underframes, etc./ which have to be developed parallely. It seemed to be practical to introduce the CAD into one, well defined field of product development. We have chosen the bus chassis family type 800. The reasons of this decision:

- this family is a new product of the company, therefore it is much easier to change a lot of "old traditions", to adjust the whole developing process to CAD
- this product-group is going to be introduced into the real competitive markets, therefor we need quick, flexible behaviour and capability to react on the demand of this market.
- it is a sophisticated product, that means we can use the advantage of the computer techniques.

2. THE PRODUCT DEVELOPMENT PROCESS.

As a first step, we examined the complex development process, starting with the costumer demand and ending with the serial production of the chassis.

This process contains the following main steps:

- Collecting the market informations. This means more than the concrete demands of a costumer /engine power, length of the chassis, its arrangement, etc/ but also the technical regulations and standards of those country, the road- and environmental conditions, etc.
- To produce offer. The technical side of the offer means the layout drawing and the Technical Description /T.D./ The other elements of the offer /like price, commerce, production, etc/ are based on these technical documents, therefor they have to be produced quickly and precisely.
- Technical design. On the basis of the accepted and agreed offer, the chassis has to be designed. The result of this work is the prototype documentation /group-list, drawings, and part-lists/ on the basis of which the prototype can be produced.
- Tests of prototype. The production and the tests of the prototype bring a lot of experiences which help to modify and develop the documentation.
- Serial documentation. The system of this documentation is similar to the earlier one, but it is more precise and detailed.

3. THE PLACE OF THE COMPUTER IN THE DEVELOPMENT PROCESS.

Analysing the obove mentioned development process we have concluded that the computer technique may be introduced along this process, which means: the first step could be the offer /together with the data-collecting/, after that the technical design, and so on. We had to answer on two questions:

a., where /in which action/ can we use the advantages of the computer?

b., how should we reorganise our work to be suitable for computerisation?

To the first question we can fix the followings:
- we have to solve the data collecting and storage. The data bank has to store different data: costumer's demands, service circumstances, data of the main units and parts, thouse of the chassis, etc.
- we need a word-processing system, while we have to produce different text-like documents /Technical Description, list of parts, etc/ This is more than the every-day text-edition.
- a lot of shorter or longer engineering calculations have to be made and their results have to be presented in a well arranged way.
- stress and strength analysis, which differs from the above mentioned engineering calculations. /different experts, different programs, different time-schedule/
- we could use the computer in drawing: as the first step producing layout drawings in two viewes, and later in technical designing, as well as producing the drawings of parts for manufacturing.

Relating to the second question, one of the most important recognition is: using computer technique in development means to standardized the development. From one hand, it is very useful but it makes the process more rigid. Therefore the whole process, the applied algorithms have to be described before putting the computers in use. The development process has a guiding line, this is the Technical Description /T.D./ The T.D. involves the main geometrical parameters, the main vehicle performance data, describes all the systems of the chassis /e.g. drive chain, brake system, steering system, electric system, etc./ and the main units and components of these systems. There are three different levels of T.D.:
- T.D. to the offer. Only the essential geometrical and vehicle performance data and a very brief description of the systems are incorporated. It is interesting to note that at this stage the chassis is not designed yet, only the layout drawing is existing /generally it is scaled 1:10/ It is very important that the offer must be well established therefor some calculations have to be carried out, because if the offer is accepted, the chassis has to be designed!
- T.D. of the prototype. The chassis has been already design at this stage, all the systems have to be described precisely and in detailed, all the vehicle performances have to be calculated and stated, strength calculations have to be connected to the T.D.
- T.D. to the serial production. After producing and testing the prototype, a lot of modifications improvements are made, the documentation of the serial production is more precize, more detailed, calculations are needed and the final T.D. has to contain all of these.

It follows from the above mentioned that the computers can be used in to ways: first as a databank and secondly as a tool for making different calculations and drawings quickly and precizely. Fig.1. shows the relation between the data bank and the three levels of T.D.

4. COMPUTERIZED DEVELOPMENT PROCESS

As we mentioned before, it was necessary to standardized the different steps of the development process to make them suitable for computerization. Before buying computers we have made a detailed study, the results of which are written in two reports. These reports contain the first results off the standardization:

- a questionary has been worked out to the negotiation with the costumers: always the same technical questions should be cleared, those which are important to the offer and to the technical design. This standardization is the first step to built up a data-bank.
- we worked out the algorithm of T.D. /structure, form, content/
- a method has been formulated to prepair a proposal, based on the T.D. This method involves the activity of the other departments /e.g. financial, production, purchizing, etc/ having them to use the PC/AT computer technique.
- we built up a new system of the technical documentation /drawings and group-lists/ and this system is closely related to the system of T.D.
- it has been decided and described: which engineering calculations have to be made to the offer, to the technical design, but to the final stage of the documentation this decision is open yet.
- the form and content of a layout drawing is defined for computer made drawings.
- we defined the general criteria of the algorithm of engineering calculations.

5. THE FIRST RESULTS OF COMPUTERIZATION.

5.1. A special method has to be developed to produce layout drawing by computer. The AUTOCAD as a CAD program is too general to this special task. The user /design engineer/ wants to produce a drawing in two views about the chasais and meantime different geometrical calculations have to be made, some parameters of geometrical compatibility have to be checked. The relation between the user and the computer should be interactive, the possibility must be given to change - time by time - the input data /e.g. new engine, or new engine position, new gearbox, etc/ of the design work. The consequences of these modifications have to be resulted either on the drawing or in the calculation, or both.

As a solution, we developed a special controlling program /using the sophisticated language "C"/ putting it between the user and the AUTOCAD. This program is suitable for modelling of discretionally complicated functions and relations. According to its goal, it can provide a two-directional communication, practically it can controll all the input-output activities. The AUTOCAD gets the orders throw this program, and it reads and interpretates the answers of AUTOCAD.

After giving the most important geometrical parameters of the chassis into the computer /e.g. wheebase, overhangs, chassis

height, angle of departure, etc/, it marks the ground, places the axles and gives the bounder conditions of the drawing. The second step is the "assembly" of the chassis frame: the distance between chassis longitudinal beams, the type and location of the cross members related to the axles has to be given as input data, and the program produces the chassis frame /see Fig.2./ This frame is the basis of the further work. The axles are put into the chassis frame by the program, calling back their layout drawings from the data bank, using their type number as reference. Before the installation of the axles, they have to be completed by the elements of the suspension /springs, shock absorbers, brake chambers, torsion bars, etc/ which can be recalled from the data bank also by their type numbers. After this the further structural elements can be placed into the drawing. Three kinds of element are there:

- the drive chane /engine, clutch, transmission/ which is the "soul" of the technical offer as well as the layout drawing. A sub-program builds together these units, on the basis off their type number, recalling their installation drawing from the data-bank, and this assembled unit, see Fig.3 is put into the chassis, using an appropriate reference point. The program meanwhile takes into account all the given limits /e.g. max. overhang, max. width, needed angle of departures, etc/ See Fig.4.
- structural elements in determined position. Their position is determined by the position of another element, like the drivers platform /pedals, steering column/ whis is related to the position of the steering gear, or the radiator which is - in the case of direct V-belt driven fan - related to the engine front face /pulley on the crank-shaft/
- structural elements with free position, the place of which can be easily changed, mostly they are related to customer demand /axle load limitations, volume of the baggage compartment, capacity of fuel tank, etc/ These elements are: batteries, spare wheel, fuel tank, air-con unit, air tanks, etc. They can be chosen also by their type number and placed in the drawing by their reference point.

Fig.5 shows a layout drawing of a chassis made by the computer.

5.2. On the basis of the layout drawing a mass calculation can be made. This program will be a subruteen of the program family. Having the final position of each elements, their mass and the geometry of centre of gravity can be recalled automatically from the data-bank. Recently the program cannot use the data-bank yet, these data should be given as input, but it calculates the masses of the frame, and finally gives the total mass, as well as the axle loads.

5.3. The calculations of vehicle dynamic involves the following calculations:

- maximum speed /the program differentiates the kinematic top speed and the dynamic one, the latter depends on the power of the engine/
- climbing capacity and the maximum speed in different gear levels.
- acceleration curves
- the maximum gradient, on which the vehicle can start /sliding clutch/ and can climb on /closed clutch/

- the max. gradient, on which the vehicle can climb on when the road is dry, wet or icy.

Today this program works also as one independent block yet. It needs - as input data - the main characteristics of the complete bus /masses, wheel base, centre of gravity, front wall area, etc/ and to give the type number of the engine, clutch, gear box, rear axle, propeller shaft and wheels. The type numbers can help to the program to call back the main features of these units, and the calculations can be made by the program. The results of the calculations: diagrams, curves and printed values are shown on Fig.6.

5.4. Manoeuvrebility and turning behaviours also must be checked in the very early stage of the design.
This program block contains the followings:
- calculation of the turning parameters of the vehicle /outer turning radius, width of the turning corridor, etc/ and the comparison of these data with standards and regulations. /See Fig.7./
- optimization of the steering mechanizm /symmetry, steering forces, etc/
- analysis of steering errors /See Fig.8/
- a strength calculation program for the pushing rods is in progress.

5.5. Brake calculations check the efficiency of the brake system. This program is based on the ECE Regulation No.13.

5.6. As it was mentioned earlier, the T.D.-s are also produced by computer, as well as the group list of the documentation.

6. CONCLUSION.

This paper gove a brief overview about our activities to introduce the CAD technique in Csepel's product development, mainly in chassis design. From this paper it seems to be clear that in our case the CAD differs a little from its traditional meaning. We introduced the computer technique mostly in the early stage of the development and design process, producing engineering calculations, layout drawings, technical texts and we are not widely using it for making the drawings of structural elements.

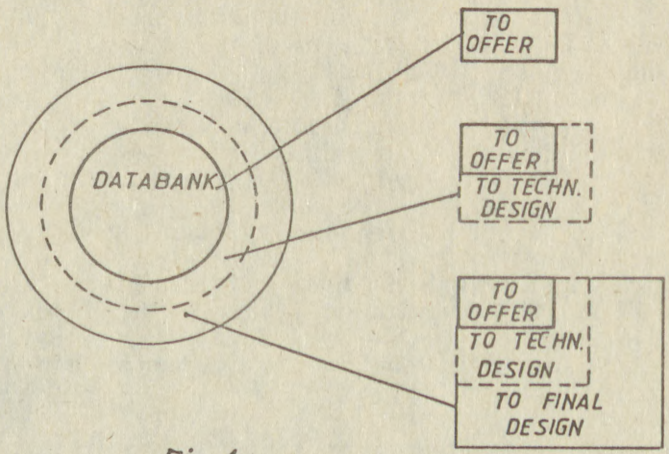


Fig.1.

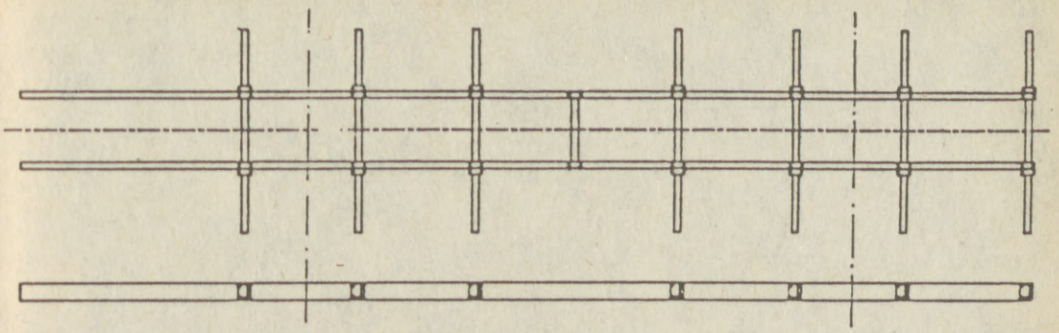


Fig. 2.

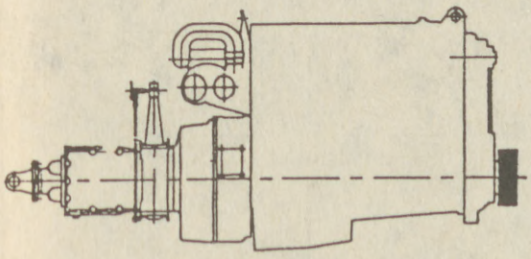


Fig. 3.

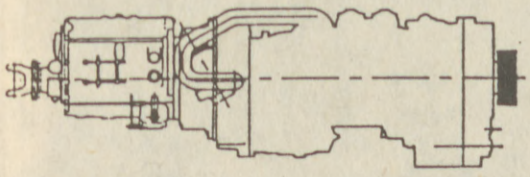
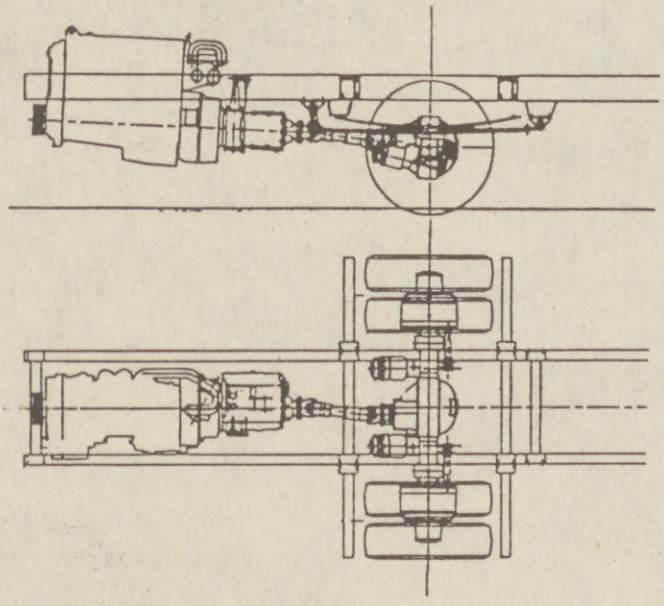


Fig. 4.



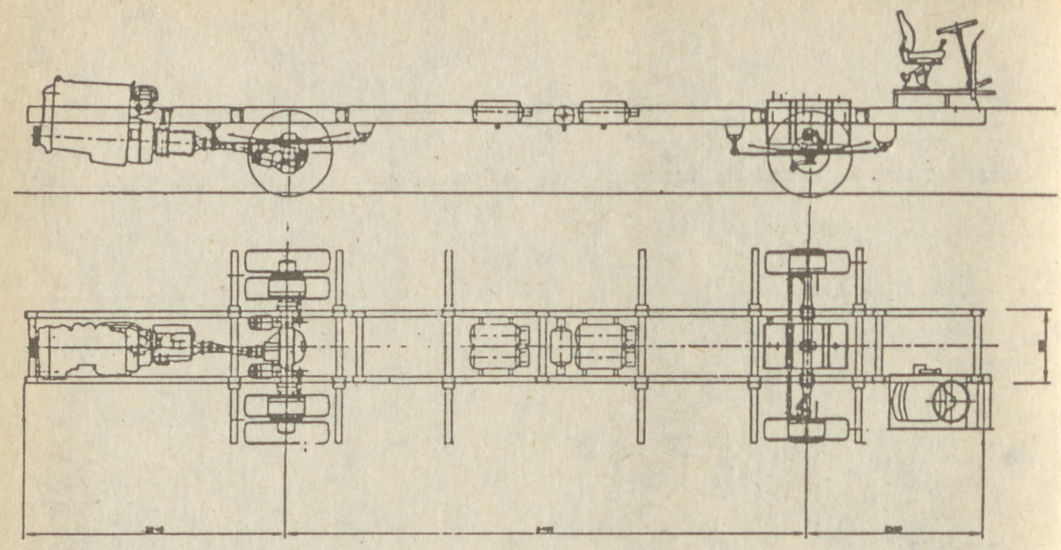
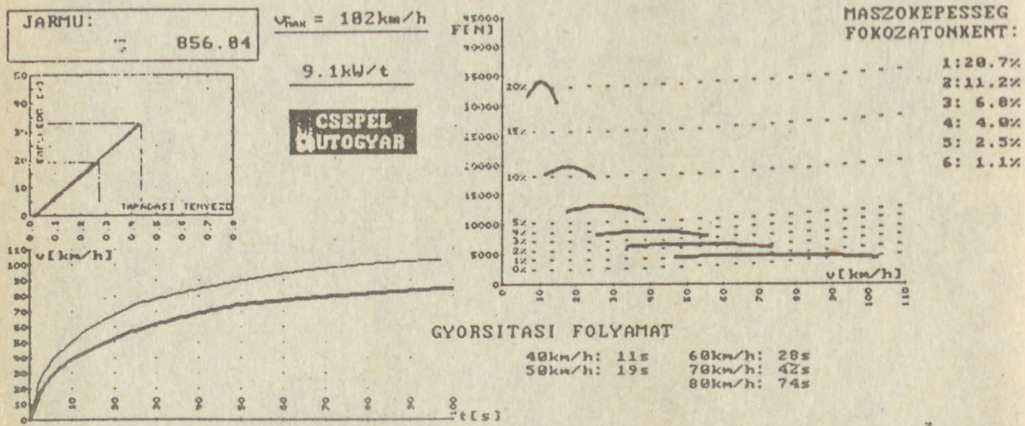


Fig.5.



MOTOR:	VALTO:	H.HID:	GUMI :
RABA D2356HM6U 87.12.14	CSA S6-98U direktes	K-807.SPEC 4,1	TAURUS 18R28 87.12.14

Fig.6.

AZ ALVÁZ MÉRVADÓ FORDULÁSI JELLEMZŐI

Típusa: 856.04

Tengelytáv T =6.215m
Mellső kilógás M =2.480m
Hátsó kilógás H =3.200m
Szélesség SZ=2.500m

Mellsőhíd típus: A-832.85-3100 [bal]
Fib= 46.8°
Fik= 33.8°
B = 0.000m

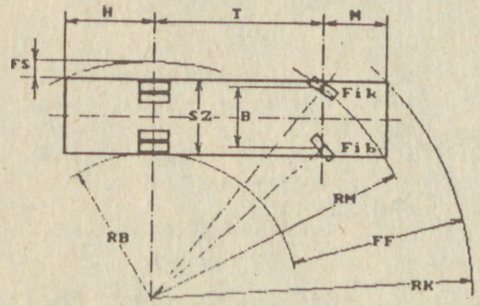


Fig. 7.

A számítás eredményei:

		max.Fib
Külső fordulókör sugár	RK=	12.31m
Belső fordulókör sugár	RB=	6.29m
Ford.forgásos szélesség	FF=	6.02m
Farsúprés	FS=	0.56m
Külső nyomkör sugara	RM=	9.77m

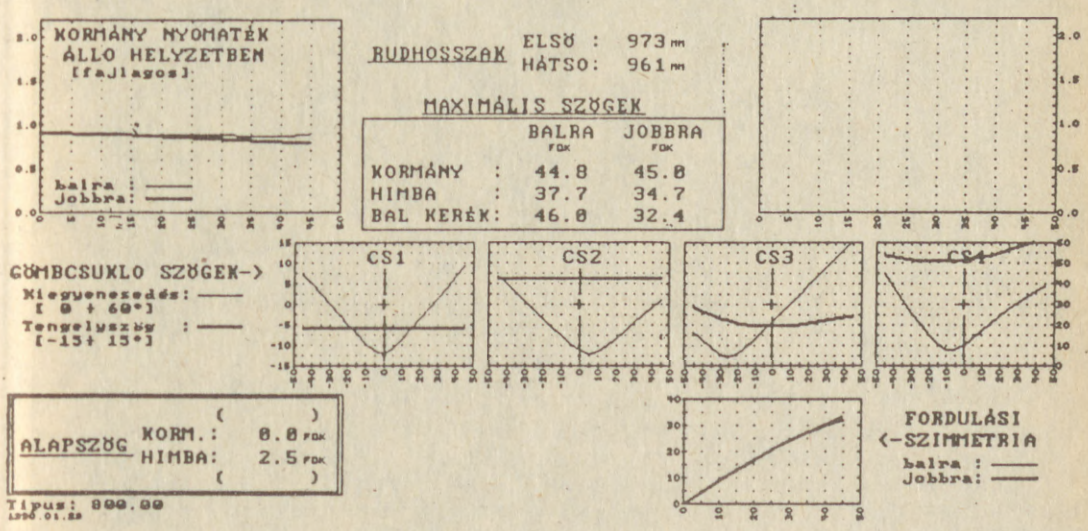


Fig. 8.

INTEGRATED SHOPFLOOR MONITORING WITH GERMAN LEITSTAND CONCEPT

Peter Merke, CPIM

Production Management Services, GmbH
Postfach 2155, D-4006 Erkrath, BRD.

INTRODUCTION

The partly conflicting aims of shopfloor control cannot be solved alone by the type of organisation chosen but require a decision for one or more order-release strategies dependent upon the requirements of the individual manufacturing unit. The decision whether and in which department production should be controlled according to the Just-in-Time principles, load-oriented order release, OPT, group technology, in-put/out-put control, MRP-despatch list or other release strategies does provide the starting point for the shopfloor control concept.

Based upon the order-release strategy chosen, the shopfloor control concept entails specification of functions, organisation structures, rules and selection of namual and computerised planning aids.

The functions describe the activities to be done; the rules describe how the functions have to be done and ensure that the order release strategies are put into effect; the organisational structure establishes the responsibilities. Which of the functions are to be stressed depends on the order release strategies adopted. The function of detailed scheduling is obviously of greater importance with Bottleneck scheduling than with a Kanban type pull system, where availability control is of paramount importance.

AIMS OF SHOPFLOOR CONTROL

The aim of production is to make money. The aim of production planning is to execute theoretically all actions necessary to achieve that goal, thereby ensuring that the future results will not be left to chance.

By definition therefore the manufacturing planning system does not stop at releasing orders to the shopfloor but plans, directs, monitors and regulates the movement of goods through the entire manufacturing cycle towards the set goal of .... making money.

But is this reality?

Most MRP systems plan the shop orders with great efficiency and then leave the control to the shopfloor personnel who are ill-equipped to carry out this task. The result? Too high work in progress, too long lead times, too high production costs, low customer service level, late deliveries, etc..

To achieve our aim of economic production we need an integrated sub-system which transforms the MRP-planned orders into completed orders in a timely and cost-effective manner, coping with the common disruptions such as machine breakdowns, material shortages, absenteeism, rush jobs, etc..

The Just-in-Time principles have not changed that aim but do place more emphasis on low work in progress and good delivery performance rather than high machine utilisation - and that for good reason. The aim of 'economic' production is as old as production itself. What did change are the market conditions. After the Second World War Germany had a great shortage of consumer and industrial products. The market place therefore did accept long lead times for standardised products. Today (and in the immediate past) the market place is saturated and requires replacement goods; these market conditions require many product options at shortest delivery time and at lowest production cost.

To meet these demands in a buyer's market one has to deliver instantly what the customer demands.

PLANNING LEVELS

Planning can be described as an activity forecasting future events. As no-one can foresee every possible eventuality, you cannot include them in your plan, leaving you with the necessity to prepare a number of different plans depending on the time horizon. As you get closer to the event you will have to increase the level of details in your plan.

1. The Prod. Plan + RRP
   * plan long-term the rate of production by family group.
2. The MPS + RCCP
   * plan long-term the units of shipable items.
3. The MRP + CRP
   * recommend medium-term the orders to be released.
4. The SFC + Leitstand
   * reviews short-term the MRP-planned order releases. This activity includes the selection of one or more order release strategies. The key to effective shopfloor control lies not in controlling orders <u>after release</u> but in <u>controlling</u> release!
   * matches them with the shop resources (man, machine, tooling, material, transport). This includes prioritising and detailed scheduling to finite capacity.
   * conducts availability control for detailed scheduled orders.
   * freezes 'firm planned shop orders'.
   * prints the shop papers.
   * despatches the frozen shop orders to the work stations on a one by one realtime basis.

* collects the shopfloor data.
* monitors the shop order status.
* regulates the work flow.

PLANNING RESPONSIBILITIES

The question, who is ultimately responsible for delivery on time has an evergreen character and is debated whenever a deadline is not met. This problem appears typically in an MRP environment as it

a) plans unrealistic due dates
b) leaves the completion of the unrealistically planned shop orders to the shopfloor personnel.

If we look back at the planning heirachy we will see that each of the four planning stages will be influenced by different people; the responsibility therefore lies with those persons being in a position to influence the particular event.

If the new paint shop for a new product line is not available on time we will look at top management, if a machine breaks down we shall look at the operator responsible for maintenance.

It is imprtant to analyse each person's contribution to the company's goals and objectives, then to establish the key performance areas and key performance criteria as well as to include these in his/her job description.

"Without personal recognition and reward based on individual efforts and achievements, man has little incentive to strive for improvement".

ORDER RELEASE STRATEGIES

The order release strategy adopted is largely dependent upon the characteristics, practices and requirements of the manufacturing process.

The Bolander Matrix shows PERT as a suitable planning and control system for 100% customer-designed projects and EPQ for the processing industry such as oil and steel.

In the following we shall take a look at some order release strategies in order to find out where the Leitstand strategy fits best.

MRP Despatch List

MRP arrives at the order release date by scheduling the planned order backwards with a standard lead time. This standard lead time is based on past performance of the job shop, on the average queue times experienced for that job or a similar job. The standard lead time therefore depends on and represents assumption of

the product mix
the plant and machinery available (by technical specification and capacity)
the number of disruptions experienced such as

machine breakdowns
tool availability
scrap rate
changes in priorities

the set-up time
the run time
the transport time
the despatching strategies used and the level of sophistication of the despatching system.

Based on all these assumptions MRP calculates latest start date for the order release.

CRP accumulates the capacity requirements for all jobs arriving at a certain work station in a particular time bucket (weekly). Infinite capacity is assumed. Only when the latest start date is still in the future can CRP calculate the earliest start date by forward planning from todate and utilize the buffer-time between earliest start date and latest start date to balance the capacity requirements with available capacity without changing the capacity constraints but still relying on all above assumptions.

If you release the MRP-planned order to the shop floor you know only one thing for certain - the start date is wrong! And no despatching rule will change it.

In-put/Out-put Control

is suitable for repetitive production which does not distinguish between individual batches.

It does provide a good guide to plan and control load and backlog and is most effective when adequate planned capacity is available on a period to period basis. It works well in a stable environment but will not compensate for poor capacity planning by the MRP system.

OPTIMISED PRODUCTION TECHNOLOGY

Managing the bottlenecks by using finite capacity, balancing the workflow, ensuring operator and tooling availability whilst remembering that 'an hour lost at the bottleneck is an hour lost of the total system' makes good production management sense.

Using secret algorithms in the schedule, making it a black box, proves hardly acceptable to the shopfloor personnel who is finally accountable for timeous deliveries.

THE MANUAL LEITSTAND

The MRP-recommended order releases together with their shop papers are filed into VISIPOCKETS for the "shop order control" function. The MRP-planned start and finish dates are marked visually on the VISIPOCKETS. The operation cards are then loaded on the planning board in order of priority indicated by the MRP due dates but finally established by the despatcher. This resulting detailed schedule is based on finite capacities whereby the length of the time marked on each operation card indicates the time reserved for every operation.

All other functions of shopfloor control such as availability control of material, tools, jigs, transport, of monitoring and order despatching, of data collection as well as order status control can be done effectively with a manual Leitstand.

Being a manual shopfloor control system, it is of necessity a centralised system providing the link between MRP and the shop-floor personnel. The "necessity" stems from the fact that all work stations have to be planned on one or more boards to provide integration of all sections; which is in itself an advantage as it does provide high transparency and visibility of order status and capacity utilisation. The disadvantage is that the despatcher is very remote from the actual shopfloor activities and that he has to react to all disruptions on the shop floor instead of the shopfloor personnel.

A manual Leitstand is a suitable shopfloor control tool when the volume of operations to be controlled (that is, to be planned, directed, monitored, regulated and evaluated) is small. It can be small due to large lot sizes, long operation times, few work stations, etc..

As the manual Leitstand is very labour-intensive and very time-consuming for up-dates, it does not cope with the demands of high flexibility, of changes of priority, of many lot-sizes, of complex products requiring specialised skills, of products being prototype or very diverse or run infrequently. The time necessary to schedule approx. 2500 operations for one week over 100 work stations with a manual planning board will be 20 to 40 hours. An optimisation or consideration of different order release strategies is manually not possible.

THE CIM-LEITSTAND

The CIM-Leitstand is the interface between MRP and the shop floor.

The task of the CIM-Leitstand is to change the periodically and roughly planned MRP host data into detailed planned order despatches under due consideration of the current situation on the shop floor.

The CIM-Leitstand can be used independently by the despatcher/ foreman who influences events and therefore is responsible and accountable for the day to day flow of work.

Let me point out here that the domination approach in Germany is for the despatcher or foreman to choose the optimal sequence, be this with a manual or CIM-Leitstand, and not to leave the scheduling function to the classic finite scheduling system.

The dominating argument is that only he, the despatcher, knows the particular short-time requirements of the shop floor, owing to the ever increasing complexity of plant and equipment and to the individual skills of operating personnel.

Melnyk and Carter also argue, "orders should never be automatically released to the shop floor". No planning system can be expected to keep pace with all the changes on the shop floor, hence the need for a flexible planning tool like the CIM-Leitstand which is a powerful tool to plan and to control the shop orders in the hands of an experienced despatcher.

The following describes the advnaced CIM-Leitstand, which has been linked with many MRP/PPS host systems:
COPICS, MAPICS, CLASS, CAPOSS on IBM;
RM-PPS on SAP;
PRODSTAR on Prodstar;
FO 4000 on Philips;
PS-Systemtechnik on Wang;
customer-owned PPS-SW on IBM, VAX, Siemens, etc..

Scheduling with a CIM-Leitstand

After the capacity requirements for the MRP-released orders have been roughly balanced (in machine groups and in weekly time buckets) with the available capacity by the host CRP system, they will be sent to the CIM-Leitstand (not to the shop floor).

At this review stage each operation will have an ESD and an LFD, based on the Standard Lead Time used by MRP/CRP.

This planned workload is now available to the despatcher for sequencing and machine loading.

To do this he can choose a particular machine group, indicating in colour code

blue:	all released operations have been scheduled and no action is required;
yellow:	low priority planned load is in the machine group requiring scheduling;
red:	at least one released shop order is in the machine group with highest priority requiring scheduling;

The 'electronic planning board' window shows all individual work stations for each machine group;

* it indicates the status of the work station (free, working, disrupted, maintained);
* it shows the shift plan by the minute;
* its colour beams show the status of the Gant chart: violet = set up, green = operation time, a thin green line indicates the buffer between the EFD and LFD;

The released orders are sequenced according to

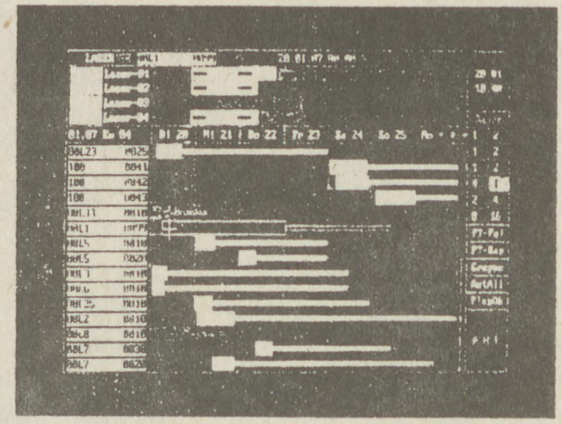
* priority as stated in the host system,
* latest start, calculated at latest finish date less (set-up and run),
* rising order and operation number.

With this method the most urgent orders will always be first.

Detailed scheduling can be done with the mouse in the following manner:

* manual: the order is scheduled with the mouse at the next available time slot. If the gap is not large enough for

the operation, the despatcher can either schedule the operation later or ask the system to shift all other operations accordingly;



* automatic scheduling af all operations within one machine group: the Leitstand schedules all operations in the work station according to a given priority; the algorithm can also be customised, e.g. optimised set-ups, least possible tooling, etc..
* automatic scheduling of all operations of one shop order: the Leitstand does is by considering transfer times, finite capacity according to the shift plan and existing queue; the result can be changed manually;
* bottleneck orientated scheduling;
  the despatcher can select bottlenecks and schedule these first; all preceding and subsequent operations will be scheduled automatically by the Leitstand;
* gaps between operations can be closed with the mouse;
* 'Plan OK':
  after the despatcher has scheduled, rescheduled and descheduled with the mouse and is satisfied with his schedule, he can use the 'Plan OK' function; this will freeze the orders like the firm planned order in the MRP.

This action will also trigger the printing of the shop paper.

Despatching

The bar-coded shop papers are printed by the Leitstand and despatched per operation or per day; the system could do without them, as communication via real-time data collection is possible; the machine operator indicates start and finish times against the bar-coded number; the Leitstand is linked and can follow the order status on a real-time basis. All information is being retransmitted to the host system.

This on-line communication between despatcher and operator as well as despatcher and HOST-MRP-System forms the heart of the

Leitstand concept; here the work flow is being monitored, disruptions are being dealt with, alternative orders are being despatched. Simulations allow the despatcher to find the shortest route through the shop floor.

The CIM-Leitstand plans the released work orders with finite capacity, directs, monitors and regulates the work flow, controls and records the order progress and thus manages the shop floor toward higher productivity and better delivery performance.

BIOGRAPHY

Peter Merke, CPIM, is a qualified Steuerbevollmaechtigter (public accountant). He obtained a diploma in business administration from the University of the Witwatersrand and the University of Pretoria.

Mr. Merke has held positions as Financial Manager and as Joint General Manager before starting his own consulting company specialising in shopfloor control applications where the financial results of a manufacturing company are determined.

He has served on the SAPICS Council for six years before serving on the GF&M (German PICS) council and is responsible for APICS COORDINATION and CPIM Education. He is a frequent speaker at SAPICS/GF&M meetings and seminars.

Mr. Merke consults with PAM - Production Management Services GmbH and teaches APICS review courses, in particular Shop-floor Control Techniques.

REFERENCES:

1. Dr. M. Strack - Optimale Produktionssteuerung, Verlag TUV Rheinland
2. St. A. Melnyk, Phillip L. Carter - Production Activity Control, Dow Jones-Irwin 1987
3. Gero Zimmerman - PPS-Systeme auf dem Pruefstand, Verlag moderne industrie.

AN OVERVIEW OF MODELS FOR ADVANCED MANUFACTURING

Istvan Mezgar*
Universita Degli Studi di Trento, Facolta di Ingegneria
Dipartimento di Meccanica Strutturale e Progettazione Automatica
38050 Mesiano di Povo (Trento), Italia

Highly sophisticated manufacturing systems, like the FMS, the CIM need an equally sophisticated set of models to analyze their behavior in the different phases of the life-cycle.The models are based on different kinds of methods that have to follow the evolution of the real systems. As today's manufacturing systems are too complex to be modelled with the needed accuracy using conventional models only, the latest results of the artificial intelligence research should be applied as well. The increasing number of model-types needs a new classification scheme in order to have a clear overview of the basic model-types and their possible combinations. The presentation proposes a classification scheme in which, based on their knowledge representation level, the models are classified into physical, graphical, mathematical, simulation, knowledge, and hybrid categories. In order to make the comparison of the different kinds of models easier a general model structure has been created. A short overview of the application fields of the different models is given too.

Keywords:analytical models, CIM, flexible manufacturing systems, hybrid models, knowledge-based systems, modelling, qualitative reasoning, simulation

1. Introduction

The structure of the manufacturing systems has changed to a large degree since the first NC machines were put to work. Today there are more then 400 flexible manufacturing systems (FMS) all over the world including the different generations of these automated systems, and computer integrated manufacturing systems (CIM) are ready to take over the power in the field of manufacturing. These advanced manufacturing systems (AMS) are more flexible and efficient then the previous ones, but at the same time they are very complex. To be able to handle the different kinds of problems during their life-cycle the only way is to build models.

A model is the simplified description of the (from a specific point of view) essential properties of an existing or planned system, representing the knowledge about the system in a useful form. It is very important to model an AMS as exactly as possible, and that is the reason why the application of knowledge based models developed with artificial intelligence technology will play a great role in the future.

2. Models for Computer Integrated Manufacturing Systems

The highest level of factory automation and flexible manufacturing are the computer integrated manufacturing systems. These systems can be handled from different aspects and on different levels with the use of models. There are two big groups of models

---

*Currently on leave from Computer and Automation Institute, Hungarian Academy of Sciences, 1111.Budapest, Kende-u. 13-17, Hungary

that can describe a CIM system: the factory model, and the product model. The different kinds of models that help to handle the processes in the factory are called factory models, while the product models describe the product itself that is manufactured in the factory. The connection between the two groups of models will be realized in the Integrated Product and Production Model through the process and technology models [1]. In the following we shall deal only with the different models belonging to the factory model, in a conceptual, non-mathematical way.

2.1 Aspects of Modelling

An AMS can be modelled with different purposes in different phases of the innovation(life-cycle), on different levels of it's hierarchy, and on different domains. These four main aspects define a four-dimensional model-space that defines the different possible model-combinations. It is obvious that more than one type of model must be permitted for any particular combination of these aspects because of the circumstantial need of accuracy, speed etc., of modelling.

Manufacturing process innovation has the following phases and model-types in each phase; setting up goals (different kinds of decision models), functional design (qualitative models for defining the logical and functional connections), technical design (quantitative models for defining the system's physical structure and analyze its behavior), implementation (installation and start-up models), operation (steady state operation and maintenance models). In this paper only those models of discrete manufacturing will be discussed that usually are applied in the technical design, installation and operation phases.

According to different national (NBS,AMRF) and international (ISO) organizations it has been shown that a six level hierarchical structure is sufficient to describe most manufacturing systems. This model, the ISO Factory Automation Model (FAM) (See Table 1.), has now been widely adopted in order to establish a basis for manufacturing standards in factory systems. There are of course some other conventional, hierarchies too, e.g. for production planning the three level hierarchy (strategic-, tactical, operational level) is widely used.

The third important factor in modelling flexible manufacturing is the professional field, i.e., the activity we want to analyze on a certain level of hierarchy in a certain phase of the life-cycle. These purposes can be, e.g., financial (estimations, analysis), technical, management, organizational, etc..

The next group of the modelling aspects refers to the subsystems that form together an advanced manufacturing system. The three basic subsystems are the information system, the control system, and the production system (material flow).

2.2 Integration of Models

There is a need for integrating some functions (that is to say the models of these functions) to achieve more accuracy, increased speed and reliability, to have higher level man-machine interfaces, and an ability for handling events in the manufacturing environment more efficient. The new requirements of running a flexible manufacturing system demand also new tools.

Till today, the different subsystems of AMSs usually were modelled separately, but because in CIM integration has an increasing role, the integration efforts between all types of models are getting stronger in a lot of combinations.

At the beginning of the model-building era a model was built only for one purpose, e.g. only for control. Today it is already obvious that the complexity of the production control system is determined in a very big extent by the product and manufacturing system design. So it is important to have a possibility for "experiments" already in this phase about the effects of the different design solutions on the control system. This means the integration of the design- and a simulation model.

The trend of modelling is to develop such kinds of models that can be applied in more than one fields (e.g., financial + operational models, production planning + control), or integrating into one model the logically connectable models e.g. Integrated Product and Production Model.

3. Classification Methods for Manufacturing Models

3.1 Benefits of Classification

The integration of systems means the integration of models with which these systems can be designed, and thus the processes going on in them can be planned and controlled. So it is important to clarify the structures and the connections of the different model-types in order to integrate them in the most effective way.

It is very important too to choose the appropriate model-types for solving a problem (costs, time of development and running, accuracy etc.), namely the classification can help to get a clear overview about the essential characteristics and connections of the models and about the possible couplings. This knowledge can serve as a good base to compare, which model can produce the "best" solution with the least complexity.

So, today it is worth to cite again Koopman's [2] version of Ockham's razor: "Complications in models are not to be multiplied beyond the necessity of practical application and insight.".

3.2 Classifications of Manufacturing Models

There are various classifications, which try to give help for orientation in the model-space. In the following we only list some aspects for grouping the models; the level of abstraction, the methods used for constructing the model, the applied tools (e.g. computer), the structure of the model, the accuracy of the result, the critical variable {time (continuous, discrete), or space(2D,3D)}, the characteristics of events (deterministic, stochastic), the connection between the elements (static, dynamic).

According to Buzacott [3] the models of manufacturing systems can be put into three groups: analytical, simulation, and hybrid simulation/analytical. The main aspect of classifying models into these categories was how deep insight can provide the individual models into the modelled system.

R.Suri [4] groups the manufacturing models into two big classes based on the characteristic of the results they produce: generative (or prescriptive) and evaluative (or descriptive) models. The definition of Futo [5] can complete this classification because he labels the AI-based models as constructive and the simulation models as descriptive, according to the level of human intervention they need during the problem-solving process. Most researchers use the same classification as Buzacott; only a few made any attempt to involve knowledge-based models into their classification but these don't make it possible to fit new types of flexible manufacturing models into them.

3.3 The Proposed Classification Method

To have a clear overview of the manufacturing models, the use of a general classification method is needed that can handle both the most simple models and the most advanced AI-based ones and their combinations too. The proposed classification method has two characteristics; it has a hierarchical structure, and it applies a general model structure. The hierarchical structure makes it possible to apply different aspects for classification on each level. The general model structure makes it easier to compare the different model-types.

In order to build up a unified classification and to make the comparison of the individual model-types easier (or in some cases possible at all), more realistic, perspicuous and clear, a general model structure (GMS) has been produced. The GMS helps to bridge the methodological differences between the various model-types, so it makes "homogenous" the chaotic world of models.

An extension to the structure of the mathematical model results the general model-structure. According to Karplus [6] a mathematical model has three major components: input, system or model structure, and output. The most important part is the model structure that can be divided into three parts : individual pieces of knowledge, type of structure to organize the pieces of knowledge, an algorithm to appropriately process the pieces of knowledge. The type of the model is defined by the structure and the algorithm. In the case that the meaning of the structure is extended and the word "algorithm" is changed to "some kind of command series", we gain a general model structure, into which most of the models can be fitted. After the extension the General Model Structure (GMS) has the following form adding to it the input-output components too (See Fig. 1.):

* Input
* Model structure
  a). individual pieces of knowledge,
  b). type of structure to organize the pieces of knowledge, (1)
  c). some kind of command series to process the pieces of the knowledge.
* Output

This GMS will be applied to introduce the model structures of the different model-types in the next chapter.

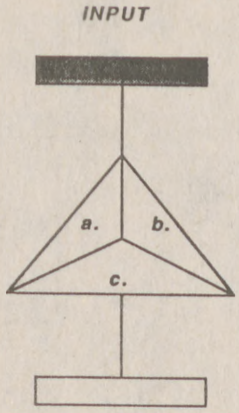
4. The Proposed Classification Scheme for AMS Models

In the following only the computer-based models will be presented in details. Of course some of the model types can be processed without a computer, but in case of AMS modelling (complex, large models) it would be impossible to get a reasonable solution without computers. The structure of the complete taxonomy is represented in Fig. 2.
Before starting with the computer-based models it is worth to have a short look at the physical models. The physical models were perhaps the first tools that helped in solving the design problems of manufacturing systems. The simple physical models have already lost their importance in most cases today, because they can be substituted with computer-based graphical models. Graphical models have from many aspects the same characteristics as the physical ones, but they are far more flexible, namely they can be modified more easily. The only field where small-scale dynamic physical models can be used effectively is the development of real-time control programs. But these kinds of models belong already to the conventional hybrid model category.

TABLE 1

ISO Factory Automation Model (FAM).

LEVEL	ACTIVITY
6 ENTERPRISE	Authorise program
5 FACILITY/PLANT	Plan production
4 SECTION/AREA	Allocate and supervise resources for production requirements
3 CELL	Coordinate multiple machines and operations
2 STATION	Command machine sequences and motion
1 EQUIPMENT	Activate sequences and motion



MODEL STRUCTURE

a. Knowledge elements

b. Structure of the knowledge

c. Series of commands

FIGURE 1

The General Model Structure (GMS).

4.1 Graphical Models

According to the topic of this paper graphical models in themselves are not interesting, so it is mentioned only that a detailed review of the different kinds of geometric models and their integration can be found in [7].

The different types of 2D and 3D geometric models can be used only for solving initial layout problems and for demonstrations. When graphical models are connected with other kinds of models e.g. with a simulation model, then as a component of a conventional hybrid model they can be used very well for different purposes.

4.2 Mathematical Models

A mathematical model is just a representation of a real-life system, or situation by means of variables and equations or inequalities. The mathematical model can give the exact, maybe optimal solution of the problem. According to the GMS (1) the mathematical model has the following interpretation:

a.) coefficients, constants, variables, observed data,
constraint equations or inequalities,
b.) equations, inequalities, matrices, tables,
c.) In O.R.: e.g. graphical, simplex method, minmax algorithm.
In solving diff.eq.: Runge-Kutta, Lagrange method.
Linear equat. sys.: Gauss algorithm, Cramer rule.

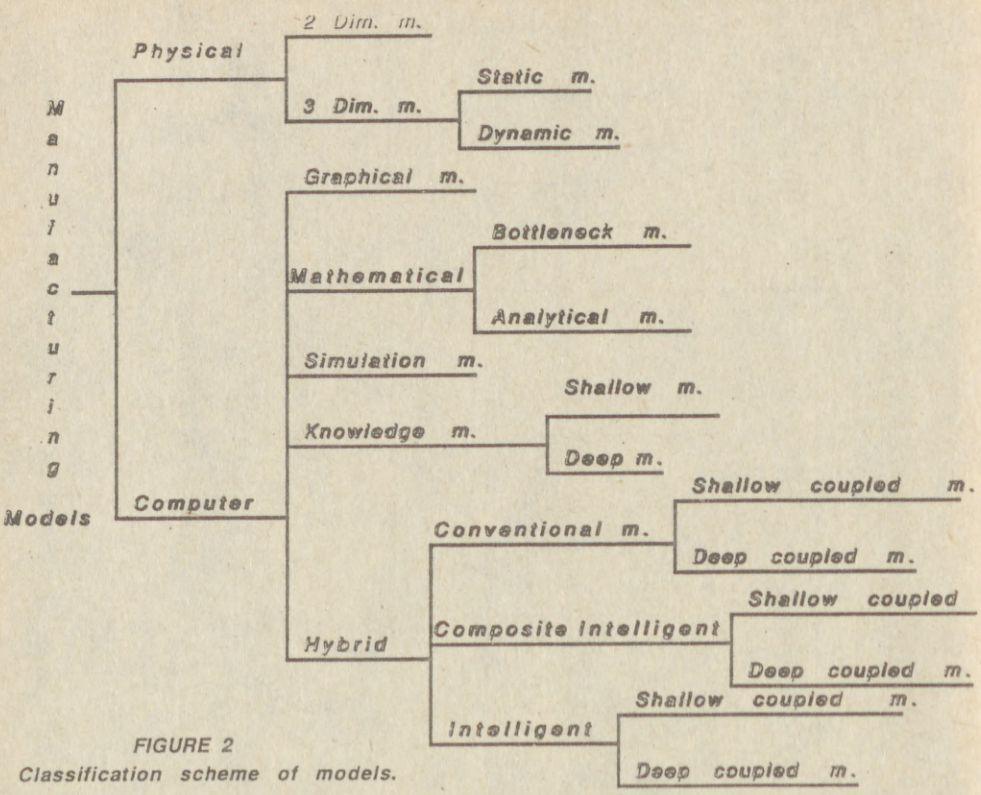


FIGURE 2
Classification scheme of models.

4.3 Simulation Models

A simulation model represents real-life systems or situations by numbers or symbols in a way that they can be easily manipulated to make possible doing experiments in order to study the behavior of the original system in different situations. The simulation models give no solution of the problem, the results must be analyzed, evaluated and based on this, a decision has to be made by a human or an "automated" (expert system) expert. Based on GMS (1) a discrete-event simulation model has the following form :

a.) events, activities.
b.) lists, matrices.
c.) next-event time scheduling algorithm, operational functions.

4.4 Knowledge Models

The knowledge models are used in different knowledge based (KB) systems.These models can be called knowledge or "intelligent" models, because they can use the knowledge elements flexibly, (as commonly used by human beings) in an intelligent way, thanks to the fact that KB systems attempt to represent the knowledge (expertise) explicitly (and therefore provide a basis for explanation). The conventional, non-AI based systems translate this expertise into program language variables and program statements. As the methodology of this model-type significantly differs from the other ones, first it will be shown how this model-type can be fitted into the GMS.

A knowledge based system has four main components: knowledge base(s), inference engine, working memory, user interface.In these systems the knowledge base and the inference engine form the model structure [8]. The three parts covering the general model structure are the following:

a). the knowledge base contains the pieces of knowledge,
b). the knowledge representation scheme is the structure into which the knowledge elements are organized,
c). the inference engine contains the commands, how to process the knowledge.

There are different types of knowledge models according to the forms of knowledge representation (production rules, frames, semantic nets or predicate calculus) and the rules of the inference engine.The inference engine can contain heuristic rules (shallow models) or rules based on basic principles and the causal relationships between the model components (deep models, eg. in qualitative reasoning systems). The knowledge models can be classified into two groups according to the level of the represented knowledge; shallow, or deep knowledge models.

Shallow knowledge model.By using shallow models conclusions can be drawn directly from observed facts that characterize the situation. In shallow models the heuristic that experts use in performing their reasoning tasks, are directly encoded in forms of rules. Shallow models are inflexible, they are unable to deal with situations even slightly different from those explicitly anticipated. The structure of shallow knowledge model covers the GMS (1) in the following :

a. facts, rules, objects.
b. production rules, frames, semantic nets or predicate calculus
c. heuristic based rules (forward- or backward chaining).

Deep knowledge model.The different forms of deep knowledge models (DKM) are used in KB or in second generation expert systems. The characteristics of deep models can be summarized as follows:
- the knowledge reflects the structure of the domain,
- the knowledge representation separates the structure from the functions of the modelled object or process,
- the representation of relationships between different objects(components) or processes reflects the underlying reasons ("reasoning from first principles"),
- uses higher level representation, usually does not utilize quantitative techniques such as classical mathematical equations or numeric values.

The deep knowledge model can be fitted into the GMS (1) in the succeeding form:

a.) domain objects, structure elements, functions,
b.) frames, semantic nets,
c.) casual relationship rules.

The knowledge based systems using deep knowledge models are more robust, are useful for generating explanations, but they are at the same time complex, and slow. A very important advantage of these systems is that their knowledge can be used for different goals in the same domain and it is reusable in a similar domain.

4.5 Hybrid Models

The hybrid models are the results of integration.A model can be called a hybrid one if it has been composed from a minimum of two models, which can be logically distinguished in some extent after the union too, and they work together somehow to produce an acceptable solution (optimal, or suboptimal). According to Kitzmiller and Kowalik [9] there are two ways for connecting models:

by coupling two models only on the "surface", a **shallow coupled model** can be created, which means that they (or one of them) use only the results produced by the other model. In this case the model structures are "black boxes", the models are connected only through their input/output part (See Fig.3.).

in the other case the two models (or one of them) are in a deeper connection, they have common part(s) in the model structure (See Fig.4.) This type of the connected models is called as **deep coupled model.**

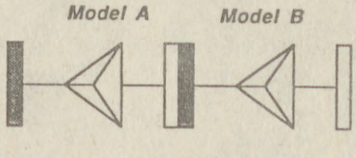


FIGURE 3
Shallow-coupled hybrid model.

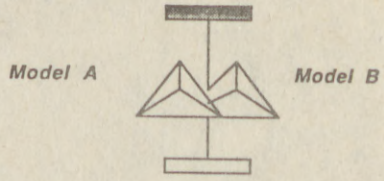


FIGURE 4
Deep-coupled hybrid model.

Three types of hybrid models can be distinguished:
- conventional hybrid models (CHM),
- composite intelligent hybrid models (CIHM),
- intelligent hybrid models (IHM).

Each of these hybrid models can have a shallow and a deep coupled version. In the following only the basic versions of hybrid models will be presented, because there are too many combinations for coupling the different model-types. The examples handle always only the connection of two models, but of course three or even more models (belonging to different model-types) can be connected, creating a very complex, multiple coupled hybrid model. The general goals of building hybrid models are the followings:

- to solve complex, difficult problems,
- to increase efficiency,
- to produce user-friendly systems.

Conventional Hybrid Models.In the case of conventional hybrid models different kinds of physical, geometric, mathematical, or simulation models are connected.

An example for the conventional hybrid shallow-coupled model is when the output of a simulation model is coupled to the input of a model based on perturbation analysis or on the linear programming method. The models of visual interactive simulation (a kind of animation) are conventional hybrid deep-coupled models. The japanese firm NEC calls its system of that kind 4D simulation, three dimensions with the addition of the time domain [10].

Composite Intelligent Hybrid Models.One component of the composite intelligent hybrid models is a geometric, mathematical or simulation model while the other is a knowledge model. In the case of the composite intelligent hybrid models in addition to the general goals of hybrid models come the following considerations:
- separately neither symbolic nor numerical computing can successfully solve the problem,
- the different models can compensate each other's disadvantageous characteristic,
- using the existing conventional models.

Connecting a simulation model with a shallow knowledge model (SKM) can be an example for the deep coupled composite intelligent model. The SKM can substitute the person who does the evaluation of the simulation results, and in this way a quasioptimal solution automatically can be reached.

Intelligent Hybrid Models.In intelligent hybrid models (IHM) two knowledge models are connected. In the case of coupling a shallow and a deep knowledge model, the deep model can generate heuristic rules for the shallow model, extending in this manner its validity [11]. The relation is as follows:

Domain theory + Problem solving knowledge = Heuristic rule
(deep knowledge) (shallow knowledge)

The field of IHMs has not been fully discovered yet, there is a lot of research to do on this topic.

5. Application of the Different Kinds of Models

In order to demonstrate that there are existing systems or prototypes which are consistent with the above described model-types, a few examples will be given in the following. A deep coupled composite intelligent model is used by Stecke [12] for the production planning of an FMS. Brandimarte [13] solves a scheduling problem with a shallow coupled composite intelligent model. Ben-Arieh [14] builds a control system for automated production in which a deep knowledge model, a simulation model, and a mathematical model are connected. Montazeri [15] illustrates how coupled analytical and simulation models can solve FMS design, planning, and operation problems. Choi and Malstrom [16] present a system in which a physical and a simulation model is connected for evaluating scheduling rules.

6. Conclusions

The complexity of manufacturing systems has been continuously increasing, so there was an urgent need for new kinds of models because with the conventional methods it was difficult to model these systems. The evolution of mathematics and computer science created a methodological base for developing high-level, integrated models for discrete manufacturing systems. Because of the great number of the models it is important to have a good overview about the different types of models and their application fields in manufacturing as well. The best way is to arrange this overview, to have a classification scheme which contains all type of models. The presentation gave a proposal for a taxonomy of this kind and interpreted some application examples of the different model categories too. The most promising tools for solving manufacturing problems are the intelligent hybrid models, but before applying them, think of Ockham's razor.

Acknowledgements

I should like to thank Carl Uhrik (University of Illinois) for the useful, valuable discussions and instructive comments. Thanks also to Professor Gianni Jacucci (University of Trento) for his support, encouragement and helpfulness.

References

[1] Grabowski, H. and Anderl, R.,Artificial Intelligence Applications in Design and Manufacturing, Preprints of IFIP W.G 5.3 Working Conf. on Software for Factory Automation, (Oct. 19-21,1987,Tokyo,Japan), pp155-170.
[2] Koopman,B.O.,An operational critique of detection, Oper.Res.,27 (1979),pp 115-133.
[3] Buzacott, J.A., Modelling Manufacturing Systems, IFAC 9th Triennal World Congress, (Budapest, Hungary, 1984), pp 2499-2504.
[4] Suri, R., An Overview of Evaluative Models for Flexible Manufacturing Systems, FMSs Operations Research Models and Applications Conference, (Ann Arbor, August 15-17, 1984), pp 8-15.
[5] Futo,I.,AI and Simulation on PROLOG Basis, Int.Symp. on AI, Expert Systems and Languages in Modelling and Simulation 2-4 June, 1987, Barcelona, Spain,Vol.I.pp1-6.
[6] Karplus, W., The spectrum of mathematical models, Perspectives in Computing, Vol.3, No. 2, (IBM, Armonk, New York,1983.), pp 4-13.
[7] Seiler,W.,Technische Modellierungs und Kommunikationsverfahren fuer das Konzipieren und Gestalten auf der Basis der Modell-Integration, VDI-Verlag, Dusseldorf, 1985.
[8] Fordyce,K., Norden,P., Sullivan,G., Artificial Intelligence and the Management Science Practioner:Links between Operations Research and Expert Systems, INTERFACES 17:4 (July-Aug. 1987), pp 34-40.
[9] Kitzmiller,C.T. and Kowalik,J.S., Symbolic and numerical computing in knowledge based systems, Coupling Symb. and Num.Comp. in Expert Systems, Worksh., Bellevue, W., 27-29 Aug.1985, Elsevier,pp 3-17.
[10] Hartley,J., A geometric approach to simulation,The FMS Magazin,5(3),1987,pp 141-142.
[11] Steels,L., The deepening of expert systems,AICOM,V.0,1,1987,pp 9-16.
[12] Stecke,K.E., et.al, A Hybrid Model-Based Approach for the Production Planning of FMSs, Proc. of the Third Int. Conf. on Expert Systems and the Leading Edge in Production and Operation Management, (Hilton Head Island South Carolina, 21-24 May, 1989, USA).
[13] Brandimarte,P. and Greco,C., Experiences in Hybrid Scheduling Systems, Proc. of the Conf. of Computers and Factory Automation, (Torino 2-5 Nov.1988, Italy), Vol.I., pp 385-390.
[14] Ben-Arieh, D.B., et.al., Control Methodology for FMS, IEEE J. of Robotica and Autom., Vol.4.,No.1.(Febr.1988.)
[15] Montazeri,M., Hierarchical Modelling Approach to Solve FMS Design, Planning and Scheduling Problems: A Case Study, in the Proc. of the European Simulation Multiconference, (June 1-3, 1988, Nice, France), pp 223-229.
[16] Choi,R.H. and Malstrom,E.M., Evaluation of Traditional Work Scheduling Rules in an FMS with Physical Simulator, J. of Manuf. Syst.,Vol.7.,No 1.,(1987), pp 33-45.

A THEORETICAL APPROACH TO THE DESIGN OF CSG ENGINE

Sadayoshi MIKAMI and Yukinori KAKAZU

Department of Precision Engineering
Faculty of Engineering
Hokkaido University
Kita-13 Nishi-8, Sapporo 060, JAPAN

1, INTRODUCTION

An increasing demand for today's information processing systems requires more rapid computation mechanisms for each of the problems which should be dealt with the systems. Most of the systems have been realized as software on an universal computer. However, the art of software seems not to be able to meet the requirements for the systems. Therefore, one effective approach has been proposed which is the implementation of the software into a hardware mechanism dedicated to the problem.

Much have been proposed for this hardware implementation, but most of them depend their hardware architectures on specific problems which will not be able to be applied to the other problems. Therefore, an explicit methodology of designing a hardware for each of the problems has been required nowadays.

This paper proposes a formal method of designing a specialized hardware processor system for a specific problem of computer aided information processing. Although the proposed method is applicable to overall the problems, an example of the application of the method is taken in the filed of Computer Aided Design system which utilizes CSG (Constructive Solid Geometry) representations as the solid model.

Although the remarkable ability for CSG solid representations of sufficiently denoting any kind of solids is feasible for CAD systems, the advantage makes the rapid execution of the applications for the model impossible. Therefore, a hardware implementation of applications for CSG CAD is required. From the point of view, an example of the design theory has been selected to the design of specialized hardware processor system for CSG CAD applications, which we name *CSG Engine*.

In the following chapters, firstly proposed is a generalized method of designing the configuration of specialized hardware processor from a specification which is based on an axiomatic formalization of the specification of a program. Secondly, the proposed method is applied to the design of CSG Engine. Finally, examples of the execution of the design of CSG Engine are demonstrated for the shaded picture generation problem.

2. GENERALIZED HARDWARE DESIGN THEORY

2.1. Formal methods for the specification of hardware

Advantage of implementing a software application into a hardware mechanism over performing on a universal computer, is the decrease of the processing time which is supported by the following two reasons: (1) realization of parallel processing by preparing multiple hardware facilities, and (2) introduction of sophisticated mechanisms for the applications.

Therefore, the strategy for the design is taken so that a multiple sort of hardware processors should be composed by parallel and/or pipeline processing into a system which performs the objective performance.

Since the design process for a hardware processor is the process of finding the hardware configuration of which performance is same as that specified by the specification, the formalization should be carried out for each of the performance of processor elements, and for the method for composition which gives the way of giving the semantics for the composite of the processor. In addition, by using the formulation, the designer is able to check the logical consistency and the completeness of the results.

To do this end, a semantic representation for the performance of a hardware processor has been proposed which is an analogous to an axiomatic formalization of a program [MAND87as follows:

DEFINITION 1 *(State, state variables, and an axiomatic notation of hardware processor)*

Let A be a hardware processor of having variables (or registers) S, namely *state variables*, which distinguishes the state of the process each other. The state of the process is described by corresponding each of the state variables to their valueV, which is sufficiently denoted by a predicate S=V. Then, the performance of a processor A is described as the style {P} A {Q}, namely *Hoare's style*, or in another word, an *axiomatic notation* [HOAR69]. Predicates P and Q, namely , a *precondition* and *post-condition* of A, are the predicates of having their variable symbols as the state variables. The precondition P holds true when the state denoted by the predicate P is available before the processor A starts, and the post-condition Q holds true when the state denoted by Q is available after the processor finishes ■

If the process F is deterministic, then the equivalent formal description is able to be introduced which is based on a functional notation as follows:

DEFINITION 2 *(Functional notation of a processor)*
A hardware processor F of {R=A∧A∈S} F {R=B∧B∈S}, is denoted as a function F such that F:A→B, if and only if,

$$\{R=A\wedge A\in S\}\ F\ \{R=B\wedge B\in S\}\ \wedge\ \{R=A\wedge A\in S\}\ F\ \{R=B'\wedge B'\in S\}\ \Rightarrow\ B=B'$$

holds true. ■

2.2. Formal representations of notions of specialized hardware

By using the above formal representations, the following definitions gives formal descriptions a notion of a generic class of hardware processor, of specialized hardware, and of distributed processing, which give the basis for the semantic representation of the composition of hardware processors.

(1) Generalization

DEFINITION 3 *(Formal representations of generalization of a processor)*
A processor F of {P} F {Q} is able to perform the same process as the processor F' of {P'} F' {Q'} if and only if, P'⊃P and Q'⊃Q. F is defined as a *generalized processor* of F'. (Note that the term '⊃' means logical implication.) ■

Intuitively, F' is the processor of having extra registers which makes correspondence between the input and the output in a same manner as F.

(2) Specialization

DEFINITION 4 *(Specialization of a processor)*
Specialization of a processor F' of F:A→B is a processor F':A'→B' such that A'⊂A, B'⊂B, and A\A'=B\B' ■

In the above definition, the performance of F' is same as F, but the hardware for F' is configured to utilize the reduced set A' and B'. Since the state space of F consists of n-tuple <Sf1,...,Sfn>, typical configuration of the specialized processor F' may be generated in the case of Sfi=ϕ,i∈{i1,...,im}=Λ, by restricting the usage of registers to Ri where i does not belong to Λ.

Intuitively, if a group of registers (or variables) exists of which contents will not vary after F works, then the hardware organization of F is able to be reduced not to utilize the data correspond to these registers. Since the sort of data is limited, then the specialized mechanisms which handle with each sort of data will easily be able to be introduced.

(3) Distributed processing

DEFINITION 5 *(Distribution of a process)*

Let a *process* be the performance of a processor. A process A:$A_0 \rightarrow A_e$ such that $A_0, A_e \in S_a$, is able to be distributed as a composition of processes A_i: $A_{i0} \rightarrow A_{ie}$, $i=1,\ldots,n$, namely processor elements, if and only if, $A_{i0}, A_{ie} \in S_a$, and $A_1 \cdot \ldots \cdot A_n$ is the generalization of A where '$\cdot$' is a composition of functions. ■

(4) Introduction of basic functions

In the definition 5, processors $A_1 \tilde{} A_n$ may be chosen from a wide range over the processors. Since A_i should be denoted their performances linguistically, the original notation A should consist of a correction of lower level definitions of functions. To do this end, we prepare a set of functions namely basic functions, that give the inseparable sets of meanings of processors, by which predicates should be described.

(5) Determination of performance of processor for the composite

Performances of processors $A_1 \tilde{} A_n$ which are composed so as to realize the performance of the objective process A in the definition 5, are derived formally by utilizing the above formulations as follows:

One of the objective of the distribution of hardware is to introduce hardware specialization. Since the specialization is intended to have as little sort of state spaces as possible, A_i should be designed so as to have as little number of registers. Therefore, each of the basic functions of which composition composes the objective specification A, should be corresponded to each of the processor elements A_i of which performance is described by a single basic function.

2.2. Process of generalized hardware design

By utilizing the above mentioned formalization, the process of generalized hardware design is performed as follows:

A. Terminologies

Let SY be a system to be designed.

(1) SYNTAX is a syntax for representing the configuration of the system SY.

(2) SEMSY is semantics for SYNTAX.

(3) LANGSY is a language which is utilized to define the semantics SEMSY.

(4) SSY is a representation of a configuration of the system by SYNTAX which describes the configuration of SY.

(5) SLANGSY(SSY) is a semantic representation of SSY which is written in the language LANGSY.

Let SP be a specification.

(6) SEMSP is semantics for SP.

(7) LANGSP is a language which is utilized to define semantics SEMSP.

(8) SLANGSP(SP) is a semantic representation of SP which is written in the language LANGSP.

B. Design process

If LANGSP = LANGSY, we can identify the equality of the expression between SLANG(SSY) and SLANG(SP) simply by comparing their linguistic notations. Thus, by using these terminologies, the design process is performed as depicted in **Fig. 1** which is linguistically described as follows:

Step 1. Prepare the 3-tuple <SYNTAX, SEMSY, LANGSY>,

Step 2. Prepare the 2-tuple <SEMSP, LANGSP>,

Step 3. Describe the specification SP in terms of LANGSP as SLANGSP(SP),

Step 4. Find SSY such that SLANGSY(SSY) = SLANGSP(SP),

Step 5. The objective system is given as SSY. Then, correspond SSY to the configuration SY.

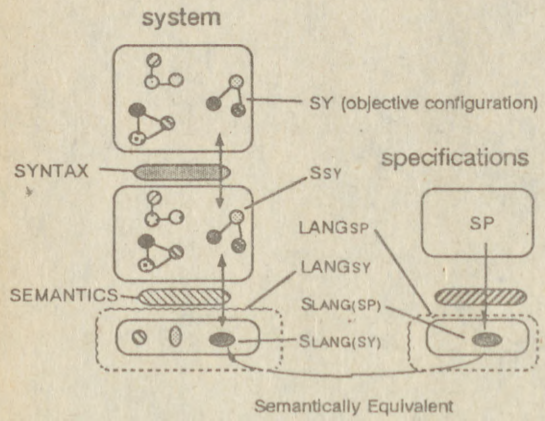


Fig.1. Spaces for the design process.

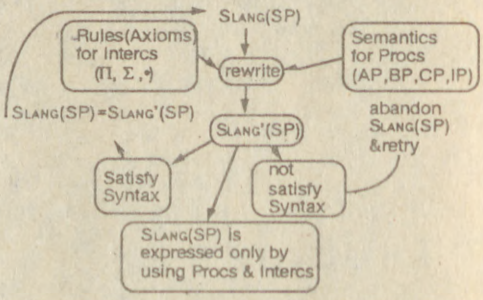


Fig.2. The design process.

In this process, the language LANGSY (or equivalently, LANGSP) corresponds to the axiomatic representation of a hardware processor as described in the definition 1. Therefore, the above design process leads to the design cycle as depicted in **Fig. 2**.

The above proposed design process gives a theoretical basis for designing the hardware system. To utilize the process, terminologies concerned with the design, such as SYNTAX, SEMSY, should be corresponded to actual linguistic representations. In the following chapter, an example of the design process will be demonstrated in the filed of applications of CAD/CAM/CAE systems which utilize CSG representation of solids which we name CSG Engine. Illustrations of these terminologies will be exemplified in this example of the design of CSG Engine.

3. APPLICATION OF THE DESIGN PROCESS TO CSG ENGINE

3.1. Formal descriptions of CSG CAD applications

Generally, an application which accesses CSG representations leads to a consecutive two processes: getting existence of the defined solid in Euclidian 3 space, and apply the processing referring to the geometric existence gained before. The above mentioned process is able to be realized by applying Ray casting algorithms [ROTH82] which we name RC-application.

The specification for RC-application is able to be described by using axiomatic notations as follows (see **Fig. 3**):

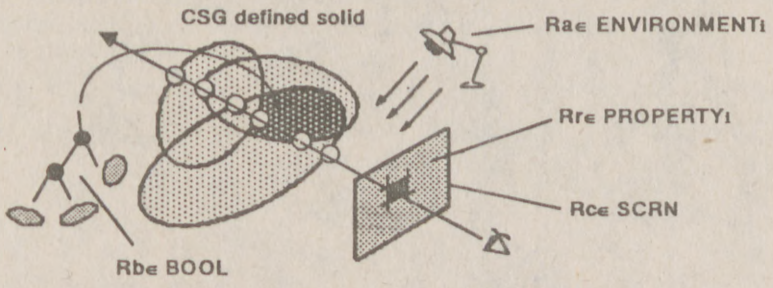


Fig.3. Formal specification of RC-application.

Assume that the sets concerned with the specification for i-th RC-application are as follows:

(1) ENVIRONMENTi : a set of the data of all possible environments for the application.

(2) PROPERTYi : a universal set of the results produced by the application.

(3) BOOL : a universal set of CSG Boolean set theoretic functions [OKIN82].

(4) PRIM : a universal set of solid.

(5) SCRN : a set of sequences of 2-tuple ($\langle P_i, Q_i \rangle$; $i \in \Lambda$) where P_i is an i-th direction vector and Q_i is a location vector which correspond to P_i. The notion of SCRN is an extended concept of a projection screen.

The semantic representation for RC-applications is defined such that,

(1) State space : ENVIRONMENTi×BOOL×PRIM×SCRN×PROPERTYi

(2) State variables : {Ra, Rb, Ri1,...,RiNp, Rc, Ry}

(3) Axiomatic notation: SLANG(SP) =

$$\{Ra=Ra0 \in ENVIRONMENTi \wedge Rb=Rb0 \in BOOL \wedge Ri1=Ri10 \in PRIM \wedge \ldots \wedge RiNp=RiNp0 \in PRIM \wedge Rc=Rc0 \in SCRN\}\ APPLIi$$
$$\{Ry=appli_i(Ra, Rb, Ri1,\ldots,RiNp, Rc) \in PROPERTYi\}.$$

where the function *appli*i is composed of the following four sorts of basic functions:

(1) *fa*: ENVIRONMENTi × RIMG → PROPERTYi,

where RIMG is an approximated solid volume on a ray [MIKA89]. The function *fa*i denotes the performances of generatin the required information by using the information about existence of the CSG defined solid.

(2) *fb*: BOOL × SOLIDNp → SOLID,

where SOLID may be either RIMG or PRIM. The function *fb* composes the primitive solids to a CSG defined solid.

(3) *fi*: RAYS × PRIM → SOLID,

where RAYS is an universal set of lines. *fi* gives the contribution of the primitive solid on a line.

(4) *fc*: SCRN → RAYS.

fc generates the set of rays from their definition SCRN.

3.2. Hardware framework

Since the strategy of the design is to compose the processor elements so as to perform parallel and/or pipeline processing, the fundamental process of connecting these pipeline processors leads to dealing with sequences. To do this end, three types of connections of sequences are prepared, namely, '#', 'π', and 'σ' connections as follows.

DEFINITION 6 (*Connection of sequences*)
Let $A_i=(a_{ik}; k=1,\ldots,n_A)$, $i=1,\ldots,n$, be finite streams.

(1) '#' connection of sequence A_i is a sequence A_i itself, that is, $\#A_i=A_i$.

(2) 'π' connection of sequences $A_1 \tilde{} A_n$ is a sequence consists of n elements such that,

$$\pi_{i=1}^{n} A_i = (<a_{1j},a_{2j},\ldots,a_{nj}>; j=1,\ldots,n_A).$$

(3) 'σ' connections of sequences $A_1 \tilde{} A_n$ is a sequence consists of n_A*n elements such that,

$$\sigma_{i=1}^{n} A_i = (a_{1j},a_{2j},\ldots,a_{nj}; j=1,\ldots,n_A). \blacksquare$$

From these definitions, the following combination of σ and π connections, namely, *πσ connection*, is able to correspond any number of sequences A_i, i=1,...,n to a sequence B of having its elements bm-tuple of the elements of A_i such that,

$$\pi_{k=1}^{bm} \#\, \sigma_{i=1}^{an} A_{i+k*an} = B = (<b_{j1},\ldots,b_{jbm}>; j=1,\ldots,an),$$

if $n=bm*an$, $bm \in N$, and $an \in N$ holds true.

Therefore, the hardware framework for CSG Engine should be determined so as to realize the above πσ connection.

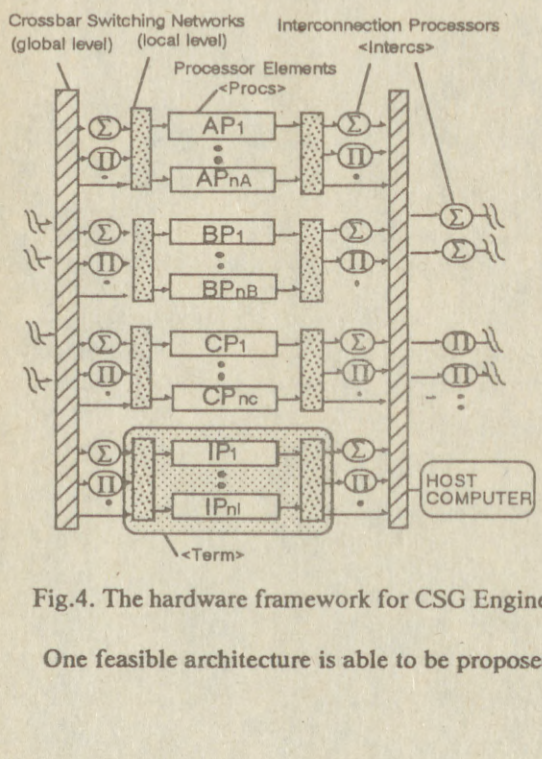


Fig.4. The hardware framework for CSG Engine

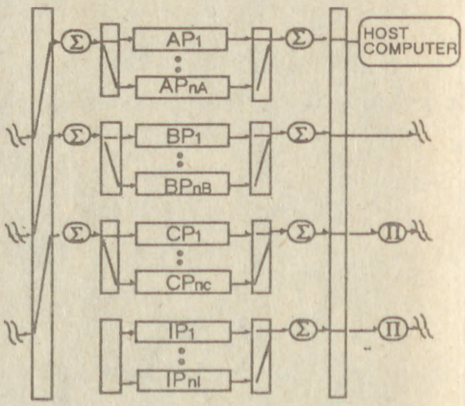


Fig.5. Configuration of switching networks for CSG Graphics Engine.

One feasible architecture is able to be proposed as the following reconfigurable parallel and

pipeline processors (see Fig.4): *Pipeline processor elements* (Procs) that perform the same performance, are connected their input and output through a *crossbar switching network* to *interconnection processors* (Intercs). Intercs are classified into two sorts, 'Π' processor and 'Σ' processor, which correspond to π and σ connection, respectively. Each of the input and output of Intercs are connected to a multiple of Intercs through crossbar switching networks for the global level.

3.3. Determination of sorts of processor elements

The next step of the design is the determination of the sort of processor elements by applying the method proposed in chapter 2-(5). The following 4 types of processor elements are determined corresponding to each of the 4 sorts of basic functions as follows:

(1) processor AP:

Let state space be ENVIRONMENTi×RIMG×PROPERTYi, and let state variables be <Re, Rr, Rt>. The axiomatic denotation of the processor AP is such that,

$$\{Re=Re0 \in ENVIRONMENTi \wedge Rr=Rr0 \in RIMG \wedge Rt=Rt0 \in PROPERTYi\}$$
$$AP\ \{Rr=fa(Re, Rr) \in PROPERTYi\}\ .$$

(2) processor BP:

Let state space be BOOL×RIMG$_{Np}$×RIMG, and let state variables be <Rb, Rs1,...,Rs$_{Np}$, R>. The axiomatic denotation of the processor BP is such that,

$$\{Rb=Rb0 \in BOOL \wedge Rs1=Rs1 \in RIMG \wedge \ldots \wedge Rs_{Np}=Rs_{Np}0 \in RIMG \wedge Rr=Rr0 \in RIMG\}\ BP$$
$$\{Rr=fb(Rb, Rs1,\ldots,Rs_{Np} \in RIMG\}\ .$$

(3) processor CP:

Let state space be SCRN×RAYS, and let state variables be <Rs, Ro>. The axiomatic denotation of the processor CP is such that,

$$\{Rs=Rs0 \in SCRN \wedge Ro=Ro0 \in RAYS\}\ CP\ \{Ro=fc(Rs) \in RAYS\}.$$

(4) processor IP:

Let state space be RAYS×PRIM×RIMG and let state variables be <Ro, Rsi, Rp>. The axiomatic denotation of the processor IP is such that,

$$\{Ro=Ro0 \in RAYS \wedge Rsi=Rsi0 \in PRIM \wedge Rp=Rp0 \in RIMG\}\ IP\ \{Rp=fi(Rsi, Ro) \in RIMG\}\ .$$

Each of the processor elements should have their hardware architecture specialized to the performance described by the basic functions. Although examples of hardware architectures are not discussed in this paper, details were presented in [MIKA89].

3.4. Syntactic representation for CSG Engine

Since the hardware framework for CSG Engine has been proposed, the next step is formally describing the configuration in a syntactic representation. The following BNF notation gives the syntax for specifying the configuration of CSG Engine (see also Fig.4):

Syntax for specifying the configuration of CSG Engine

CSGENGINE ::= Host {•<Interc>•<Term>};
Term ::= <Proc> | [<Interc>]•<Proc>•[<Interc>];
Interc ::= P,S;
Proc ::= AP, BP, CP, IP.

where {A} denotes an arbitrary times of repetition for A, [A] denotes that A is able to be neglected, the term Interc stands for 2 types of interconnection processors, and '•' stands for connection through a switching network. ■

3.4. Formal descriptions of Intercs

To introduce semantics for CSG Engine, the semantic representation for the Intercs should be defined. In the case of Intercs Π and Σ, the semantic representations are denoted in the following form: if a certain condition holds true for a process, then the process is able to be expressed by an expression utilizing Σ or Π. In this sense, the semantic representation is considered to be an inference rule for the design activity as follows:

(1) Semantic representation for the performance of Π processor.

Rule 1 (Π *composition rule*)
Let A, B be predicates such that {A} P {B}. For i=1,...,n, let Ai and Bi be predicates such that {Ai} Pi {Bi}. If,

$$(A_1 \supset A) \wedge \ldots \wedge (A_n \supset A), \text{ and } B_1 \wedge \ldots \wedge B_n \supset B,$$

hold true, then the following holds,

$$\{A\} \prod_{i=1}^{n} P_i \{B\}. \blacksquare$$

(2) Semantic representation for the performance of Σ processor.

Rule 2 (Σ *composition rule*)
Let A, B be predicates such that {A} P {B}. For i=1,...,n, let Ai and Bi be predicates such that {Ai} Pi {Bi}. If,

$$A \supset A_1 \wedge \ldots \wedge A_n, \text{ and } B_1 \wedge \ldots \wedge B_n \supset B,$$

hold true, then the following holds,

$$\{A\} \sum_{i=1}^{n} P_i \{B\}. \blacksquare$$

(3) Semantic representation for '•'.

Rule 3 ('•' *composition rule*)
Let A, B be predicates such that {A} P {B}. Let C, D be predicates such that {C} Q {D}. If B⊃C holds true, then the following holds,

{A} P • Q {D}. ■

3.5. Design of CSG Engine

Since the syntax, its semantics for the CSG Engine, and the semantic representation for RC-application, are prepared, the design process is applied to produce the objective configuration of CSG Engine. In the case of CSG Engine, the semantic representations for Intercs is written as rules which composes several semantic representations to an equivalent notation which is syntactically correct as described above. Therefore, the design process of finding the syntactic representation which is semantically equivalent to the RC-application, leads to the symbolic manipulation as follows:

Step 1. prepare SLANG(SP) as an initial semantic representation S,

Step 2. rewrite S by applying the rules of Intercs with the semantic representations for Procs, along with checking the syntactic correctness of S,

Step 3. if S is expressed only by terminals of Intercs and Procs, then the process terminates. S results in the objective syntactic representation.

For example, let {A} P {B} be S, let the rule '*' be $\{X\}\, a\, \{X'\} \wedge \{Y\}\, b\, \{Y'\} \wedge X' \supset Y' \Rightarrow \{X\}\, a^*b\, \{Y'\}$, and let the Procs be {A} Q {A'} and {A'} R {B'}. S is rewritten to the notation {A} Q*R {B}, where Q*R corresponds to the resultant syntactic representation.

3.6. Issues for introduction of parallel processing

This scheme of design allows the designer to introduce parallelism as follows: Preparing one or more Procs of a sort, introduction of parallelism is carried out by combining these Procs with rules because a duplicate of Proc is able to be prepared by restricting the original Proc from the definition 3.

For example, suppose a syntactic representation of Proc P is defined such that $\{r=r0 \in R \wedge s=s0 \in S\}\ P\ \{r=r0 \in R \wedge s=p(r) \in S\}$. From the definition 3, Proc Pi of $\{r=r0 \in R\,i \wedge s=s0 \in Si\}\ Pi\ \{r=r0 \in R \wedge s=p(r) \in Si\}$, i=1,...,n, such that,

$$\bigcup_{i=1}^{n} Ri = R, \quad \text{and} \quad \bigcup_{i=1}^{n} Si = S,$$

are able to be performed by the original processor P. By utilizing Pi, the representation for P should be rewritten as follows:

$$\{r=r0 \in R \wedge s=s0 \in S\} \sum_{i=1}^{n} Pi \sum_{i=1}^{n} \{r=r0 \in R \wedge s=p(r) \in S\},$$

The above representation utilizes more that a processor of Pi which represents parallel processing. Thus, the original syntactic representation is rewritten to introduce parallelism by utilizing processors which are restricted their spaces.

3.7. Example: the design of CSG Graphics Engine

To demonstrate the practical utilization of the proposed design method, the following shows an example of the design of CSG Engine for shaded picture generation problem, namely CSG Graphics Engine, which is the stereotypical problem in the field of CSG model based CAD applications.

STEP 1: *Semantic representation for the specification*

The RC-application for shaded picture generation problem (which we name *CG-application*)

is able to be denoted by composing the 4 types of basic functions into the following specifications :

Let SCRN = (<Pi, Q>), ENVIRONMENT = <light-source, illumination-model>, and RESULTS = (<COLi, POSi>), i=1,...,n, where COLi ∈ COLOR, and COLOR is a set of colors. The semantic representation of CG-application is SLANG(SP) such that,

$$\text{SLANG(SP)} = \{\omega\}\ \text{APPLI}\ \{\omega'\}$$

where ω, ω' is such that,

$$\{\omega\} = \{\text{Ra=Ra0} \wedge \text{Rb=Rb0} \wedge \text{Ri1=Ri1} \wedge \ldots \wedge \text{RiNp=RiNp0} \wedge \text{Rc=Rc0}\}.$$
$$\{\omega'\} = \{\text{Ry=}fa(\text{Ra},\text{Ri1},\ldots,\text{RiNp},fb(\text{Rb},fi((\text{Ri1},fc(\text{Rc}),\ldots fi(\text{RiNp},fc(\text{Rc}))))\},$$

STEP 2: *Derivation of the syntactic representation*

Applying the design process as described in chapter 3.5, the syntactic representation is given for CSG Graphics Engine as follows:

$$\text{SLANG(SP)} = \{\omega\}\ \sum_{i=1}^{nA} \text{APi} \sum_{i=1}^{nA} \cdot \sum_{i=1}^{nB} \text{BPi} \sum_{i=1}^{nB} \cdot \prod_{j=1}^{Np} \cdot \sum_{i=1}^{ni} \text{IPij} \sum_{j=1}^{Np} \cdot \prod_{i=1}^{ni} \cdot \sum \text{CPi}\ \{\omega'\}.$$

STEP 3: *Correspondence to the configuration of switching networks*

Finally, paths of switching networks are selected so as to realize the syntactic representation as depicted in Fig.5 which gives the configuration of the resultant CSG Engine.

4. CONCLUSIONS

In this paper proposed has been a theoretical framework for designing a specialized hardware processor system from a specification in the case of composing specialized hardware processor elements into a system so as to perform parallel and/or pipeline processing. The results are summarized as follows:

1. A formal method has been proposed for describing the specification of hardware processor which is based on an axiomatic formalism.

2. Formal representations have been established for the notions of specialization and distributed processing for hardware processors.

3. A theoretical method has been proposed for the design of specialized hardware processor.

4. A framework for specialized hardware system for CSG model based CAD/CAM system has been proposed, namely CSG Engine, as an example of the application of the proposed design method.

REFERENCES

[MIKA89] Mikami, S., "A Theoretical Approach to the Design of CSG Engine," *PhD thesis*, Hokkaido University (1989).
[OKIN82] Okino, N., *Methodology for Computer Aided Design*, Yokendo (1982) (in Japanese).
[MAND87] Mandrioli, D., and Ghezzi, C., *Theoretical foundations of Computer Science*, John Wiley & Sons (1987).
[HOAR69] Hoare, C.A.R., "An Axiomatic Basis of Computer Programming," *Communications of the ACM*, Vol.12, No.10, pp.576-580 (1969).
[ROTH82] Roth, S.D., "Ray Casting for Modelling Solids," *Computer Graphics and Image Processing*, No.18, pp.109-144 (1982).

AN APPROACH TO AUTOMATIC DIMENSIONING PROBLEM ON MODELED CSG

Masaaki MINAGAWA and Yukinori KAKAZU

Faculty of Engineering, Hokkaido University
Kita 13-Jo, Nishi 8-Chome Kita-Ku
Sapporo ,060 Japan

This paper describes an approach to the automatic dimensioning problem. Given a geometry data of CSG representation, dimensions are extracted depending on the types of Primitives. The extracted dimensions are arranged under the constraint that related dimensions such as size of Primitives must not be missed. These arranged dimensions are drawn automatically so as to avoid intersections and overlaps between lines and symbols. Experiments are conducted by using TIPS-1 Solid Modeler and practical mechanical parts are automatically dimensioned.

1. Introduction

Dimensioning, because of its nature, is time consuming work and is expected to be automated. To realize automatic dimensioning, many research efforts have been made. However, it can be pointed out that dimensioning is still done by designers' interactions with CAD systems although pictures such as three orthographic views are drawn automatically. In this work, the problem is divided into three sub-problems and a problem description and an approach method is given to each of them.

First problem is dimension extraction problem. This problem can be defined differently depending on representation scheme of geometry. In this study, CSG representation (hereafter CSG) is adopted because CSG data is considered to have sufficient geometry information for automatic dimensioning. Given a geometry data of this representation, the geometric pattern is recognized and dimensions are extracted depending on the types of Primitives.

Second one is dimension determination problem. After the extraction of dimensions, two types of dimensions have to be arranged, i.e. dimensions within each Primitive and dimensions among the Primitives. These dimensions have to be connected to each other under the constraint that related dimensions must not be missed. It is easy to determine the former. To determine the latter, however, there are no explicit rules. To do, this, graph theory is applied. To obtain a tree graph of dimensions, the shortest path calculation is done.

To show the arranged dimensions, dimension drawing problem is to be solved. When the dimensions are shown with pictures such as three orthographic views, various types of lines (such as extension lines, object lines etc.) and symbols have to be placed taking avoidance of intersections and overlaps between them into consideration.

2. The problem description

First, we define terms and symbols to be used in the problem description. The description is given by using predicates and functions of the following form.

$$\mathrm{PRED}(x_1, x_2, \ldots, x_n), \quad \mathrm{FUNC}(x_1, x_2, \ldots, x_n)$$

where PRED represents a predicate symbol and FUNC represents a function symbol, and $x_1, x_2, \ldots, x_n$ are variables of conditions. Each predicate will have T(true) or F(false) value and each function will return a corresponding value when their variables are fixed. The list of defined predicates and

functions is shown in Table-1.

In the following description, dimension is defined as the distance between two parallel planes which are constrained to be perpendicular to one of three coordinate axes in the 3D geometry space. We call these planes dimension extractions planes (abbreviated as DEPs) and by using these planes geometric entities such as points, line segments and planes are expressed. Graphs of dimensions are constructed in each direction of coordinate axes (see Fig.1).

2.1 The dimension extraction problem

Given 3D geometry as CSG solid model, we extract geometric entities from the geometry. First, the model M is described as follows,

$$\text{UNISET}(M, P(i)) \qquad (i = 1,2,.., n)$$

where P(i) is the i-th Primitive of the model. P(i) is defined as the product set of half space E(i, j).

$$\text{PROSET}(P(i), E(i,j)) \qquad (j = 1,2,..., m)$$

E(i,j) defines a set of points in j-th half space bounded by function F(i,j)(X).

$$\text{DEFSET}(E(i,j),\ X,\ \text{COND1})$$
$$\text{COND1} = (\ \text{MEMBER}(X, S)\ .\text{AND.}\ \text{GE}(F(i,j)(X), 0)\ )$$

where S is the Euclidian 3D space. From the geometry described above, we extract DEPs and each of them is defined as follows.

$$\text{DEFSET}(H(k,l),\ X,\ \text{COND2}) \qquad (k = 1,2,3.\ \ l = 1,2,...,N_k)$$
$$\text{COND2} = (((x = C_1)\ .\text{AND.}\ \text{EQ}(k,1))$$
$$.\text{OR.}\ ((y = C_1)\ .\text{AND.}\ \text{EQ}(k,2))$$
$$.\text{OR.}\ ((z = C_1)\ .\text{AND.}\ \text{EQ}(k,3)))$$

where H(k,l) is l-th DEP in k-th axis direction.

And we define a set of DEPs :

$$\text{DEFSET}(W(k),\ H(k,l),\ \text{NULL})$$

The problem is formulated as follows.

$$\text{DET}(W(k))$$

under the constraints.

$$\text{NE}(N_k,\ 0)$$

and, for each k, calculation result of

$$\text{PROSET}(H',\ H(k,l))$$

is

$$\text{EQ}(H',\ \text{NULL})$$

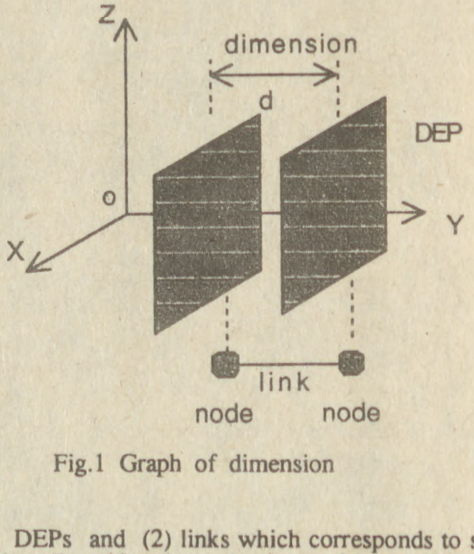


Fig.1 Graph of dimension

2.2 The dimension determination problem

Given, (1) a set of nodes which correspond to DEPs and (2) links which corresponds to size dimensions and tolerance dimensions, we formulate dimension determination problem as follows. First, graph G is given as :

GRAPH(G, V, E)

DEFSET(V, v(i), COND3)
COND3 = MEMBER(i, l_v)

DEFSET(l_v, (1,2,...,N_v), NULL)

DEFSET(E, v(j)v(k), COND4)
COND4 = (MEMBER(j, l_v)
.AND. MEMBER(k, l_v)
.AND. NE(j, k))

v(i) : node , v(j)v(k) : link

And then

DET(G_t)

under the constraints

GRAPH(G_t , V , E_t)
SUBSET(E_{tol} , E_t)
SUBSET(E_{size} , E_t)
CONNECT(G_t)
EQ(NLINK(G_t), NNODE(G_t) - 1)
(TOL(v(j),v(k)) .AND. DIM (v(j), v(k)))
(SIZDIM(v(j), v(k)) .AND. DIM(v(j), v(k)))

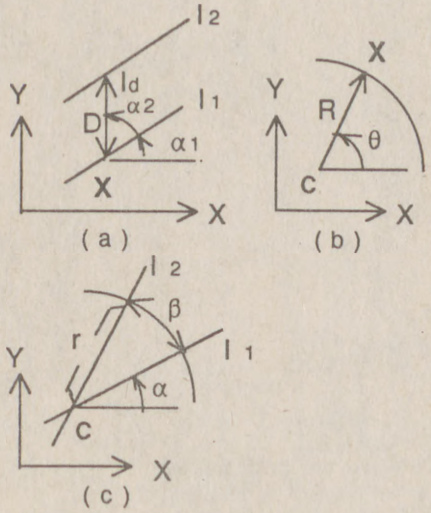


Fig.2 Constraints within a d-pair

where E_{tol} and E_{size} are links which correspond to dimensions with tolerance and size respectively.

2.3 The dimension drawing problem

Given (1) a set of d-pairs (a set of DEPs whose corresponding two nodes in the graph are connected) and (2) p-elements (lines and arcs used in wireframe drawing), we formulate the problem as follows.

DET(VAR)
DEFSET(VAR , (X, θ , r), NULL)

under (1) the constraints within a d-pair and (2) the constraint among d-pairs, where X is the start point of the dimension line, θ is the angle of the dimension line, and r is the length of the dimension line(see Fig.2).

2.3.1 Constraints within a d-pair

Each d-pair is considered to have its own dimensioning pattern. Such patterns can be classified as shown in Fig.2. Patterns (a), (b) and (c) show dimensioning of the distance between two parallel lines, radius and the angle between two lines respectively.

(a) Distance between two parallel lines : variable x
PARA(l_1, l_2)
ANGLE(l_1, l_d) = α_2

(b) Radius : variable θ
RADIUS(C) = R

(c) Angle between two lines : variable r

ANGLE(l_1, l_2) = β

ANGLE(l_1, x-axis) = α

2.3.2 Constraints among d-pairs

We express this type of constraint as prohibitive rules such as prohibition of overlaps and intersections. We define d-elements and p-elements as follows.

D-elements	Dimension lines	: DEFSET(A, a, NULL)
	Extension lines / Leader lines	: DEFSET(E, e, NULL)
	Symbols / Numerals	: DEFSET(S, s, NULL)
P-elements	Object lines	: DEFSET(F, f, NULL)

1) Overlaps

For an arbitrary element of A, E, F and S, we assume

PROHIB(OVRLAP(f(i), s(j)))
PROHIB(OVRLAP(s(i), s(j)))
PROHIB(OVRLAP(s(i), a(j)))
PROHIB(OVRLAP(s(i), e(j)))
PROHIB(OVRLAP(f(i), a(j)))
PROHIB(OVRLAP(f(i), e(j)))
PROHIB(OVRLAP(a(i), a(j)))
PROHIB(OVRLAP(a(i), e(j)))

PERMIT(OVRLAP(e(i), e(j)))

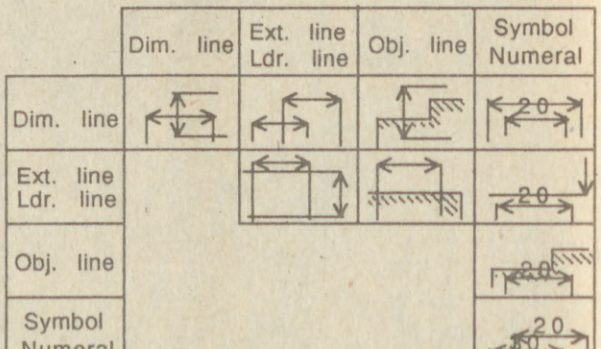


Fig.3 Positional relations to be checked

2) Intersections

First, we give the same strict prohibitions to intersections as overlaps, and in case of violation, some constraints are loosened as follows.

PERMIT(INTSCT(f(i), a(j)))
PERMIT(INTSCT(f(i), e(j)))
PERMIT(INTSCT(a(i), a(j)))
PERMIT(INTSCT(a(i), e(j)))

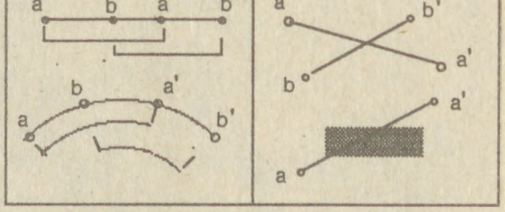


Fig.4 Overlaps and intersections

3. The approach method

3.1 Dimension extraction

Fig.5 (a) and (b) show dimension extraction according to types of Primitives. Fig.5(a) shows the extraction from Primitives with planar surfaces. In this case, the number of DEPs will be 1(plane), 2(line) or 3(point).Primitives with curved surfaces are represented by their center lines or centers of curvature. The former are replaced by lines and the latter by points as described above(diameters, radii are not converted to DEPs).

Since, to construct a model, Primitives are combined by means of set operations (such as union, product and difference),some DEPs will be deleted or merged after the operations. Conditions to be checked are shown below.

(1) Invalid faces (delete)

For all x such that

MEMBER(x, E_i)

and for all j such that

NE(j, SN(i))
GT(F_j(x), 0) .OR. EQ(F_j(x), 0),

where
E_i : i-th geometric entity
F_j(x) : the penalty function
SN(i) : Primitive identifier of the i-th geometric entity

(2) Coaxial cylinders (merge)

EQ(DIST(H_{ki}, H_{kj}), 0)
.AND. EQ(DIST(H_{li}, H_{lj}), 0)

where
H_{ki},H_{kj} : DEPs in k-th axis direction
H_{li},H_{lj} : DEPs in l-th axis direction

(3) Coplanar parallelopiped (merge)

NE(PROD(E_i, E_j), NULL)
.AND. EQ(DIST(H_{ki}, H_{kj}), 0)

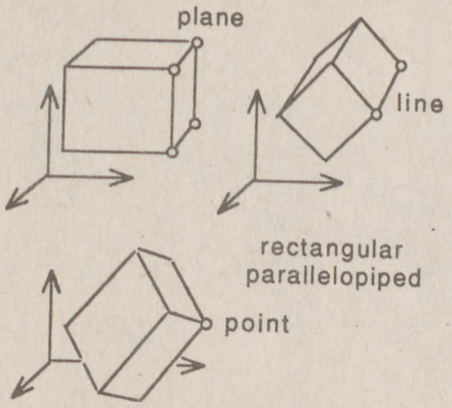


Fig.5(a) Dimension extraction from Primitives with planar surface

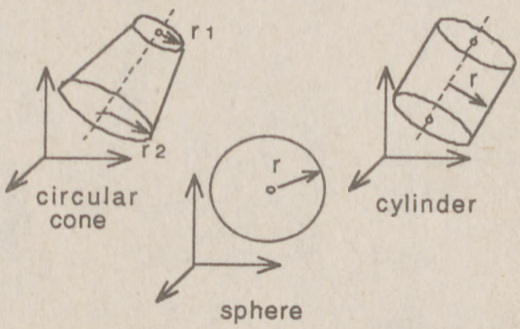


Fig.5(b) Dimension extraction from Primitives with curved surface

3.2 Dimension determination

The problem is solved as optimization problem. Given a set of nodes with respect to extracted DEPs, a complete graph is constructed. And then, to obtain a connected (tree) graph, the graph is reduced by calculating the shortest path.

In this calculation, dimensions between corresponding DEPs are used as distances between the nodes. To express such information on distances, we introduce the distance matrix C. And, to calculate reachability between two arbitrary nodes, we use the relation matrix R.

(1) The relation matrix R

R = (r(j,k)) (j,k = 1,2,..., m)
((EQ(r(j, k), 1) .AND. LINK(j, k)) .EOR. ((EQ(r(j, k), 0) .AND. NOT(LINK(j, k))))
(m is the number of nodes , orthogonal entries of R are 0s)

(2) The distance matrix C

C = (c(j, k)) (j,k = 1,2,..., m)

where c(j,k) is the absolute value of (d(j) - d(k)) and d(j),d(k) are coordinates corresponding to the nodes v(j) and v(k) respectively.

Before the calculation, matrix C is manipulated as follows.

(1) Give infinite value to the paths directed to and adjacent to the start node(given as l-th node).

For all j such that (MEMBER(j, l_V) .AND. (NE(j, l)))
c(j,l) := + ∞
where
DEFSET(l_V , (1,2,...,m), NULL)

(2) Give the links which correspond to size dimensions a negative value.

For all j,k such that
(MEMBER(j, l_V) .AND. MEMBER(k, l_V) .AND. (NE(j, k) .AND. EQ(PRIM(v(j)), PRIM(v(k)))),
c(j, k) := a_1 (a negative value).

(3) Give the links which corresponds to dimensions with tolerance a negative value.

For all i,j such that
(MEMBER(i, l_V) .AND. MEMBER(j, l_V) .AND. TOL(v(i),v(j))),
c(i, j) = a_2 (a negative value)

These weighted links come to have high priorities when the shortest path is calculated.

3.3 Dimension drawing

3.3.1 2D space recognition

The dimension drawing problem is considered as 2D space allocation problem. We use the bit map to recognize the status of given drawing area (we call this 2D allocation space). The bit map is a collection of small rectangular cells which are obtained by dividing the space into small rectangular areas of equal size. To represent the status of the space at each allocation step, each cell will be assigned a code value depending on involved element (p-element, d-element or combination of them). When there exists (M x N) cells, the bit map BM is expressed as

$$BM(i,j) = c \qquad (i = 1,2,..., M,\ j = 1,2,..., N)$$

where c is the code value which varies depending on each cell's condition.

3.3.2 The base point G

In this approach , we limit the extension into four directions, as often seen in engineering drawings , to the right, left, upward and downward. To separate given d-pairs into one of four extension groups, we set a reference point. We call the point base point G and assume that G expresses complexity of a given drawing. G is obtained as follows.

(1) Given p-elements, divide them into line segments with length of unity.
(2) Calculate the center of gravity by using the line segments as weights.

The area around the obtained points G(x_G, y_G) is considered to be complex and relative to this point , dimension lines are extended to outward directions.

3.3.3 Determination of extension directions

There may be more than one pair of candidate starting points for a d-pair (see Fig.6). The selection from them is made so that the points are on the side of extension with less intersections.

First, we define the set of d-pairs DP as

DEFSET(DP, dp(i), MEMBER(i, l_{dp}))
DEFSET(l_{dp}, (1,2,...,N_{dp}), NULL)

where dp(i) is the i-th d-pair, and N_{dp} is the number of given d-pairs. And, we define the set of start points of extension CSP as

DEFSET(CSP, SP(i), MEMBER(i, l_{dp}))
DEFSET(SP(i), sp(j), MEMBER(j, l_p))
DEFSET(l_p, (1,2,...,N_p), NULL)

where sp(j) is the j-th start points for extension and N_p is the number of the candidate points for the i-th d-pair. Using these points and executing the following procedure, we determine the start points for a d-pair.

```
DEFSET( ER, NULL, NULL )
DEFSET( EL, NULL, NULL )

for i = 1 to Ndp do
begin
  nt := 0
  for j = 1 to Np do
  begin
    if GE( sp(j), XG )
      then nt := nt + 1
      else nt := nt - 1
  end;
  GE( nt, 0 ) then
    ER := ER ∪ dp(i)
  else
    EL := EL ∪ dp(i)
end;
```

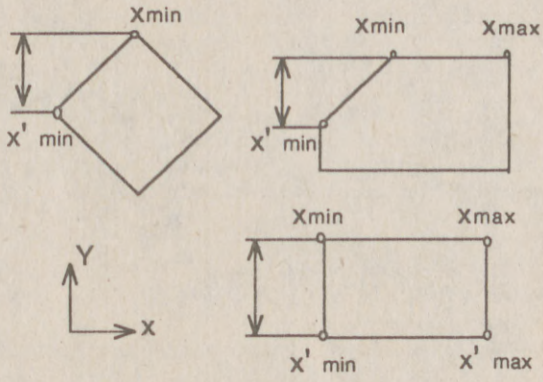


Fig.6 An example of candidate points for extension

where ER and EL are the sets of d-pairs which are to be extended to the right and left respectively, n_t is the number of the candidate points on the right or on X_G.

Next, We define l_{er} and l_{el} as follows.

DEFSET(l_{er}, (1,2,..., N_{er}), NULL)
DEFSET(l_{el}, (1,2,..., N_{el}), NULL)

where N_{er} and N_{el} are the numbers of d-pairs which are extended to the right and left respectively. After determining extension direction of d-pairs, we determine positions of d-elements.

3.3.4 Location determination (part 1)

Fig.7 shows the possibility of violating the constraints between d-pairs. The picture illustrates possibilities of intersection between dimension lines and extension lines. (As explained above, this type of intersection is not strictly prohibited.)

We define dp(i) as

dp(i) = (y(i), y'(i))

where y(i) and y'(i) are y-coordinates of end points of a dimension line. And, we defined a function INTCHK using Fig.7. To explain this function, we use EL as an example. For all i, j such that

(MEMBER(i, l_{el}) .AND. MEMBER(j, l_{el}) .AND. NE(i, j)),
INTCHK(dp(i), dp(j)) := int

where

MEMBER(int , l_{code})

DEFSET(l_{code} , (1,2,..., 8) , NULL)

Each assigned value of int corresponds to each row number of Fig.7. By using the values of int , intersection patterns are classified.

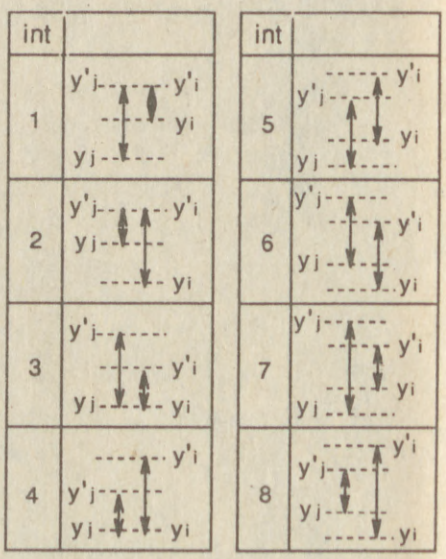


Fig.7 Check list of intersections

3.3.5 Location determination (part 2)

To place n d-pairs with less intersections, we introduce the procedure of dimension line projection. This procedure is based on the assumption that " by placing longer dimension lines in outer drawing areas and placing shorter dimension lines in inner areas, the number of intersections decreases".

Fig.8 illustrates this projection. As seen in the pictures, each grouped dimension lines are placed without intersections. The procedure for the grouping is explained below. First, we define the ordered set SEL using EL.

DEFSET(SEL, dp(i), COND)
COND = (MEMBER(i, l_{el}) .AND. GE(ABS(y'(i) - y(i)), ABS(y'(j) - y(j))) .AND. LT(i, j))

SEL is used in the following grouping procedure. (In the same manner, SRL is defined).

```
      ng := 0
LBL   ng := ng + 1
      mem( ng ) := 1
      PGL( ng ) := dp(1)
      SEL := SEL - dp(1)
      for i = 2 to Nel do
      begin
        typ := INTCHK( dp( 1 ), dp( i ) )
        if MEMBER( typ , NI ) then
          mem( ng ) := mem( ng ) + 1
          PGL( ng ) := PGL( ng ) ∪ dp(i)
          SEL := SEL - dp( i );
      end ;
      Nel := Nel - mem( ng )
      if NE( SEL, NULL ) goto LBL;
```

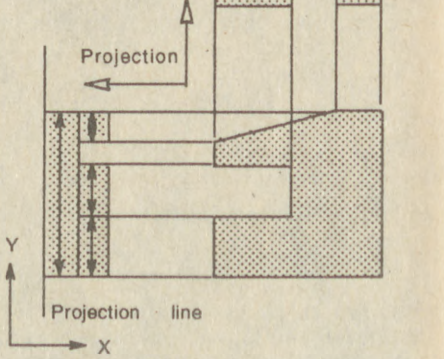


Fig.8 Dimension line projection

where

DEFSET(NI, (1,2,3,4,7,8), NULL)

n_g : the group number

mem(n_g) : the number of the members in n_g-th group

3.3.5 Reallocation of dimensions

As the final step, we reallocate the d-lines by using the relation matrix. We define related dimension using the matrix R as follows.

For i,j such that
(EQ(r(i,j), 1) .AND. EQ(r(j,k), 1) .AND. ((LT(d(i), d(j)) .AND. LT(d(j), d(k)))
.OR. (GT(d(i), d(j)) .AND. GT(d(j), d(k))))

When this holds, dimensions defined between the pair of nodes (i,j) and (j,k) are considered as related dimensions. The related dimensions are obtained by searching the tree graph expressed in R.

4. Experiments

Fig.9(a) shows a wireframe drawing of the test piece. This piece consists of 17 Primitives. Fig.9(b) shows extracted starting points for extension. Starting points for d-pairs are selected among these candidate points. Fig.9(c) shows a final output. The point G in the picture shows the base point. ▲ shows datums for dimensioning. Totally required CPU time was about 2 minutes on HITAC M280H (mainframe).

5. Conclusions

1. The automatic dimensioning problem based on 3D solid geometry was proposed
2. The automatic dimensioning problem was classified into three sub-problems-- dimension extraction problem, dimension determination problem and dimension drawing problem. These problems and their approach methods were described using predicates.
3. Dimension extraction problem was solved as 3D pattern recognition problem. CSG was used as the geometric model.
4. Dimension determination problem was solved as optimization problem by using graph theory.
5. Dimension drawing problem was solved as 2D space allocation problem. The 2D space was recognized using the bit map.
6. Experimental results were obtained employing proposed approach method and applicability of the developed method to the problem was shown. Solid Modeler TIPS-1 was used for the experiments.

Predicates	Conditions to be T
DEFSET(A, B, C)	The set A of B is defined under the condition C
UNISET(A, B)	A is a union set of B
PROSET(A, B)	A is a product set of B
SUBSET(A, B)	A is a sebset of B
DET(A)	A is determined
MEMBER(A, B)	A is a member of B
GRAPH(A, B, C)	Graph A is defined with the set of nodes B and the set of links C
CONNECT(G)	The graph G is a connected graph
TOL(V1, V2)	Tolerances are specified between nodes v1 and v2
DIM(V1, V2)	A dimension is given between nodes v1 and v2
SIZDIM(V1, V2)	A size dimension is given between nodes v1 and v2
PARA(A, B)	A is parallel to B
PROHIB(A)	The condition A is prohibited
PERMIT(A)	The condition A is permitted
OVRLAP(A, B)	A overlaps B
INTSCT(A, B)	A intersects B
NOT(A)	A is false
NE(N, M)	N is not equal to M
GT(N, M)	N is greater than M
EQ(N, M)	N is equal to M

Functions	Return value
NLINK(G)	The number of links in graph G
NNODE(G)	The number of nodes in graph G
ANGLE(A, B)	The angle between A and B
RADIUS(C)	The radius of C
DIST(A, B)	Distance between A and B
PRIM(v)	Primitive identifier corresponds to the node V
ABS(A)	Absolute value of A

Table.1 Predicates and functions

References

1. M.Minagawa, 'A Study on Automatic Dimensioning Problem in CAD/CAM' Ph.D. Dissertation , Hokkaido University (1986).
2. M.Minagawa et. al. 'Development of Full Automatic Dimensioning System Based on 3D Solid Geometry' Proceedings of PROLAMAT 1985, Paris
3. Christofides, N., 'Graph Theory - An Algorithmic Approach' Academic Press, London(1975)

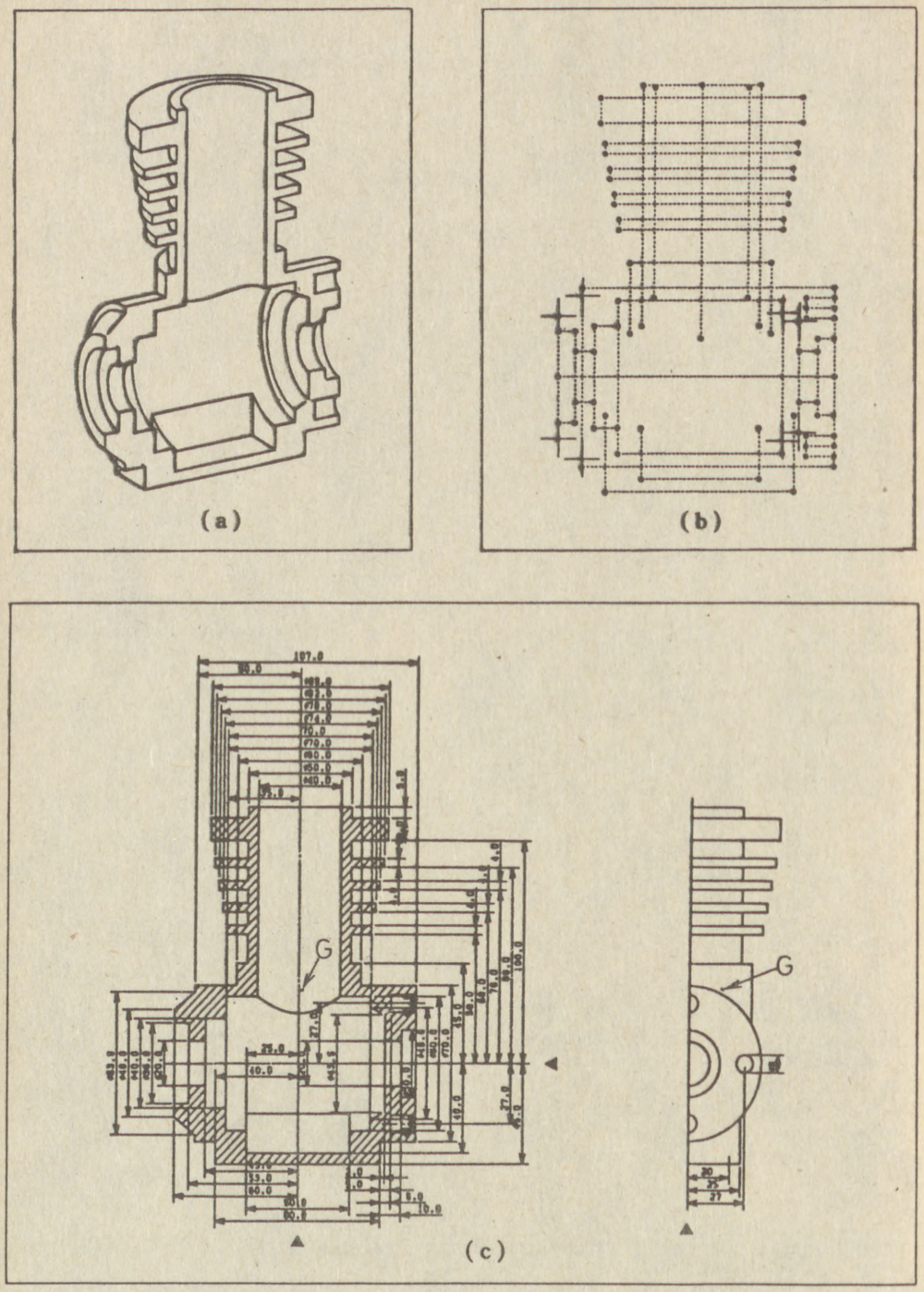


Fig.9 An example of output

APR 2,5 ROBOTIC SYSTEM AND ITS APPLICATION POSSIBILITIES

PALKO ANTON, VUKOV PREŠOV, CZECHOSLOVAKIA

The discrete manufacturing processes are typical of a broad variability of operations. Their automation presupposes application of programmable devices such as industrial robots, transport devices, production machines, etc.

By an appropriate integration of these devices it is possible to implement process systems either for partial or complete technological processes.

A design of such a system must be done - apart from an optimum technical solution - with respect to the required economic benefits for a user.

Present development indicates that an effective way here is a consistent application of modular principles in the greatest possible number of technological devices that are used in the robotic process systems. There must be met a requirement for their mechanical, energetic and information compatibility.

The advantages are as follows:

- custom devices with optimum technical and economic parameters,
- new kinematic structures, relatively simple module reconfiguration, which provides an easy and flexible transition to new process tasks,
- higher reliability provided that the modules are appropriately tested,
- lower manufacturing, maintenance and service costs due to reduced number of components.

The modular principles have been applied in the development of the APR 2,5 robotic system that is produced in VUKOV Prešov.

System structure and specifications

The APR 2,5 modular system structure can be divided into four hierarchical levels:

I. Level of purpose-made modules.
These are components of the lowest level and fulfil elementary functions:
- interconnection modules designed for supplying power to the information and actuator units at the higher levels,
- mechanical interfaces,
- worktables, etc.

The main purpose of these modules is to serve for building higher level modules. Therefore they are not supposed to be used independently.

II. Level of functional modules.
They represent the basic components of the modular structure. They are used for simple handling and process tasks. We distinguish:

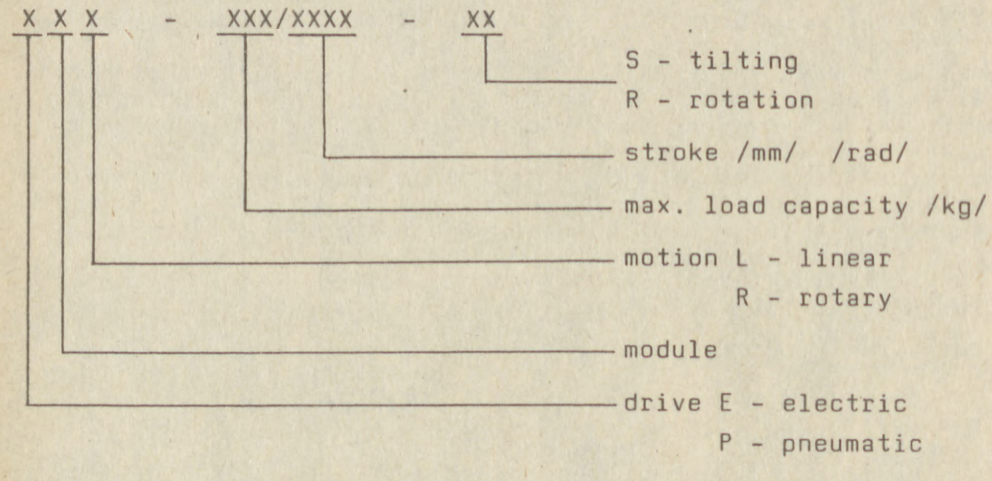
a/ Linear and rotary modules. Their basic drive units are DC disk-rotor motors equipped with speed-voltage generators for measuring speeds, and incremental sensors for measuring positions. The drive motor is connected with a gear unit

that enables to perform linear or rotary motions of a module actuator /rod, carriage, rotary unit/. The functional modules are divided vertically according to the maximum load capacity to 90, 40, 10 and 5 kg. Horizontally, each typified size can be specified by strokes. The linear modules include typified sizes of 100, 300, 400, 1500 and 3000 mm. The rotary modules have motion ranges of 90° /1,57 rad/, 180° /3,14 rad/ and 300° /5,25 rad/, respectively.

A special case is represented by a linear module that, in addition to the main motion, provides also a wrist rotation used for end effector spacial orientation. A standard wrist unit has two kinds of motion - tilting and rotation. By combining these motions it is possible to obtain six different wrist modifications with electric servodrives. For simples tasks there are used modules with two-position pneumatic drives.

The specifications of the functional modules being manufactured are given in Table 1. An example of a catalogue sheet specifying the linear functional modules is enclosed.

The symbols used for designation the types:



b/ Control modules. They include modules designed for the programming and control of the purpose-made robots. At present the RS 3A/2,5 control system is used that in its standard configuration consists of the RJ 3A/2,5 control unit, JP-3A/2,5 drive unit and a stand with a control panel. The system is built on a modular principle, with 2 - 6 controlled servodrives and possibility to control four discrete feedback axes and two discrete axes without a feedback. The robots are programmed by the JRR 32 teach pendant. The programs can be stored on the KPP 484 cassette tape unit. 24 input and 24 output signals are available for communication purposes in the standard modification. Their number can be increased to 48. The system enables to communicate with a master computer via the RS 484 communication channel.

In July 1989 VUKOV entered into cooperation with the Hungarian

company Mikromatika. The aim is to combine its control system with the APR 2,5-06 robot and to deliver the APR 2,5 robot modules with this control system.

c/ Process modules. They are used for process and handling operations, thus increasing the utility value of the system. The process modules are available for grinding, milling, boring, tightening the screws, gripper changing as well as custom grippers. In this respect we closely cooperate with NOKIA from Finland.

III. Level of custom robots.
They represent various modifications built from the modules of the 1-st and 2-nd levels.

Their task is to perform complex handling and process operations. The existing range of modules enables to build cylindrical and cartesian robots of the column, gantry and bridge types with 2 - 5 degrees of freedom and load capacities from 3 to 10 kg.

At present we produce six modifications designated as APR 2,5-01 to 06. The specifications of the types selected are given in the enclosed catalogue sheets.

IV. Level of robotic process workplaces.
These are high level independent systems. They are built from the modules of the previous three levels and can perform a part of or complete processes in an automatic mode. As an example robotic workplaces for palletization, assembly, welding etc. can be mentioned. The examples indicate multi-purpose nature of these workplaces.

Application fields

The concept of an open system based on the modular principles enables to flexibly respond to the different user requirements. The drawing documentation of the system has been produced on a computer graphic station, which makes it possible to find and implement an optimum solution in a very short time. Our goal is to deliver technically optimum and economically efficient robotic systems.

Good dynamic performance and high accuracy motions enable to apply the APR 2,5 systems also in complex processes such as assembly in mechanical engineering and electrical engineering, testing, laser cutting, water jet cutting, etc.

Here are the examples of industrial applications of the system:

- assembly of refrigerator driers,
- assembly of brake cylinders,
- application of caulking compound on headlight glass for the Favorit cars,
- mounting of integrated circuits,
- laser centre with APR 2,5-04 robot, etc.

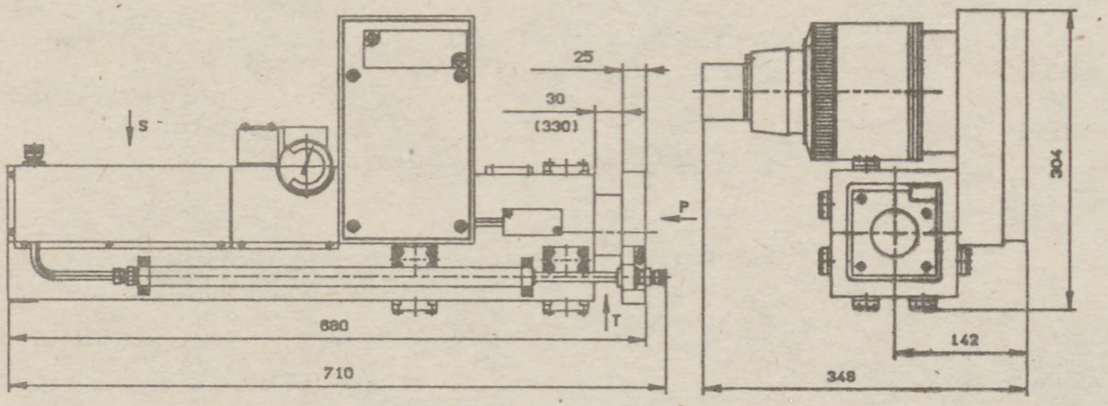
Our engineering departments can help with integrating the functional modules of the system directly on the manufacturing equipment, e.g. machine tools, textile machines, stamping machines etc.

Parameter \ Module type	EML-003/ 400 SR	PML-005 0100	EML-010 0400	EML-040 0300	EML-090 3500	EMR-005 0180	EMR-090 0300
Load capacity (kg)	5	5	10	40	90	5	90
Maximum movements (m)	0,4	0,1	0,4	0,3	1,5(3)	-	-
(rad)	-	-	-	-	-	3,14	5,23
Speed /ms^{-1}/	1	0,2	1	0,8	1,2	-	-
/$rads^{-1}$/	-	-	-	-	-	3,14	3,5
Repeatability /mm/	$\pm$0,03	$\pm$0,02	$\pm$0,03	$\pm$0,03	$\pm$0,03	-	-
(rad)	-	-	-	-	-	$\pm 1{,}75 \cdot 10^{-4}$	$\pm 5{,}26 \cdot 10^{-4}$
Maximum acceleration (ms^{-2})	4	6	4	3	3,8	-	-
(rad s^{-2})	S=8,R=12	-	-	-	-	70	5
Mass (kg)	38	3	29	40	107	4	90

Table 1 Parameters of functional modules

APR 2.5
system

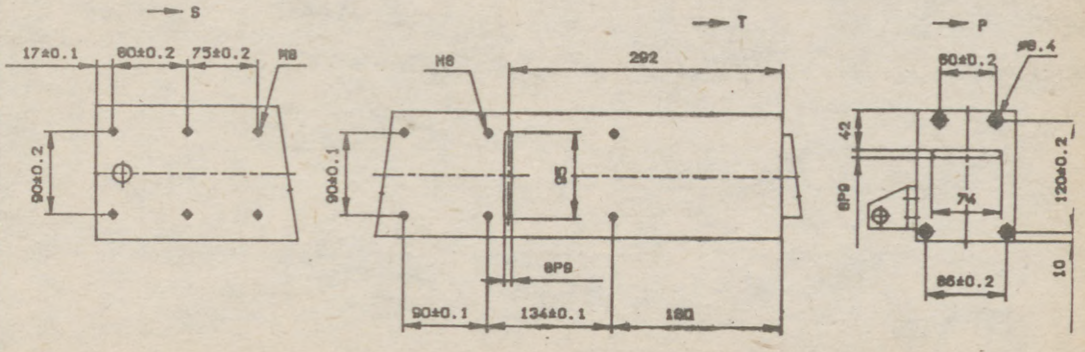
Linear module EML - 040/0300



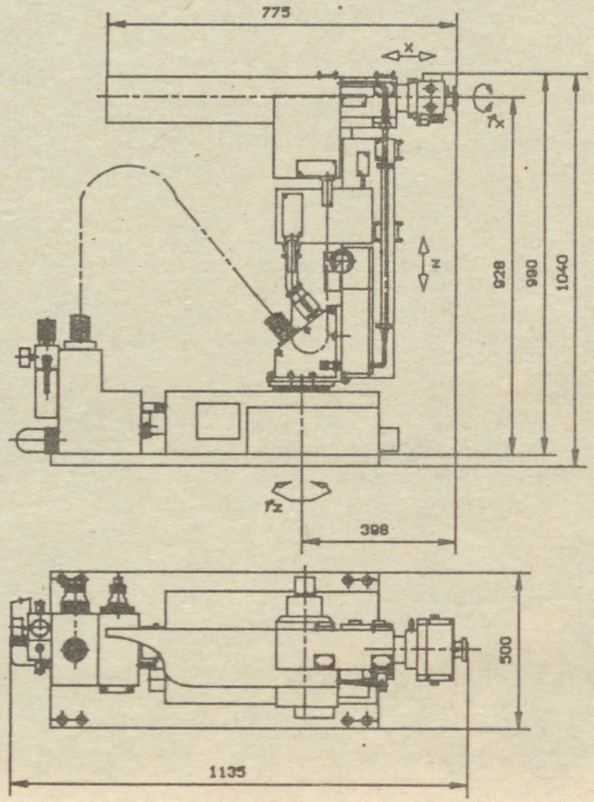
TECHNICAL PARAMETERS

DRIVE	DC ELECTRICAL SERVODRIVE
BALANCING	PNEUMATIC (0.3 MPA)
POWER INPUT (kW)	0.35
MASS (kg)	40
LOAD CAPACITY MAX. (kg)	50
STATICAL TORQUE (Nm)	80
TRAJECTORY MAX. (m)	0.3
MAX. SPEED (ms^{-1})	0.8
MAX. ACCELERATION (ms^{-2})	3
REPEATING POSITIONING ACCURACY (mm)	±0.03

CONNECTING DIMENSIONS

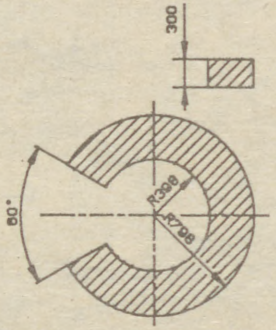


VVUKOV	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-01



Modules used
Rotation module PMR - 005/0180
Linear module EML - 010/0400
Linear module EML - 040/0300
Rotation module EMR - 090/0300
Connecting module - MP 1
Frame

WORKING AREA



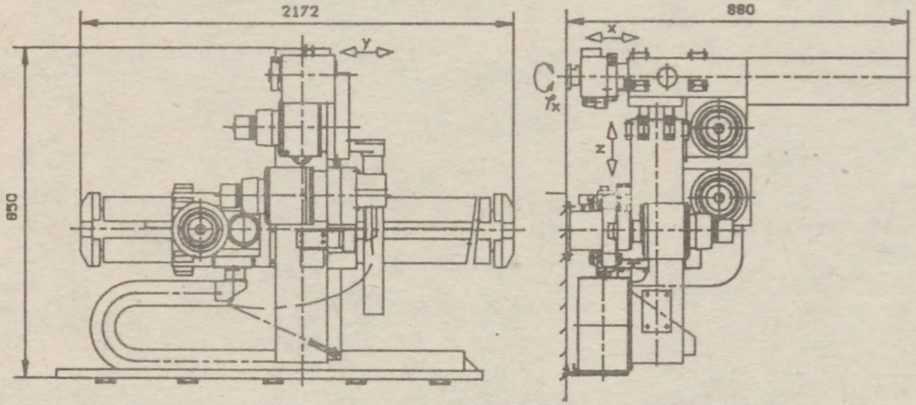
TECHNICAL PARAMETERS

Number of degrees of freedom	4 (φz,z,x,φx)
Art of drive	DC servodrives (φz,z,x) Pneumatic drive (φx)
Load capacity (kg)	3.5
Repeating positioning accuracy (mm)	± 0.1
Mass (kg)	120
Control system	RS 3A/2.5

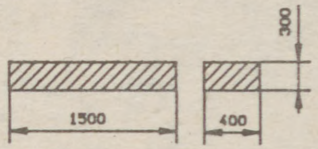
Motion ax	Speed
φz	3.5 rads^{-1}
x	1 ms^{-1}
z	0.8 ms^{-1}
φx	1 rads^{-1}

VVUKOV	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-02

VUKOV	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-02



WORKING AREA



TECHNICAL PARAMETERS

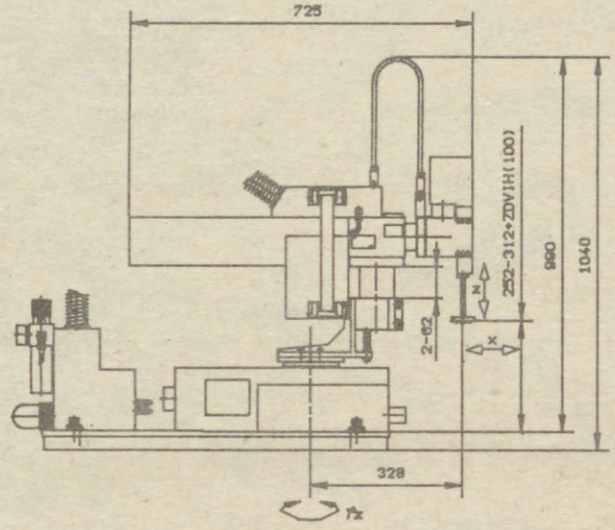
Number of degrees of freedom	4 (y,x,z,Ψx)
Art of drive	DC electric servodrives(x, z,y); Pneumatic drive (Ψx)
Load capacity (kg)	3.5
Repating positioning accuracy (mm)	±0.05
Mass (kg)	100
Control system	RS 3A/2.5

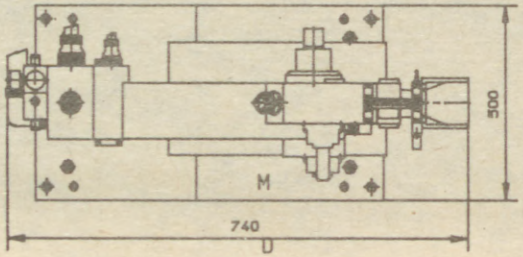
Motion ax	Speed
y	1 ms^{-1}
x	1 ms^{-1}
z	0.8 ms^{-1}
Ψx	1 $rads^{-1}$

MODULES USED

Rotation module PMR -005/0180
Linear module EML - 010/0400
Linear module EML - 040/0300
Linear module EML - 090/1500
Connecting module-MP 3

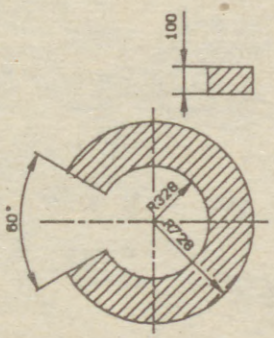
VUKOV	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-03





MODULES USED
Linear module EML - 005/0100
Linear module EML - 010/0400
Rotation module EMR - 090/0300
Connecting module - MP 4
Frame

WORKING AREA



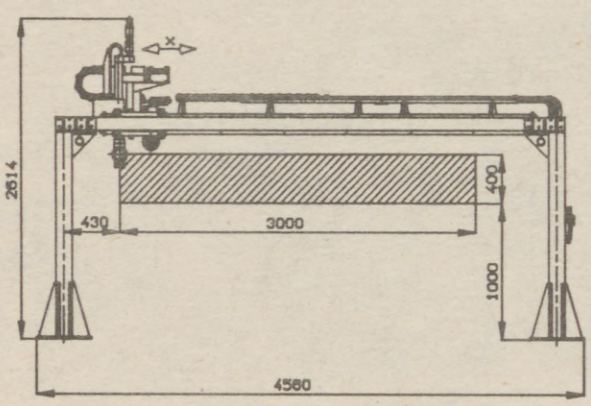
TECHNICAL PARAMETERS

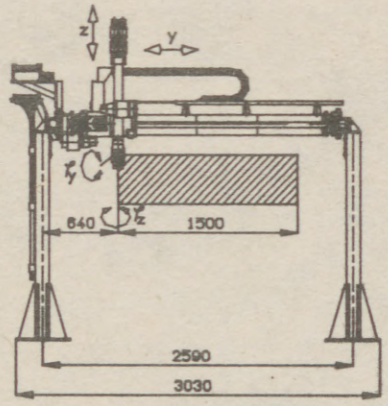
Number of degrees of freedom	3 (fz,x,z)
Art of drive	DC servodrives (fz,x,z) Alternative for ax z Pneumatic ON/OFF drive
Load capacity (kg)	5
Repating positioning accuracy (mm)	± 0.1
Mass (kg)	80
Control system	RS 3A/2.5

Motion ax	Speed
fz	3.5 rads^{-1}
x	1 ms^{-1}
z	0.2 ms^{-1}

VUKOV	APR 2.5

VUKOV	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-04





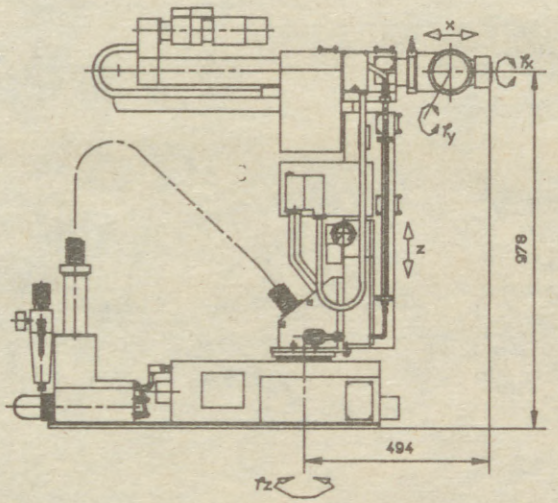
TECHNICAL PARAMETERS

Number of degrees of freedom	5 (x,y,z,γz,γy)	Motion ax	Speed
Art of drive	DC electric servodrive	x	1 ms^{-1}
Load capacity (kg)	5	y	1 ms^{-1}
Repating positioning accuracy (mm)	±0.2	z	0.8 ms^{-1}
Mass (kg)	300	γz	2.3 $rads^{-1}$
Control system	RS 3A/2.5	γy	2 $rads^{-1}$

MODULES USED

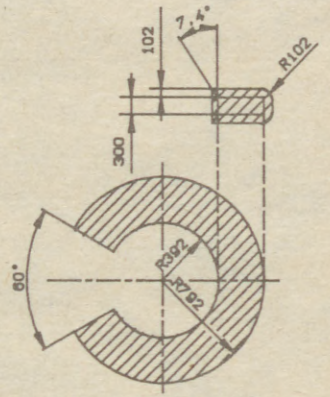
Support structure
Linear module EML - 090/3000
Linear module EML - 090/1500
Linear module EML - 003/0400 SR

	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-05



MODULES USED
Linear module EML - 003/0400 - SR
Linear module EML - 040/0300
Rotation module EMR - 090/0300
Connecting module - MP 2
Frame

WORKING AREA



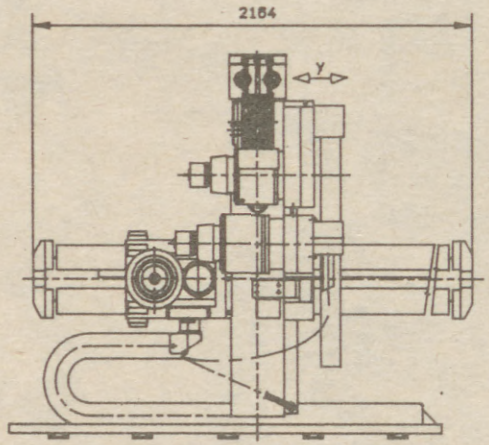
TECHNICAL PARAMETERS

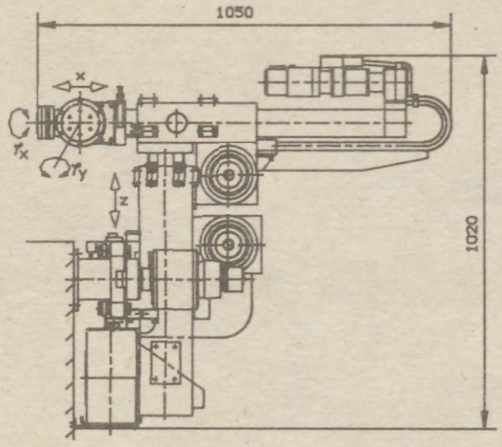
Number of degrees of freedom	5 (z,x,z,x,y)
Art of drive	DC electric servodrives
Load capacity (kg)	5
Repating positioning accuracy (mm)	± 0.1
Mass (kg)	130
Control system	RS 3A/2.5

Motion ax	Speed
z	3.5 rads^{-1}
x	1 ms^{-1}
z	0.8 ms^{-1}
x	2.3 rads^{-1}
y	2 rads^{-1}

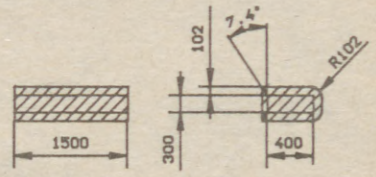
	APR 2.5 system	INDUSTRIAL ROBOT	APR 2.5-06

	APR 2.5 system	INDUSTRIAL ROBOT APR 2.5-06





WORKING AREA



TECHNICAL PARAMETERS

Number of degrees of freedom	5 (y,x,z,r'z,r'y)
Art of drive	DC electric servodrives
Load capacity (kg)	5
Repating positioning accuracy	±0.05
Mass (kg)	115
Control system	RS 3A/2.5

Motion ax	Speed
y	1 ms^{-1}
x	1 ms^{-1}
z	0.8 ms^{-1}
r'x	2.3 $rads^{-1}$
r'y	2 $rads^{-1}$

MODULES USED

Linear module EML - 003/0400 - SR
Linear module EML - 040/0300
Linear module EML - 090/1500
Connecting module - MP 3

ON THE DETERMINATION OF THE PART TYPES AND MIX IN FMS

Peng Wei, Wu Naiqi and Xue Jinsong
Shenyang Institute of Automation
Academia Sinica
Shenyang, P.R.China

Abstract In this paper the problem of the part type selection and the determination of mix in FMS is considered. In order to obtain better result we model the problem by considering the routing and sequencing together and solve it iteratively.

1. Introduction

Maintaining hogh level utilizations of the equipment is an important problem for the system effectiveness of the FMS. This goal is to be achieved often by selecting suitable part types to be manufactured in it and effective scheduling. Generally, the part types are selected separarely from the scheduling, but, in doing so, the result is not good, for the utilizations are not only dependent on the selection of part types, but also on the scheduling. It is better to consider part type selection and scheduling together so as to estimate more accurate utilizations for a deterministic set of part types.

In this paper a hierarchical method is proposed. We extend the method in [1] to solve the routing problem by considering load balance, and for the sequencing problem a heuristic method is used. With the determination of routing and sequencing we can estimate the utilizations, and the utilizations information in turn is used as a feedback for the selection of part types and mix determination. Then the problem can be solved iteratively.

2. System Assumption

We consider the FMS of job-shop type, in the system there are m machine centers $MC_1,\ldots,MC_m$. By forecasting there n part types for manufacturing, the demand, due date and the profit of each part are $q_1,\ldots,q_n$; $a_1,\ldots,a_n$ and $l_1,\ldots,l_n$ respectively. It is assumed that an operation can be processed at more than one machine center, in other words, each part can have more than one processing route. Before each machine center there is a buffer with capacity large enough. Each part J_i have I_i operations with processing time t_{ij} $(j=1,2,\ldots,I_i)$.

3. Routing Problem

For each part J_j we can describe the relation of the operations and machine centers which the part cad be processed at by the following matrix

$$A_i=(a_{ij})=\begin{array}{c} \begin{matrix} MC_1 & MC_2 & \cdots & MC_m \end{matrix} \\ \begin{pmatrix} 0 & 1 & \cdots & 0 \\ 0 & 0 & \cdots & 1 \\ 1 & 1 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 1 & 0 & \cdots & 0 \end{pmatrix} \end{array} I_i \times m$$

where the rows correspond to the operation and the columns to the machine centers. If $a_{ij}=1$, it denotes that operation i can be processed at machine center MC_j, if $a_{ij}=0$, it cannot. We call the matrix as manufactruring matrix. Corresponding to the manufacturing matrix we have a processing time matrix as follows

$$T_i = \begin{pmatrix} 0 & t_{12} & \cdots & 0 \\ 0 & 0 & \cdots & t_{2m} \\ t_{31} & t_{32} & \cdots & 0 \\ t_{I_i 1} & 0 & \cdots & 0 \end{pmatrix}, \quad I_i \times m$$

Let $T_{ij}=\sum_{k=1}^{I_j} t_{kj}$ and $CMT_j=\sum_{i=1}^{n} T_{ij}$

In routing for each operation we select one machine center to balance the load of the machine centers as possible as we could.

In a manufacturing matrix for a part if a row containes only one "1" element, or only one machine center can process the corresponding operation, then there is no routing to do, otherwise we can do it as follows. Divide CMT_j into two parts, CMT_j^1 and CMT_j^2, such that $CMT_j^1 \leq T$ (T is plan time period) and $CMT_j^2 > T$ and let $N'=\{j/CMT_j \leq T\}$, $N^2=\{j/CMT_j>T\}$, then select the routine as follows.

1°. In matrix A, for each i, if there is only one $j\in N'$ such that $a_{ij}=1$, then set $a_{ik}=0$ for all $k\neq j$; if there exists a set $D\subset N'$ and D has more than one elements, then set $a_{ik}=0$ for all $k\neq j$, at the same time, set $t_{ik}=0$ in T_i and j is determined by $CMT_j \prec CMT_t$ for any $t\neq j$, $t\in D$.

2°. Arrange the elements in N^2 such that $CMT_{j_1}^2 \leq \ldots \leq CMT_{j_L}^2$, and for each matrix A_i calculate $g_i=\sum_k a_{kj_1}$, and arrange $B=\{g_1,\ldots,g_n\}$ such that $g_{b1} \geq \cdots \geq g_{bn}$, then in matrix A_{b1}, if $a_{kj_1}=1$, set $a_{kj}=0$, $i\neq j$ and set $t_{kj}=0$ in T_{b1}, in matrix A_{b2} do the same, and so on, untill the load of machine MC_{j_1} $\tau \doteq T$ ($\doteq$ implies equal or closed to).

3°. For $j_2,\ldots,j_L$, in 2° repeat the work of 2°.

4°. Let $\tau'_{jh}=CMT_{jh}^2-\tau_{jh}$, and replace CMT_j by τ'_{jh}, and repeat the work above, until for any A_i ($i=1,\ldots,n$) for all k, there is only one j such that $a_{kj}=1$.

Obviously, in doing so, we assign each operation to a machine.

4. The Determination of Part Types and Mix

Based on the routing above we discuss the problem of determination of part types and mix in this section.

Let $c_{ij}=\sum_{j'=j} T_{ij'}$

be the processing time of part J_i at MC_j, and $d_i=\sum_{j=1}^{I_i} T_{ij}$ be the total processing time of part J_i. The objective function is

$$J=\sum_{i=1}^{n} l_i x_i \qquad (1)$$

where x_i is the number of parts of type J_i. Then the problem of the determination of part types and mix is to maximize J under the constraints in shop floor. This is a linear integer programming as

follows.

$$\max J \tag{2}$$

$$\text{s.t.} \sum_{i=1}^{n} c_{ij}\, x_i \;(1-(p_j^1+p_j^2))T, \quad j=1,\ldots,m \tag{3}$$

$$x_i \leq q_i, \quad i=1,\ldots,n \tag{4}$$

$$d_i x_i \leq a_i (1-p_j^3), \quad i=1,\ldots,n \tag{5}$$

where (3) are the load constraints for the machine centers, (4) are the demand constraints, (5) are the due date constraints. considering the breakdown of the machine centers we denote the rate of the time during which the machine center deos not work resulting from the machine failures for machine center MC_j to T by p_j^1 and it can be given statistically, p_j^2 is the idle rate of machine MC_j caused by the preceding constraints and it is dependent on the sequencing, p_j^3 is a parameter which affects the due date and is also dependent on the sequencing. Because of the existence of p_j^2 and p_j^3 the solution of the problem above is connected to the sequencing, conversely, the change of part types and mix causes the change of sequencing. So the problem should be solved iteratively.

5. Sequencing Algorithm

We use a heuristic algorithm to solve the sequencing problem. Assume that there are n parts to be processed, and the part set is denoted by

$$E=\{J_1,\ldots,J_n\}$$

Set E contains several parts of same type. The processing path of part type J_i determined in section 3 is denoted by

$$J_i \longrightarrow MC_{i_1},\ldots,MC_{i_{K_i}}, \quad i=1,\ldots,n$$

where i is for the number of part and i_j for the number of machine center.
Correspondingly the series of processing time is

$$c_{i i_1},\ldots,c_{i i_{K_i}}, \quad i=1,\ldots,n$$

Let $M_j(t)$ denotes the set of parts at time t in the buffer of machine center j for processing, then

$$M_j(0)=\{J_i / i_1=j,\ i=1,\ldots,n\},\ j=1,\ldots,m$$

and let $$TM_j(t)=\sum_{\substack{i_1=j \\ i\in M_j(t)}} c_{i i_1} \qquad j=1,\ldots,m$$

we call $TM_j(t)$ as the task waiting before machine center j at time t.

Let $T_j(t)$ denote the total task remained for processing at machine center j
at time t, then

$$T_j(0)=\sum_{\substack{i_h=j \\ i=1,2,\ldots,n}} \sum_{h=1}^{K_i} c \quad , \ j=1,\ldots,m$$

Obviously, if for j $T_j(t)$ is the maximum one, then machine center j is

the bottleneck at time t. Let A(t) be accumulative idle time at time t then

$$T_j(t)=T_j(0)+A(t)-t$$

let $C_j(t)$ denotes the processing task of those parts which enter into the buffer before machine center j in the time interval from time 0^+ to t^-, then

$$TM_j(t)=TM_j(0)+C_j(t)+A(t)-t.$$

Further, we let

$$B_j(t)=T_j(t)-TM_j(t)$$

$$D_h(t)=TM_j(t)+C_{hh}-x_j(t)$$

where $$x_j(t)=T_j(t)\sum_{i=1}^{m}TM_i(t)/\sum_{i=1}^{m}T_i(t)$$

Using the notation above we can give a sequencing rule as follows.

1). Arrange the due dates $a_1,\ldots,a_n$ corresponding to parts $J_1,\ldots,J_n$ such that $a_{h_1}\le a_{h_2}\le\ldots\le a_{h_n}$, the part corresponding to a_{h_i} is J_{h_i}. If there exists an h_j such that $a_{h_j}\le T$ and $a_{h_{j+1}}>T$, then we give the priority level as

$$J_{h_1}\succ J_{h_2}\succ\ldots\succ J_{h_j}$$

where $J_{h_i}\succ J_{h_\alpha}$ means that J_{h_i} has higher priority level than J_{h_α}. And $J_{h_i}\succ J_{h_k}$ if $i\le j$ and $k\ge 1+j$.

2). For the part set $\{J_{h_k}/k\ge j+1\}$, we give the following rule. Let

$$B_i(t)=\max_h B_h(t),\quad B_k(t)=\max_{h\ne i}B_h(t)$$

then a machine center should select the part to process such that the next operation of the part will be processed at machine center MC_i. If there are no such parts for MC_i then search the parts for MC_k, and so on.

If there is another $B_L(t)$, such that $B_L(t)=B_i(t)$, then the parts are searched for machine center m such that $T_m(t)=\max(T_i(t),T_L(t))$.

If there are more than one parts whose next operation will be processed at machine center MC_i, then the part is selected such that $D_h(t)$ is minimized.

By the rule we can find the solution of sequencing problem. The goal of using this rule is to rednce the makespan and keep the due dates as possible as we could.

6. The Solution of the Problem

After sequencing algorithm has been given we can solve the problem given in
section 4, and an iterative algorithm will be given in the following.

1). Set $p_j^2(0)=p_j^3(0)=0$ $(i=1,\ldots,n,\ j=1,\ldots,m)$, then solve the problem given by (2)--(5);

2). Based on the solution in 1) solve sequencing problem using the rule given in section 5, and find $p_j^2(1)$ and $p_j^3(1)$;

3). If all due dates and constraints (3).(4) are satisfied then stop, otherwise if some due dates are not satisfied, for instance, $a_{i'}$ is not

satisfied, then we creat a constraint given by

$$x_{hk}^{(1)} \leq x_{hk}^{(0)} - 1 \tag{6}$$

where $J_{hk} \in \{J_{h1}, \ldots, J_{hi'}\}$ has smallest profit rate. If m' constraints of (3) are not satisfied and the differences are $b_1, \ldots, b_{m'}$ respectively, for this we solve the following problem

$$J' = \min \sum_{i=1}^{n} y_i l_i$$

$$\sum_{i=1}^{n} y_i c_{ij} \geq b_j \qquad j=1,\ldots,m'$$

where $$b_j' = \begin{cases} b_j & , j \in \{1,\ldots,m'\} \\ 0 & , \text{otherwise} \end{cases}$$

so we obtain a constraint

$$x_i^{(1)} \leq x_i^{(0)} - y_i^{(0)} \tag{7}$$

solve the problem (2)--(7). Then repeat the procedure above until satisfactory solution is obtained.

In the following we discuss the convergence of the iterative algorithm. Assume that after j iterations we have

$$x_{hk}^{(j+1)} = x_{hk}^{(j)} - 1 \text{ and } x_i^{(j+1)} = x_i^{(j)} - y_i^{(j)}$$

satisfied constraint condition and as the result then we have

$$J_j = \sum_{i=1}^{n} x_i^{(j)} l_i \leq J_{j+1} = \sum_{i=1}^{n} x_i^{(j+1)} l_i \tag{8}$$

and

$$J_n \leq \max \sum_{i=1}^{n} x_i l_i \qquad \text{for any n} \tag{9}$$

hold. If (8) holds as an equality, then $x_i^{(j)} = x_i^{(j+1)}$ (i=1,...,n), or the convergence has been reached. Otherwise from the property of series J_n we know the algorithm is convergent.

7. Conclusion

In this paper a method for determining the part types and mix is presented. Because we use the feedback infomation from routing and sequencing, a better result is obtained. It is useful for the planning and scheduling in the FMS.

References

[1] J.B Tazewicz et al, "New trends in machine scheduling", European Journal of Operational Research 37(1988) 304--317.

International Operations Research Methodologies

Gerhard Plenert, Phd, CPIM
Director, **California Productivity and Quality Center**
California State University, Chico
Brigham Young University
3988 Orval Way
Carmichael, CA 95608
USA

When I started working in operations research it was primarily in the United States. I was soon given the opportunity to work overseas and watch Western techniques be implemented into plants in developing countries. It wasn't long before I realized that the bright ideas of the West are not always appropriate for a developing environment.

I returned to academia to do research in this area. The research started with a search all over the world for different operations research methodologies. About 150 were found, many of which were combinations of several techniques and could be broken up into smaller units. This research effort resulted in a book that is about to be published by TAB Books titled International Management and Production Techniques.

The next stage of my studies required that I test these techniques against each other in order to develop some type of guidelines on when a particular technique was appropriate. This was done by comparing the installation of these various techniques. Then a simulation model was to be built that would test the various techniques against each other. Evaluation criterion for tools used in factories was based on three measures:

Reduction in Inventory
Reduction in Operating Expense
Improved Throughput

We classified different types of manufacturing into several categories:

Discrete Manufacturing - Job Shop
Discrete Manufacturing - Flow Shop
Discrete Man. - Departmentalized Repetitive
Process Manufacturing

Within these categories it was easy to simulate and compare the various production planning and control tools against each other. Unfortunately we soon realized that it was possible to have two plants sitting side by side, and the techniques that seemed to be the most successful in the one

plant would turn out to be a total disaster in the other. For example, in one plant a technique was implemented that should achieve all three of the previous objectives. Unfortunately, as inventory was decreased, the asset ratios like the Current Ratio and the Quick Ratio started to look worse. This cause the corporate financial gurus to come down hard on the manager of the plant. The result was that the manager of the plant discarded the system and increased inventory back up to a level that would be acceptable to the financial wizards.

What we realized was that when selecting an operations research tool it was more important to consider the goals of the environment. The type of manufacturing was less important. This also reflects the failures that are found in developing countries. For example, lets consider the following goals:

Labor Efficiency
Productivity
Financial Goals

These all look like appropriate goals for a manufacturing establishment. Unfortunately they are in direct contradiction with each other. For example: financial goals require annual profits (at least in the United States they do). Productivity goals look for maximum throughput. In order to maximize throughput, advanced technology is necessary. Advanced technology requires long term investments. Long term investments destroy short term profitability. As a result, plant managers will tend to repair an old piece of junk rather than replace it with something new and more efficient, simply because the repair is cheaper.

From these examples we can see how two factories sitting side by side can require different methods for managing their production environment. When we look at developing countries we find even more dramatic examples of conflicting goals. For example, the goals of:

Full Employment
Appropriate Technology

Full employment and labor efficiency are completely in conflict. And appropriate technology and productivity are also in conflict. The result of the research is that we simply don't have just one right answer of how to run a factory. We need to determine the goals of the environment, and then within these goals we need to find the most appropriate technique that's available.

An example of how the goals of an organization dictate the appropriate operations research methods can be seen in manufacturing. One question that can be asked immediately is which manufacturing resource do we want to minimize:

Labor
Materials

Machinery
Burden (which includes items like:)
Energy
Maintenance

If the organization is looking to optimize Labor, it could select a system like MRP (Material Requirements Planning) which has its best performance in a Job Shop. If the organization is looking to optimize on Materials, JIT (Just-In-Time) would be appropriate. JIT was developed in Japan and gets its best performance in a repetitive discrete shop. If Machinery optimization is the goal, OPT (Optimized Production Technology) would probably be helpful. This was developed in Israel and gets its best performance in Repetitive Discrete and Process shops. Another Machinery optimization methodology is BAM (Bottleneck Allocation Methodology).

In summary, applied operations research is one area where simulation has not been too helpful. The overriding plant goals, the culture, and the environment of the organization have the most control and influence on the optimal method that should be used.

ABOUT THE AUTHOR

Gerhard Plenert spent 15 years working in management in private industry. His specialty was in MIS (Management Information Systems) and POM (Production / Operations Management). He traveled throughout the world in this capacity. He recently returned to school to earn his PhD at the Colorado School of Mines and he currently teaches and does research at California State University, Chico. He is the Director of the California Productivity and Quality Center. He also does manufacturing systems consulting. His research specialty is in International Industrial Management with an emphasis on Developing Countries.

RESTRUCTURING AND REORGANIZING AN EXISTING EDP ENVIRONMENT TO OPTIMIZE INFORMATION LOGISTICS - AN EXAMPLE OF A SUCCESSFUL CIM PROJECT WITHIN A MAJOR AUTOMOTIVE SUPPLIER

Dr.Axel W. Poestges,Hewlett - Packard GmbH
European Industry Marketing
Discrete Manufacturing Industries
Herrenberger Straße 130
D-7030 BOEBLINGEN (Germany West)
Telephone 0049-7031-14-3876

Presented during the INTERTECHNO '90, 11-14 September 1990 in Budapest, Hungary

1 INTRODUCTION

CIM is something that seems to be of same importance for the computer manufacturers, consultants, system integrators and information technology users. But computer integrated manufacturing is no longer a conglomerate of automation islands but there is a strong force leading towards CIM as an integration of data, functions and logistic process steps. The automotive industry is a good example, how market trends can influence a whole industry with all typical IT- buying behaviours and application patterns. The use of electronic data interchange has caused specific integration scenarios in the automotive industry that are really unique in the manufacturing environment. EDI links market segments together that have been seperated for quite a long while. Especially the suppliers to the automotive industry are forced to hook themselves into the infomation network covering quality, design, engineering and logistic data. Therefor the pressure on most of the suppliers means automate, emigrate or evaporate. For the computer manufacturers the automation of such an automotive supplier is a real challenge. To show how the automotive IT framework gives an appropriate guideline for a CIM project that is bound to be successful.

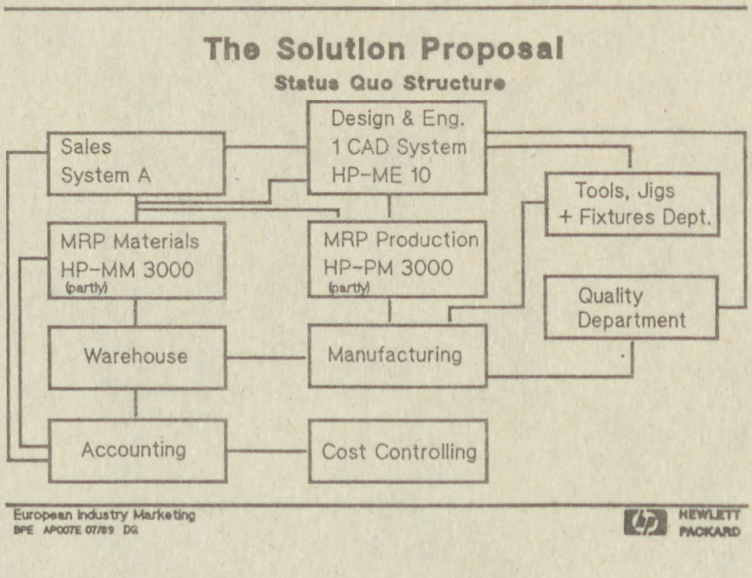
The project that is going to be presented during INTERTECHNO is one that was succesfully implemented roughly two years ago. The example shows how the existing EDP infrastructure was optimized to make the best out of proven organisational and infrastructural systems. The functional enhancements of some important IT building blocks like CAD or CAM are explained so that the whole spectrum of benefits can be discussed. The consequences in terms of personell and cost are documented detailed and outline very clearly the requirements and commitments of management to make such a CIM project a reference for computer manufacturers customers and other automotive suppliers as well. Having listened to the presentation you are wellcome to ask for any further details ore reference visits at any time.

2 STATUS QUO AND SOLUTION PROPOSAL

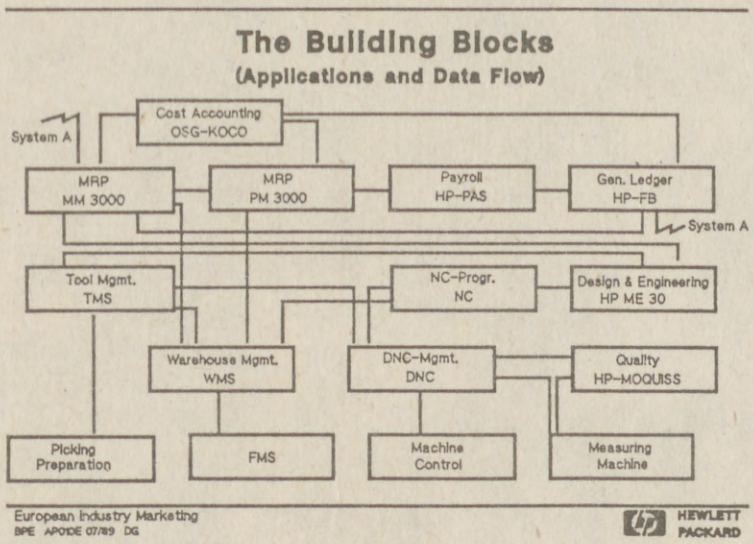
Fortunately the customer was no IT newcomer but had a quite well developed IT infrastructure in place. The company is a typical midsized mechanical manufacturing automotive supplier. Roughly 1000 employees work at 3 different locations. They produce fairly simple parts made out of sheet metal. Most of their business goes through prime contracts or via sparepart sales. Only a small amount belongs to what they call special products.

The management of the company asked HEWLETT PACKARD as prime IT supplier to work out a company specific future bound IT-strategy including the idea of an integrated information technology for a manufacturing company. The management did not know at that time, what CIM could mean in terms of investment pay back and upcoming changes, but they gave a commitment to any kind of CIM proposal that would meet their expectations and that could be financed.

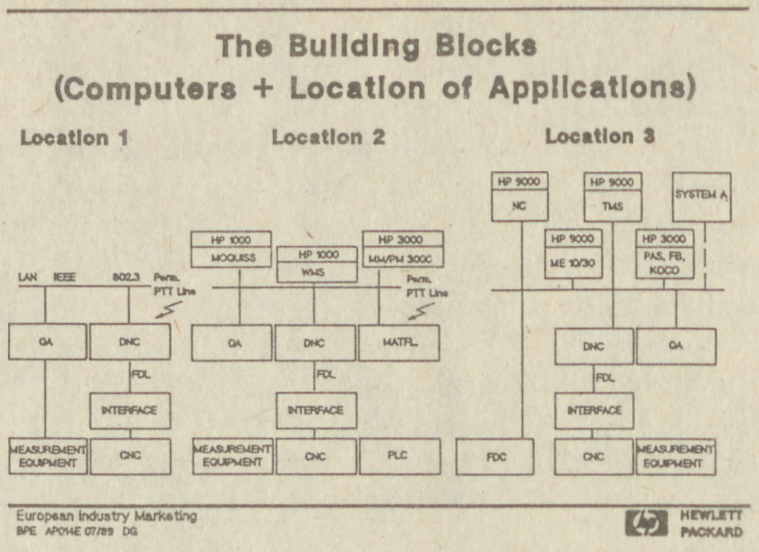
The status quo structure of the IT landscape is shown in picture 1. MRP and a pilot CAD implementation are already in place. A dedicated sales order management system to handle the required number of products coming in via EDI had to be installed for quite a long while and was successfully running on another hardware platform.



All other important departments like shopfloor, financial management, quality and warehousing were managed more or less manually. Productivity was not the main reason for approaching a new age of IT strategy, but more the wish, to use the IT advantages more effective to optimize the competetive position. This was mainly because of the lack of unique technologies in the products the company manufactures.
The picture 2 shows the proposal that was presented to the management and was agreed upon in the end. The building blocks cover all important and influencing application areas of the company. The existing application structure is embedded in the proposal and the former IT free departments have a dedicated application that is integrated in the whole picture.

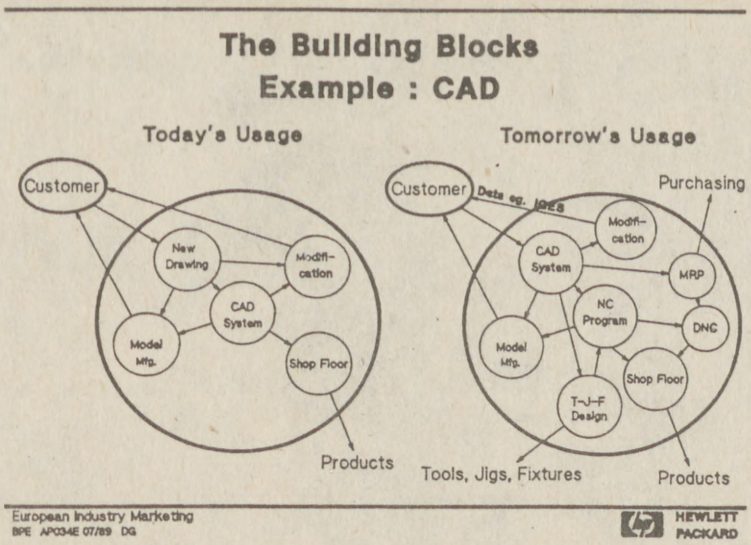


Even the fact that three different locations cause some logistic and infrastructural disadvantages is covered by the proposal. As administration design & engineering as well as materials management and quality assurance are located differently the allocation could be done quite simple by using permanent PTT lines between the different locations. Picture 3 shows the different applications, computers and locations.



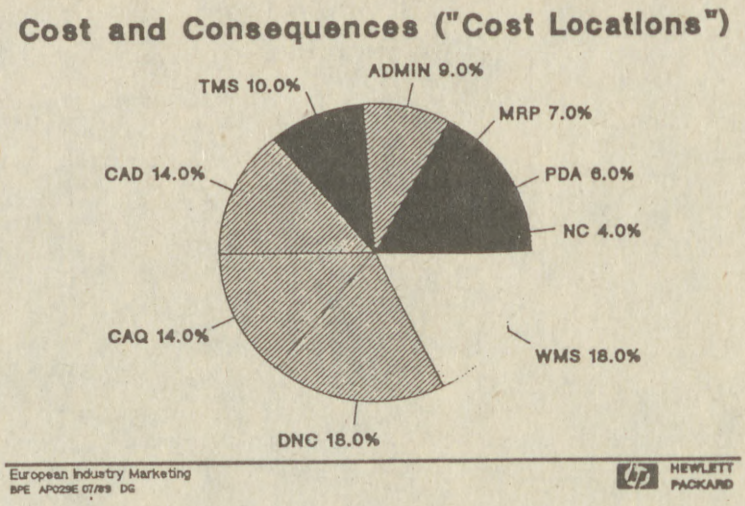
3 BUILDING BLOCK EXAMPLE

To show what tremendous impact even the functional enhancements of already used applications could have by just linking them properly into an existing environment, the building block CAD is used as anexample. The befor mentioned CAD pilot implementation was more or less used as a drafting system that was providing drawings for the shopfloor. Functional enhancements and integration change the picture completely. The link to the NC programming with a further link to the DNC library provides a straight link from design to manufacturing. Dedicated interfaces allow the exchange of technical data with the car manufacturers via EDI. A link to the MRP system gives way to the materials classification system to make use of group technology techniques in the design phase. Even the purchasing department could be adressed out of R&D directly for new parts or materials specifications. Tools jigs and fixtures could very easy be integrated in the design phase of a product, when the required product related data are made available as early as possible. By that the way to simultaneous engineering is is very short. Picture 4 shows the mentioned example.



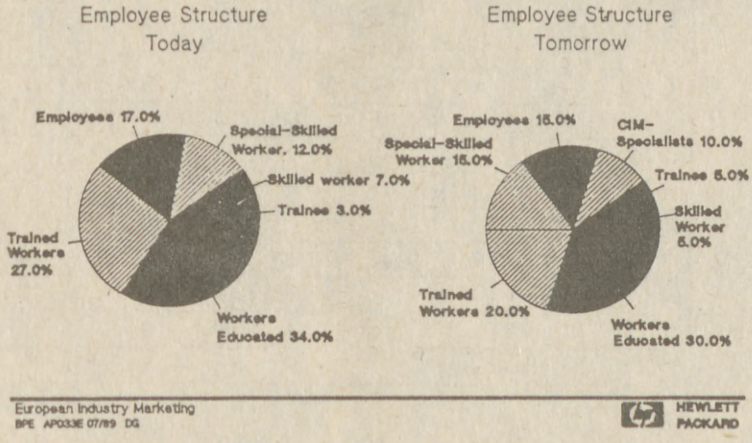
4 COST AND CONSEQUENCES

The more standardized and off the shelf a solution can be implemented, the lower the cost niveau normally is. The cost structure of the project shows that more or less the "individual" parts of the software building blocks swalloed most of the money. DNC and warehouse management system are individually tailored systems that of course demand more effort in terms of adaptation and integration. The same applies to systems, that have to be configured to the customer specific demands. From that point of view CAD and CAQ are application development environments and not just standard applications. Core applications normally demand a greater portion of integration and customization than add on application. Admin /finance and MRP therefor demanded only a small portion of the whole volume. Picture 5 shows the different "cost locations" with the different percentages. Nevertheless the figures shown in picture 5 do not represent a typical CIM project but only that specific project related cost structure. CIM specific cost structeres to calculate the investment effort are not available and would defenitely provide a wrong picture.



A look at the consequences for personell provides a clearer picture in terms of the company's future training and education strategies. The share of trained and educated workers goes significantly down, whereas CIM specialists appear on the scene for the first time. Right now none of our established university or technical highschool educations provides a specific kind of CIM qualification. The demand towards these CIM specialists will continuosly increase in the near future, but our education systems still do not have the right answer to that problem. On the other hand there have to be upqualifying programs to help the trained and educated workers along to find their new CIM related job in the future. The company in this example has set up mid term training plans to offer new opportunities in each department, to give attractive options especially to the elder employees in the company. The total number of people has grown and the average qualification level will be raised significantly by the end of last year. Picture 6 gives a brief overview, how the employee structure has changed due to the realization of the CIM project.

Cost and Consequences (Employees)



5 DETERMINED SUCCESS OF THE PROJECT

Determination of success of CIM projects is always a very dangerous attempt. Only by summarizing the critical success factors of a specific industry and company allows us to draw a clearer picture. There is a very simple interconnection between these critical success factors and the IT affected application areas. And by simply collecting the specific CSF and correlating them with all important application areas in the company shows the action priorities. By adding the importance of each critical success factor in terms of competetive influence this matrix points out, why this CIM project had to be successful: most of the critical success factors have a more or less important influence on the reorganized application areas. Picture 7 shows the mentioned matrix and answers the question. And this exercise could be done by every experienced manufacturing manager in order to be able to provide CIM investment proposals that have to be successful.

Determined Success of the Project?

OPTIMIZED APPLICATION AREAS	CRITICAL SUCCESS FACTORS: EDI	OPTION HANDLING	PROCESS PLANNING	CAPACITY PLANNING	DEADLINE ADHERENCE	QUALITY	INVENTORIES	LOGISTICS
CAD	●	●	◒		◒	◒		
MRP	●	◒	◒	◒	●		●	●
CAQ			◒		◒	●		
NC		◒	●	◒	◒	◒		
DNC		◒	●		◒	●		
TMS		◒	●	◒	◒	●		
WMS					◒		●	●
PDA			◒	◒	●	●	●	◒

● =Important ◒ = Influencing

European Industry Marketing
BPE AP035E 07/89 DG

HEWLETT PACKARD

6 CLOSING REMARK

The presented example of a successfully implemented CIM project is taken out of the day to day business of a local part of the HEWLETT PACKARD project center organization in Germany. There are numerous example in other countries and other industries.

Design in Mechanical Engineering and Process Plant Construction - a Task of Information Processing -

W. POTHS

Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA)
Federal Republic of Germany, Frankfurt (Main)

Summary

In numerous pertinent publications it is pointed out that construction is a first-rate information exchange market.
The reason is not only that innovation cycles get shorter and shorter, but especially that - owing to the fact that a very high technological level has been reached - creativity in the construction and design of increasingly complex products accounts for sometimes less than 10 per cent of the know-how content (VDI-Guidelines 2211). That means that 90 per cent of the know-how information must be stored and administered, i.e. must be retained in a storage and made accessible to the construction engineers via terminal - if necessity arises also in a manipulated form. Furthermore abundant information for further and new product developments as well as product manufacture must be opened up from internal and external sources.

1. Introduction

This paragraph will give definitions of the key terms used in this paper and will explain the problem dealt with in the following comments.

1.1 Terms

Design engineering ranges from function finding to documentation and includes the design of innovative products, adjustments/modifications, variants as well as symbols. Thus design engineering comprises all activities that are required to get from the **"concept to the graph"**, i.e. the presentation of a product in the form of a graph, no matter whether this graph shows a total machine, a sub-assembly or a component or is to be integrated into assembly, operation, maintenance and repair instructions or a spare parts catalogue. Even the preparation of a graph to be included in an offer is also considered to be a task of design.

In effecting the design tasks - strongly differing in kind and volume - the design engineers are dependent on a wealth of information, rules and regulations. On the way from the concept to the graph, the point is to optimally combine and chart the relevant information with a view to the given tasks.

The product (result) of design engineering is information (purpose-oriented knowledge) - in the form of instructions for the manufacture of machines and plants -, and the above comments show that - independently of all tools used - design can be interpreted as an information processing technique since in the course of the design process the design engineers link information in the sense of purpose-oriented knowledge (W. Wittmann) to complex information structures (informare = design, form) /1/.

	VDI-Guidelines		March 73
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Methods and Tools Calculations in Design Engineering	VDI 2211 Leaf No.2 Draft	
DK 681.3:658.512.2 (083.132)	VDI-Guidelines		November 75
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering An Analysis of the Design Process with a View to the Use of EDP	VDI 2210 Draft	
DK 681.3:62.001/.002 (083.71) 001.4.001 (083.132)	VDI-Guidelines		March 1979
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Definitions of Terms	VDI 2217 Draft	
DK 681.3:62.001/.002 (083.132)	VDI-Guidelines		April 1980
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Methods and Tools Task, Principle and Use of Information Systems	VDI 2211 Leaf No.1	
DK 681.3:62.001/.002.741.02:744.3 681.3.06:65.011.4 (083.132)	VDI-Guidelines		June 1980
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Methods and Tools The Machined Preparation of Graphs	VDI 2211 Leaf No.3	
DK 62.002.2 681.3.06:658.512.2 (083.132)	VDI-Guidelines		November 1980
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Programme Development	VDI 2214	
DK 62.002.2 658.512.2:681.3 (083.132)	VDI-Guidelines		November 1980
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Organizational Prerequisites and General Tools	VDI 2215	
DK 681:658.512.3 (083.132)	VDI-Guidelines		November 1980
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering The Systematic Search for and the Optimal Design of Constructive Solutions	VDI 2212	
DK 681.3:658.512.2 (083.132)	VDI-Guidelines		October 1981
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering Approach in the Introduction of DP in Design Engineering	VDI 2216	
DK 681.3.658.512.2.012 (083.132)	VDI-Guidelines		May 1985
VEREIN DEUTSCHER INGENIEURE	Data Processing in Design Engineering The Integrated Preparation of Design and Production Plans	VDI 2213	

Fig. 1: VDI-GUIDELINES REFERRING TO:
DATA PROCESSING IN DESIGN ENGINEERING /2/

In this papier information processing in design engineering is considered to be:

- searching and finding relevant information
- linking this information
  - ° in the form of batch processing (variant programme with determined operation structure)
  - ° in a dialogue between the engineer and the computer

  to come up with new information of more sophisticated content,
- making these work results available for further use in other departments of the company (storing, retrieving, documenting, on suitable storage media, distributing).

Computer-assisted integration, however, will expand the scope of information processing in design and engineering into new dimensions (see Fig.1).

As it is, the design engineer at a conventional workplace must laboriously gather all the necessary information from a variety of sources in order to link this information into new solutions and to make a graph of them in the course of the design process; but now data techniques enable us to satisfy the information needs of the designing engineer immediately on the spot. There is no more "running about" for information, but the information is transported via data lines from the data stores to the place of use (also see /3/).

1.2 The tasks of design engineering

Within the scopes of the above mentioned information processing process, it is the task of the design engineering department to generate product-defining data for the goods to be manufactured and to make them available for the preceding and subsequent departments in the company. Thus it acts as a supplier (Fig. 2).

Supplier of Product-Defining Data
- in the necessary quantity
- in a functional quality
- at the right time / at a fixed date
- at the right place
  - * operation planning
  - * manufacturing
  - * assembly
  - * control institutions (e.g. TUV = Technical Control Authority, customs regulations)
  - * etc.
- in a clear form
  - * graphs
  - * lists of parts
  - * calculation files
  - * operation instructions
  - * etc.
- in due consideration of all relevant
  - * standards
  - * guidelines
  - * laws
  - * etc.

for marketable products, i.e.:
- meeting the economic guidelines with the aid of
- data from the preceding departments
  - * marketing
  - * supply and store departments
- data from the subsequent departments
  - * operation planning (manufacturing schedules, lists of parts, NC-plans)
  - * manufacturing (machinery, equipment, tools ...)

Fig. 2: TASKS IN DESIGN ENGINEERING /4,5/

According to Sata "the information required for the manufacture of a product is mostly generated in the design engineering and operation planning processes"/6/. But in many other publications, too, /7,8/ it is pointed out that the design engineering department is a first-rate information exchange. This is not only owing to the fact that the innovation cycles of products get increasingly shorter, but is especially caused by the fact that the share of creativity in the increasingly complex products sometimes to less than 10 % of the know-how content due to the high technological level already reached (VDI-Guidelines 22 11/9/). As a consequence, 90 % or more of the know-how information

must be stored and managed, i.e. supplied and be made accessible to the engineers at their workplaces via terminal and - if necessity arises - also for further manipulation. In addition abundant information for further product developments and innovations as well as the manufacture of products must be opened up from internal and external sources.

2. The requirements of computer assisted design systems

The above comments show that the design engineering process is primarily an information processing process, and the point is to support the creativitity of the engineer in two ways:

- by setting him free of the routine tasks in information acquisition and the representation of results
- by offering assistance and thus adding an impetus to his associative and creative abilities.

The CAD-systems offered today meet these two requirements only to a very limited extent. "Almost always, they are oriented towards the functional criteria and requirements" /10/; but in reality the point is to effect orders starting from product design and ranging to the supply of specifications for the manufacture and assembly of goods (job engineering, see Figure 2).

2.1 The design engineering department as a data/information-"consumer" and a data-/information-"supplier"

In carrying out their tasks, the design engineers first need information and help in order to be able to link or utilize this information; but they are processing the work results "fit for the consumer".

2.1.1 The design engineer as a data/information-consumer

It is a matter of course that the design engineering department is not a consumer in the strict sense of the word, since information is the only raw material that cannot be used up, but can be used again and again. This use of information is relevant to all phases of the design engineering process ranging from function-finding to documentation of the work results and the generation of manuals for the users of the machines and plants manufactured in line with the stages designed from the "graph to the solid product". The necessary information can be classified as follows:

- in-house information (internal communication and integration)
- information to be found outside the company (external communication and integration)

- systems-immanent information.

The supply of in-house information

The wealth of in-house information is listed in Figure 3. The designers of systems must see to it that the design engineer can tap this information at his workplace without having to run about for it as was usual up to now. As it is today, nearly all in-house data are processed with computers and stored in computer systems. Why then shouldn't it be possible to tap this information via terminals or PCs at the workplaces? The direct communication between computers must render it possible to make repeated use of existing work results so that existing solutions need not be generated again and again. Let me quote an especially incriminating example: a cylinder cover with identical functions and measures was constructed more than 300 times with smallest modifications because it was easier to make a new design than to look for the old one in the design records. From the limited point of view of the design engineering department, the design engineers no doubt did the right thing. They tried to achieve an optimum for the department. But for the total company the effects were most disagreeable. No consideration was given to the consequences for the following work processes: no notice was taken of the fact that because of the changes in dimensions, e.g. fixtures had to be adapted, new work plans had to be worked out, and changes in the final cost calculations had to be made.

In carrying out his task (preparing offers and orders), the design engineer needs a broad information basis with in-house data

- existing product-defining data
  - graphs
  - lists of parts
  - if available: operation schedules/control plans
- data referring to materials budgets and supplies
- data referring to manufacturing equipment
  - machinery
  - equipment
  - tools
  - measuring tools
- data referring to offers
  - running offers
  - earlier offers not resulting in orders
- data referring to orders
  - running orders
  - accomplished orders
- data referring to projects
  - running projects
  - accomplished projects
- data referring to research and development results

Fig. 3: IN-HOUSE INFORMATION RELEVANT TO DESIGN /11,12/

As it is, the message contained in VDI-Guideline 2211, that creativity has a share of less than 10 % in the know-how content of "new" products, has neither reached the design engineers nor the systems developers.

The supply of external data

When setting out to work on a new order, the designing engineer not only needs a large number of in-house data, but also a wealth of external data. Today he will use tabulations, guidelines and standards, etc. documented on paper. The topicality of these data is not always guaranteed.

For several reasons increasing efforts are being made to get to a direct exchange of information between the customer and supplier (to speed up work, to avoid mistakes, to save cost). Figure 4 shows which communication should be aimed at.

In carrying out his tasks (preparing offers and orders), the design engineer needs a broad information basis with external data. He must have access to

- FIZ Technical rules
- FIZ Materials
- FIZ Energy
- FIZ Engineering (DOMA)
- Documentation Automotive Engineering
- Patent Data Banks
- Technology Data Banks
- Deutsches Institut für Normung (DIN) - The German Institute for Standardization
- Methodology and Software Data Banks
- Customers (VDAFS, IGES, STEP)
- Suppliers (of tools, standardized parts)
- Deutsches Forschungs-Netz (DFN) - the German Research Network

FIZ = Information Center for a special branch

Fig. 4: EXTERNAL INFORMATION RELEVANT TO DESIGN /13/

The aim of integrating external data into the information processing of design engineering can only be reached if systems are supplied that reduce the communications barriers by means of appropriate interfaces to networks and data banks.

In fact, the problem of external as well as internal integration is not only a problem of software and hardware experts, but above all a definition problem. Communication between systems is only possible if there is a general agreement on syntax and semantics; this means an agreement on standard data structures for the description of product models. The first steps in this direction have already been made with the standardization concept STEP (Standard for the Exchange of Product Model Data).

Systems-immanent information

This term refers to the capabilities of or the possible support through CAD-systems. Software packages for given branches or sub-branches or for the support of the design of specific machine categories should include **information catalogues** which the engineer can leaf through to find solutions for new orders and which will add an impetus to his creative and associative capabilities /14/. Such information catalogues are of special importance for function finding, the generation of principles, design and dimensioning (Figure 5). For example: specific functions can be realized through different physical principles (coupling: mechanical, hydraulic, magnetic ...) at different cost (relative cost catalogue) in different modes (morphologic box) and in different processing techniques (cutting, working, turning, milling, broaching, etc.).

Design Phase	Information Catalogue	Classification Principle(s)
Function Finding	functions examples	machinery/systems categories
Generation of principles	physical principles examples	functions
Design	alternative features morphologic cage examples	materials (cast iron, steel, etc.) .. framed structure, full, etc. ...
Dimensioning/ Techn. Calculation	methods/techniques examples	precision, speed, necessary tools
Optimum Design - cost	relative cost examples	functions, physical principles, performance
- weight	relative weights examples	functions, physical principles, performance, cost
- space	relative space requirement examples	functions, physical principles, performance, cost
- time * to realize a function	relative amount of time necessary examples	functions, physical principles, performance, cost
* to manufacture a function	relative amount of time necessary examples	production technique, functions, physical principles, performance, cost

Fig. 5: INFORMATION CATALOGUES IN CAD-SYSTEMS

It is expected that these systems-immanent information catalogues with trade specific information will bring about a buoyant increase in quality and innovation. These enriched possibilities of information processing in design engineering will give new impulses to the creativity of the design engineer so that the products of design engineering will reach a hitherto unequalled performance level.

The systems-immanent information also includes notes for the consideration of restrictions (Figures 6,7).

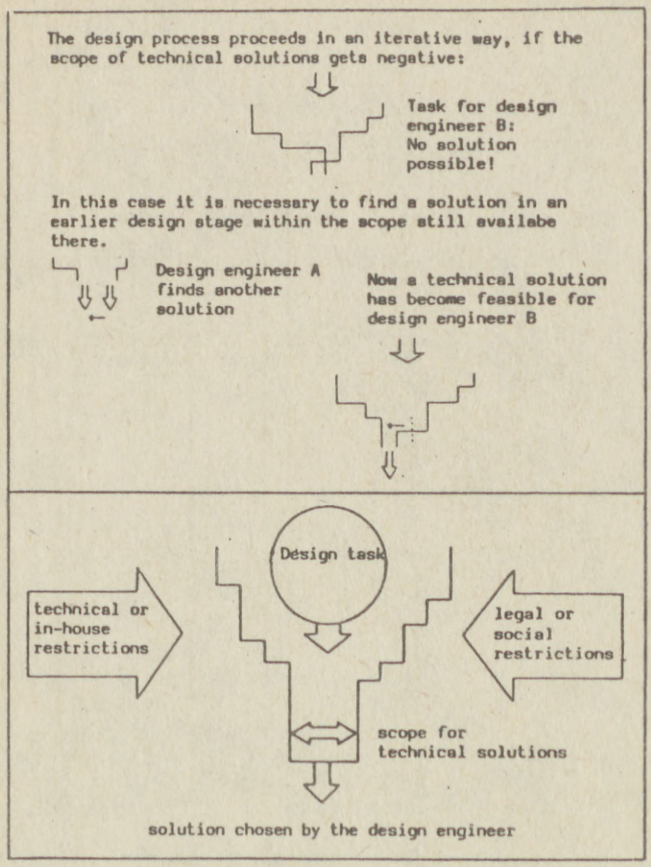


Fig. 6: RESTRICTIONS NARROW THE SCOPE FOR DESIGN SOLUTIONS /15/

Technical restrictions:
- laws of nature
- general design rules
- static or dynamic requirements

In-house restrictions:
- available production means
- use of standardized parts
- regular suppliers

Customer restrictions:
- available space
- allowed weight
- connecting measures to be considered
- compulsory external components

Supplier restrictions:
- power graduations in external aggregates
- dimensional graduations in external parts

Social restrictions:
- adaption to man
- little energy consumption
- little consumption of input material
- high rate of recycling
- high service and maintenance friendliness

Legal restrictions:
- safety regulations
- allowed noise levels
- admissible radiation exposure

Other restrictions:
- climatic conditions
- road conditions (transport)
- guidelines (VDI, AD-specifications)
- standards (DIN, ISO)

Fig. 7: EXAMPLES FOR RESTRICTIONS IN THE DESIGN PROCESS THAT MUST BE CONSIDERED /15,16/

But a very important point is that the CAD-software must also comprise **calculation programmes.** Dimensioning and thus the total execution of the order will be cut down. Furthermore, solution alternatives for products can be checked in an optimum way.

2.1.2 Design engineering as a data-/information-supplier

The design engineering department is the innovation centre of a company. Its work results are a substantial contribution to the success of a company. They are the basis for further work processes in the preceding and following departments of the company. For this reason, the processing of work results "fit for consumption" is of special importance. The systems should support the engineers in the processing of the following information (e.g. by means of the appropriate use of the layer-technique):

- information referring to lists of parts
- information relevant to NC
- information relevant to customers.

To explore all the possibilities generated in the Layer-technique, this process should be assisted by a systems-immanent Layer-user-organization.

2.2 The importance of "fragments" for design engineering

The development and further development of CAD-systems not only has to be oriented towards the partial processes of design engineering, but must also take into consideration the available solutions and solution approaches in the form of fulfilled orders, not realized offers, etc. to a much larger extent. That means that the development of systems must be influenced more strongly than before by the experts from the design engineering department; the informatics specialist must not be left alone in his endeavours to improve the design systems. The design engineers must not only bring in their experience into all phases of the design engineering process, but must also stress the crucial importance of the available know-how for new solutions and re-done solutions (also see VDI 22 11). In Figure 8 an attempt is made to match the design modes with the available support systems.

Design category	Support systems
Innovative design	development results - in-house - external/technology data banks
	Files on accomplished offers which did not result in orders.
	Library of standardized parts
	All tools in the design phases (see Fig.5)
Adjusted design	as in innovative design but in addition
	Files on accomplished orders - graphs - calculations - lists of parts - cost
	relevant tools for the design phases (see Fig.5)
Variant design	as in adjusted design but in addition
	Variant programme with the allowed parameters
	relevant tools for the design phases (see Fig.5)

Fig. 8: SUPPORT AND TOOLS FOR THE INDIVIDUAL DESIGN CATEGORIES

If engineering tasks can be represented by means of variants, it is evident that design engineering is largely an information processing procedure. This is especially true if a design problem can be described in an algorithmic form. In this case it is sufficient to describe the parameters of the design tasks so that the computer will be able to supply all necessary documents for further processing in operation planning and production by means of stack processing.

3. Know-how-based support systems for design processes

These comments have shown that the design engineers need a large quantity of information in the sense of specific knowledge in order to be able to

fulfil their design tasks. The supply of existing in-house and external know-how (including data of previous offers, accomplished orders, stopped development projects, technology data banks, etc.) will inspire the design engineer in the execution of his tasks. To date it has been the design engineer who, in every specific case, had to draw the right conclusions from this available knowledge. For the future, however, it is feasible that know-how-based systems will do a lot of preliminary jobs for the design engineer so that he will be in a position to concentrate on more sophisticated tasks requiring more of his creative and associative abilities.

Quellenangaben

/ 1/ Capurro, Rafael: Was ist Information?
In: Handbuch der modernen Datenverarbeitung (HMD) 133/1987, S. 107 ff

/ 2/ VDI-Richtlinien zum Thema "Datenverarbeitung in der Konstruktion":
- 2210: Analyse des Konstruktionsprozesses im Hinblick auf den EDV-Einsatz
- 2211 Blatt 1: Methoden und Hilfsmittel, Aufgabe, Prinzip und Einsatz von Informationssystemen
- 2211 Blatt 2: Methoden und Hilfsmittel, Berechnungen in der Konstruktion
- 2211 Blatt 3: Methoden und Hilfsmittel, Maschinelle Herstellung von Zeichnungen
- 2212: Systematisches Suchen und Optimieren konstruktiver Lösungen
- 2213: Integrierte Herstellung von Konstruktions- und Fertigungsunterlagen
- 2214: Programmentwicklung
- 2215: Organisatorische Voraussetzungen und allgemeine Hilfsmittel
- 2216: Vorgehen bei der Einführung der DV im Konstruktionsbereich
- 2217: Begriffserläuterungen

/ 3/ Forschungszentrum Informatik (FZI) an der Universität Karlsruhe (Hrsg.)
Referat Informatik für die industrielle Automation - INFINA: Arbeitsbericht 1986, S. 5 f

/ 4/ Poths, W. und R. Löw: CADCAM Entscheidungshilfen für das Management,
Frankfurt, Heidelberg 1986, S. 20

/ 5/ Poths, W.: Von CAD zu CIM - Integration - Zentralproblem der Automation.
In: Der Konstrukteur 1-2/1987, S. 12

/ 6/ Sata, T.: Die Industrie Japans auf dem Weg zu CIM. In: CIM,
die informationstechnische Herausforderung -, Vorträge zum Produktionstechnischen
Kolloquium (PIK), Berlin 1986, Nachtrag zum Vortragsband PIK 86, S. 2

/ 7/ Mewes, D.: Der Informationsbedarf im konstruktiven Maschinenbau.
VDI-Taschenbuch T 49, VDI-Verlag, Düsseldorf 1973

/ 8/ Gnatz, R. und K. Samelson (Hrsg.): Methoden der Informatik für rechnerunterstütztes
Entwerfen und Konstruieren. GI-Fachtagung, München 1977. Band II der Informatik-Fachberichte,
herausgegeben von W. Bauer im Auftrag der Gesellschaft für Informatik (GI).
Springer-Verlag, Berlin/Heidelberg/New York 1977

/ 9/ VDI-Richtlinie 2211, Blatt 1: Datenverarbeitung in der Konstruktion, Methoden und Hilfs-
mittel, Aufgabe, Prinzip und Einsatz von Informationssystemen, VDI-Verlag, Düsseldorf 1980

/10/ Tönshoff, H.K.: Forderung der Fertigung an die rechnerintegrierte Konstruktionstechnik.
In: CIM, die informationstechnische Herausforderung - Vorträge zum Produktionstechnischen
Kolloquium (PIK) Berlin 1986, S. 105 ff

/11/ Poths, W. und R. Löw: a.a.O., S. 27

/12/ Encarnacao, J. und H.-E. Hellwig, E. Helleshelmer, W.F. Klos, S. Lewandowski,
L.A. Messina, W. Poths, K. Reimer, H. Wenz: CAD-Handbuch, Auswahl und Einführung
von CAD-Systemen, Reihe Informatik-Handbücher, Hrsg. R. Gnatz im Auftrag der Gesellschaft
für Informatik e.V., Springer-Verlag, Berlin/Heidelberg/New York/Tokyo 1984, S.37 ff

/13/ Poths, W. und R. Löw: a.a.O., S. 27

/14/ Vgl. Koller, R.: Automatisierung von Konstruktions- und Darstellungsprozessen mittels CAD.
In: Proceedings zur Kongreßmesse "Computer Aided Technologies in Manufacturing (CAT 86)",
Stuttgart 13.-16.5.86

/15/ Westermann, A.: Soziale und arbeitspolitische Aspekte beim Einsatz von Graphischer
Datenverarbeitung im Konstruktionsbüro. In: IBM Deutschland GmbH (Hrsg.): Zum Thema
Graphische Datenverarbeitung: Beiträge von IBM und Kundenanwendungen, S. 177 ff.,
IBM Form W 120031, 1981

/16/ Poths, W. und R. Löw: a.a.O., S. 29

A DIGITAL-OPTICAL HYBRID TECHNIQUE ON IMAGE RESTORATIOM OF HIGH-SPEED TECHNICAL PHOTOGRAPHY

Qiong Zhang

Department of Precision Machine
University of Science and Technology of China

Shifa Wu

Southwest Institute of Fluid Physics

I. Introduction

A schematic diagram for the formation of a high-speed technical image using a scanning camera is shown on Fig. 1. The time-resolution is an important technical parameter in the high-speed scanning photography. It influence the precision of the measurement directly. Degradation of the high-speed scanning image is caused by many factors. For example, the width of the slit, focusing error, deformation of the spinning mirror when it is spinning at a high speed, all of them degrade the image. This presentation concentrates primarily on the author's attempt to restore the high-speed scanning image by means of image restoration techniques.

II. Analysis of Time-Resolution in High-Speed Scanning Photography According to the Image Degradation

When a high-speed moving object is being recorded by a scanning camera, the image of the slit is scanning on the film. At the film plane, the high-speed scanning image is described by

$$g(x)=\int_0^T f(x-V_s\cdot t)\cdot dt \qquad (1)$$

where V_s = the scanning velocity
$T = b'/V_s$
b' = the width of the image of the slit

Assuming that the film is used in the linear region of the H&D curve. g(x) presents the image of the object to be recorded.

Equation (1) indicates, g(x) has the same form as the image degraded by the relative movement between a camera and the objects. In this point of view the scanning image can be considered as the image degraded by relative movement. The impulse response of the image formation system

is described by

$$h(x) = \begin{cases} 1 & 0 \leqslant x \leqslant b' \\ 0 & \text{else} \end{cases} \qquad (2)$$

Thus the image of an ideal spot at the film plan is $\delta(x) \circledast h(x)$. Because the width of this image is b', so the minimum distance of two points in the direction of scanning which could be recognized at the film is b' and the time-resolution is b'/V_s. Using technique of image restoration, we can minimize this kind of degradation and improve the time-resolution.

III. Using Wiener Filtering to Improve the Time-Resolution of High-Speed Scanning Photographs of the Detonating Wave

By using microdensitometer to measure the photographic density of the film on which the image of the slit is recorded, we get the impulse response of the image formation system: $h(x,y)$. A Fourier transformation of $h(x,y)$ yields $H(u,v)$, the transfer function of the image formation system. If digital Wiener filtering method is employed. The transfer function of the frequency-plane filter should be

$$F(u, v) = \frac{H^{*}(u, v)}{|H(u, v)|^{2} + S_n(u, v)/S_f(u, v)} \qquad (3)$$

where $S_n(u, v)$ = power spectrum of the noises
$S_f(u, v)$ = power spectrum of the signal

Since the ideal image is unknown, we can't obtain the $S(u, v)$. In the process of the restoration experiment, we define

$$S_n(u, v)/S_f(u, v) = C \text{ (constant)}.$$

Selecting C properly, we are able to obtain obvious results of image restoration.

$$F(u, v) = \frac{H^{*}(u, v)}{|H(u, v)|^{2} + C} \qquad (4)$$

This method has been employed to improve the time-resolution of high-speed scanning photographs of detonating wave by means of computer. Results of the restoration experiment are good. (Photographs are avoided according to the guidelines for the prepration of the manuscript.)

IV. Digital-Optical Hybrid Image Restoration Method

Because the experiments mentioned above are performed with computer, so the method employed is a digital image processing technique. Although digital image processing has many advantages, its expenses are very high because of the vast amount of image data in the computer and it is not a

real-time processing. On the hand, optical image processing can do Fourier transform by means of a integrating lens, in addition it is a parallel and real-time processing.

The coherent optical system employed for image restoration (spatial filtering) is shown in Fig. 2. The photographic film placed in the object plane is a copy of the original photograph. The light-amplitude transmittance of the film transparency is proportional to the intensity distribution which exposed the original film. By virtue of the integrating lens, the Fourier transform of this intensity distribution is physically accessible in the Fourier plane as a two-dimensional spatial light-amplitude distribution. This permits optical spatial filtering whereby the image frequencies may be altered in amplitude and phase by an appropriate spatial filter. The filter is a photographic film with a pattern of densities registered on it.

The difficulty in the optical image processing is the synthesis of filter on photographic film. We has designed a digital-optical hybrid method with the help of computer and the inversion of the high-precision A/D convertor, the microdensitometer. Using this technique we can generate a lot of complicated filters conveniently.

A schematic diagram for the inversion of the microdensitometer is shown in Fig. 3. For the physical realization of complex filters on photographic film, a Vander Lugt holographic filter was generated by the microdensitometer. The transfer function of the filter is

$$Y(u, v) = F e^{i\phi} + F^{*} e^{-i\phi} + C \qquad (5)$$

where C = a positive constant
$e^{i\phi}$ = reference wave

Assuming $F(u, v) = A(u, v) + B(u, v)\, i$, the required filter on the frequency-plane which is synthesized in the computer. So Y is described by

$$Y = 2 (A\cos\phi - B\sin\phi) + C \qquad (6)$$

Selecting C properly, we can make Y positive everywhere. So Y is a real intensity distribution. By means of the inversion of the microdensitometer, Y is exposed on the film.

When such a filter is placed in the Fourier plane of the coherent optical system, the various image frequencies will be altered differently. By performing an inverse Fourier transformation, the imaging lens produces the filterd image in the image plane.

Several filters have been generated conveniently by means of this technique. The expected results are archived. (Photographs are avoided according to the guidelines.)

V. Conclusion

1. The time-resolution of high-speed scanning photography can be improved with the image restoration technique.
2. Using computer and the inversion of microdensitometer, we can synthesize proper filers to restore the degraded images in the coherent optical system.
3. Experiments show the feasibility of the methods.

VI. References

1. R. Gonzalez and P. Wintz, "Digital Image Processing", Addisonwesley, New York, 1977
2. George A. Krusos, "Restoration of Radiologic Images By Optical Spatial Filtering", Opt. Eng., No.3, 1974, 208-218

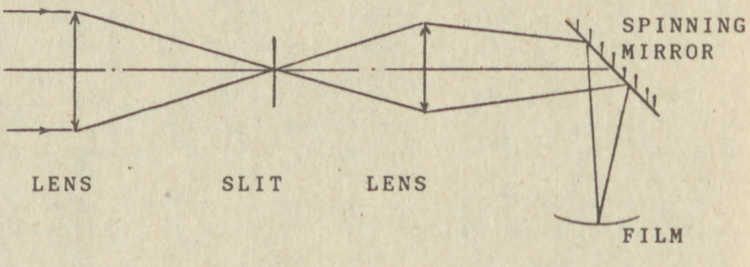


Fig. 1. Schematic diagram for the formation of a high-speed technical image using a scanning camera

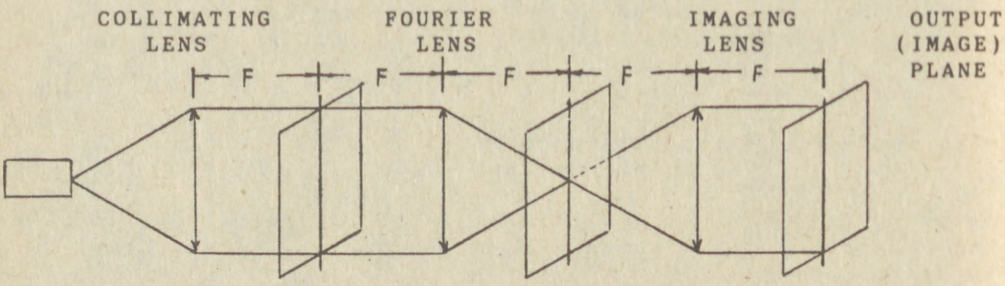


Fig. 2. Coherent optical system for image processing

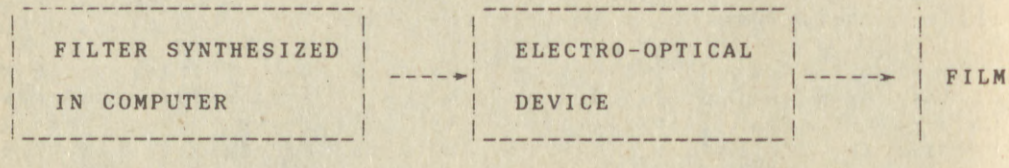


Fig. 3. Schematic diagram for the inversion of the microdensitometer

CAD / CAE / CAM
APPLICATIONS AND CONCEPTS IN ENGINE DEVELOPMENT

Dr.-Ing. Gotthard Rainer, Head of "Computer Aided Engineering",
AVL-Company for Internal Combustion Engines and Instrumentation Ltd., Graz, Austria

1. Introduction:

The development of high-tech products increasingly demands the combination of various calculational and experimental methods during the entire development phase. In order to achieve ever shorter development cycles, it is necessary to develop methods which allow optimizations as early as at the design stage so that experimental investigations and, consequently expensive and time-consuming modificiations on the prototype can be minimised.
Since in the early development stage only few models are available computer programs have been developed in the last few years to help simulate the functionality and working conditions of the product.

AVL have following product branches:

- Engine development
- Development of equipment for
  - Engine Instrumentation
  - Ballistic Instrumentation
  - Medical Instrumentation.

AVL aim to be active in a market segment only in case

- high-tech products are in demand and

  it is certain that owing to AVL-expertise

- a product of excellent quality can be offered.

To achieve this goal both highly qualified staff and sophisticated tools are necessary. These tools consist of hardware and software components, which are only partially available on the market or have to be adapted to the specific needs of AVL.
This results in the following requirements of various specialized departments:

- Search of the best tools on the "free market" and adaptation to the specific needs of AVL
- Supply tools which base on AVL expertise and cannot be bought externally
- Optimal application of the tools to the respective tasks

2. CAD / CAE / CAM

The "CA*" technologies are an important part of the new engineering techniques. The success depends to a high degree on the application of CAD. CAD as an aid for the design department is economically not viable on its own. Its actual merits are rather in the connection with calculation and manufacturing. Therefore it is necessary to evaluate a CAD-system covering the needs of integration and optimal adaptation for special applications.

2.1 Requirements of CAD

CAD-application to engine development needs extensive abilities as regards software and hardware, owing to the complex geometries of each component.

Since AVL use CAD not only as a kind of "drawing board substitution" but also for the design, it was absolutely necessary that the CAD-system to be installed not only has a 3D-wireframe model but also an efficient surface and solid model [1].
Moreover, AVL carry out engine development for a large number of customers all over the world who require CAD data to be transferred to their own CAD systems. Because these customers use different systems, standardized interfaces (IGES, VDAFS) must be available for the data transfer.
For the in-house data flow it is necessary to provide complex calculation methods and CAD-geometry data for the manufacturing.
It is also important that macro programs can be created and used.

Fig.1 shows the necessary integration of CAD into AVL-Engineering software environments for the support of the product development.

2.2 Steps to increase the efficiency of a CAD system:

The CAD systems usually available on the market are "General Purpose" systems. They may be applicable in many areas, however, in defined product environments they can only be applied optimally if specific adaptations and additional extensions are made.

According to application at AVL following steps have to be considered:

- Adaptation of CAD-system parameter:

  As an example the definition of standards is mentioned, e.g. DIN or ISO.

- Assembly of often used command sequences:

  Often used commando sequences are to be assembled to simple commands and made available to the user.

- Graphic procedures for similar geometries:

  Many CAD-systems offer a "Graphic Language", with the help of which the user can write menu-controlled programs for the creation of geometries. These languages are easy to use but very CPU-time consuming because they work interpretatively.

- Building up of geometry libraries:

  During the development of new products there are few "novel designs" but more "design modifications". The novelty most often consists of modifications of details of engine components and, therefore it is useful to store the completed projects in the form of "geometry libraries".
  The structure of geometry libraries requires a systematization of designs. For an efficient application it is necessary to have a special data base in the CAD-system (drawings' administration).

- Building up of macro programs:

  The creation of macro programs is of all other possibilities the best way to define component geometries. They are not only applicable in the design department but also for the creation of FE-structures, [2,3]. The connection between macro programs and CAD-system can either be established by subprograms, which are made available by the CAD-system for data storage and graphic representation, or by file-oriented data transfer.

2.3 Examples for integrated Development

Below two examples of engine development for the areas

- development and manufacturing and
- complex finite element calculations

show the integrated application of various development methods which consist of components partially developed at AVL and partially bought externally.

2.3.1 Example 1: Development and manufacturing of valve ports:

Compared with other engine components valve ports have special features:

While the customer usually gets calculation reports, drawings and test reports, as regards valve ports, he receives a core box and a port core in the form of "hardware".

The various steps during the development within the common procedure have been:

- Definition of the geometry according to prescribed boundary conditions and demanded specifications
- Creation of cross sectional drawings
- Manufacture of a core box
- Flow development and iterative optimization of the geometry

Fig.2 shows the whole conventional and future process of the development phases.

The above mentioned development steps often were a "bottle-neck" within the design phase.

Though the complexity of this engine component hardly allows the geometry description by means of macro programs, the integration of development and manufacture of valve ports was an important criterion during the CAD-system-evaluation-phase. It was thought to be entirely computer controlled and, thus be considerably time and money saving.

The aim of the use of CAD macro programs was to define the valve port in its geometry and to manufacture it on a milling machine.

In the first step the geometry of the valve port was calculated iteratively; here in this macro program the AVL-expertise necessary for the development of this component had been integrated as the "knowledge base". The calculated geometry is transferred to the CAD-system as a wireframe model in such a way that detail drawings can be made more easily, Fig.3. This step has already proved to be timesaving.

As a second step procedures had been created in the CAD-system which enable a timesaving structure of a surface model from the wireframe model. It proved to be more efficient to manufacture the core box instead of the core since on the one hand, the manufacture is easier and, on the other hand the model has thus been available for the flow test, Fig.4.
During the flow tests geometry modifications have to be carried out. As a third step therefore procedures have been installed so that the digitized modified geometry zones were integrated into the original CAD-surface model by means of a coordinate measuring machine. Instead of the hardware the customer can be supplied with a digital CAD-model which can be manufactured on his own facilities.

To reduce the production time for prototypes the stereolithography will be applied for a "Rapid Prototyping" [4]. First tests have already been made.

Furthermore AVL use their own fluid dynamics programs [5], for the theoretical prediction of the flow behaviour. The preprocessing for the very complex calculations will also be integrated into the macro program.

2.3.2 Example 2: Dynamic - acoustic FE-Calculation:

At AVL FE-calculations have already been in use for many years [6,7] and are State of the Art in engine development. The development in the areas of hardware and software allow the calculation of both ever more complex geometries and static and dynamic load cases. These increasing demands were one of the reasons why AVL integrated a vector computer into the computer network as a "number cruncher" for technical calculations.

A characteristic application for complex FE-calculations is the dynamic-acoustic simulation of engines [8,9].
The noise emission reduction has gained more and more importance in the last few years. AVL has developed a method which bases on the combination of FE-calculation, engine tests, acoustic measurements and result analysis, Fig.5.

Here each section of this procedure is described in brief:

- Definition of the FE-model:

  The FE-model contains two kinds of structural parts:

  - Structural parts which are directly taken from the design (e.g. cylinder block and cylinder head)

    By means of the CAD geometry provided by the design department the mesh which is necessary for the FE-calculation will be created. The FE-preprocessor has direct access to the geometry data so that there is no need for an additional interface.

  - Structural parts for which mechanical models are made (e.g. pistons, con-rods, crankshafts)

To reduce the number of degrees of freedom it is necessary to describe the parts of the crank train by means of beams and bars. For this abstraction masses and moments of inertia as geometry data are needed. These values may also be obtained from the CAD system if a solid model is taken for the geometry.

- Building up of the dynamic loads:

  Owing to engine tests the pressure distribution in the combustion chamber have been made available. These values are taken over into the calculation either by a prototype of the engine to be optimized or -in the design stage- from test results of engines with similar specifications.

- Carrying out the FE-calculation:

  The FE-calculation of both the natural and forced vibrations are partially carried out by standard programs and partially by programs developed at AVL.

Calculations are still done linearly, however, in the future also the nonlinear behaviour of the bearings (oil film) will be considered.
The result verification of these calculations is carried out on the prototype with experimental results (modal analysis, acceleration measurements)

- Acoustic analysis:

  The programs for the acoustic analysis of the FE-results have been developed in-house and supply

  - speed and acceleration levels and
  - transfer mobilities

  The result verification also takes place with the help of experimental results.

- Result presentation:

  Until recently the presentation of dynamic processes had been carried out by means of static plots. To make available visual aids for the quick and reliable result assessment the dynamic result presentation is used more and more.

  For the result presentation both in-house programs and external programs are available.

  The most important ways of presentation are:

- Diagram description for a direct comparison of results on individual points of various geometry variants, Fig.6
- Coloured presentation to visualize the total result of a geometry variant, Fig.7 and
- Video recordings (animation) for the dynamic result presentation

Summary:

The integrated methods for development and manufacturing of engine components show that the combination of experimental and calculational systems are absolutely necessary for high quality products. However, for this purpose it can be seen that no efforts have to be spared for the "development of development tools".

References:

[1] Rainer, G.: "CAD-Introduction and Application for the Development of Engine Components", Congress Proceedings "CAD/CAM as a Part of CIM-Component", 1989, Vienna, ADV-Meeting

[2] Rainer, G.: "Structure of a Program System for the CAD-System independent Macro Development" Konstruktion 38 (1986), Volume 7 to 10

[3] Rainer, G.: "Calculation of Stresses in Welded Joints by means of the Finite Element Method", Forschungsheft FKM, Volume 74, Frankfurt/Main, Maschinenbauverlag, 1979

[4] N.N "Stereolithography: Limits and Possibilities of a new Technology", Technologiebericht, SPECTRA-PHYSICS GmBH, Darmstadt, 1989

[5] Bachler, G., Brandstätter, W., Steffan, H., Wieser, K. "3D-Simulation of Fluid Mechanics-, Fuel Injection-, and Internal Combustion Processes", Meeting " The Working Process of an Internal Combustion Engine", Oct. 1989, Institute of Internal Combustion Engines and Thermodynamics, Tech. University, Graz

[6] Affenzeller, J., Gschweitl, E.: "Contribution to the Design Optimization of Water Cooled Cylinder Heads", ASME, 1986, Energy-Sources and Technology Conference, New Orleans

[7] Affenzeller, J.: "Deformation Investigations on Reciprocating Engines with Dry Liners by means of the Finite Element Method" ,MTZ 39 (1978), Volume 3

[8] Rainer, G.: "The Integration of the FEM into the Product Development by means of a Calculation Method for the Prediction of the Dynamic-Acoustic Behaviour of Engines", Congress Proceedings "8th Meeting in Reutlingen - FE in Practice", 1985, T-Programm Reutlingen

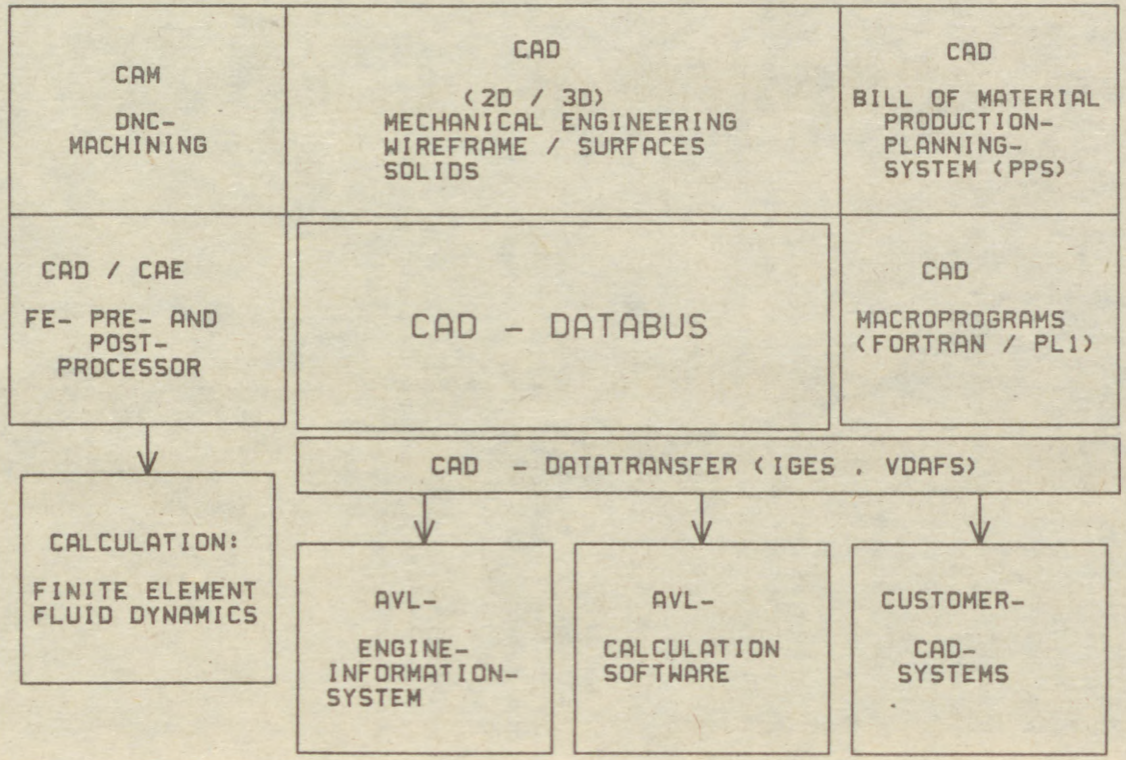
[9] Affenzeller, J., Priebsch, H.H., Rainer, G.: "Influence of Attached Parts on the Dynamic Characteristics on Cylinder Blocks", MTZ-Magazine 45 (1984)

AVL GRAZ-AUSTRIA

CAD / CAE / CAM APPLICATIONS AND CONCEPTS

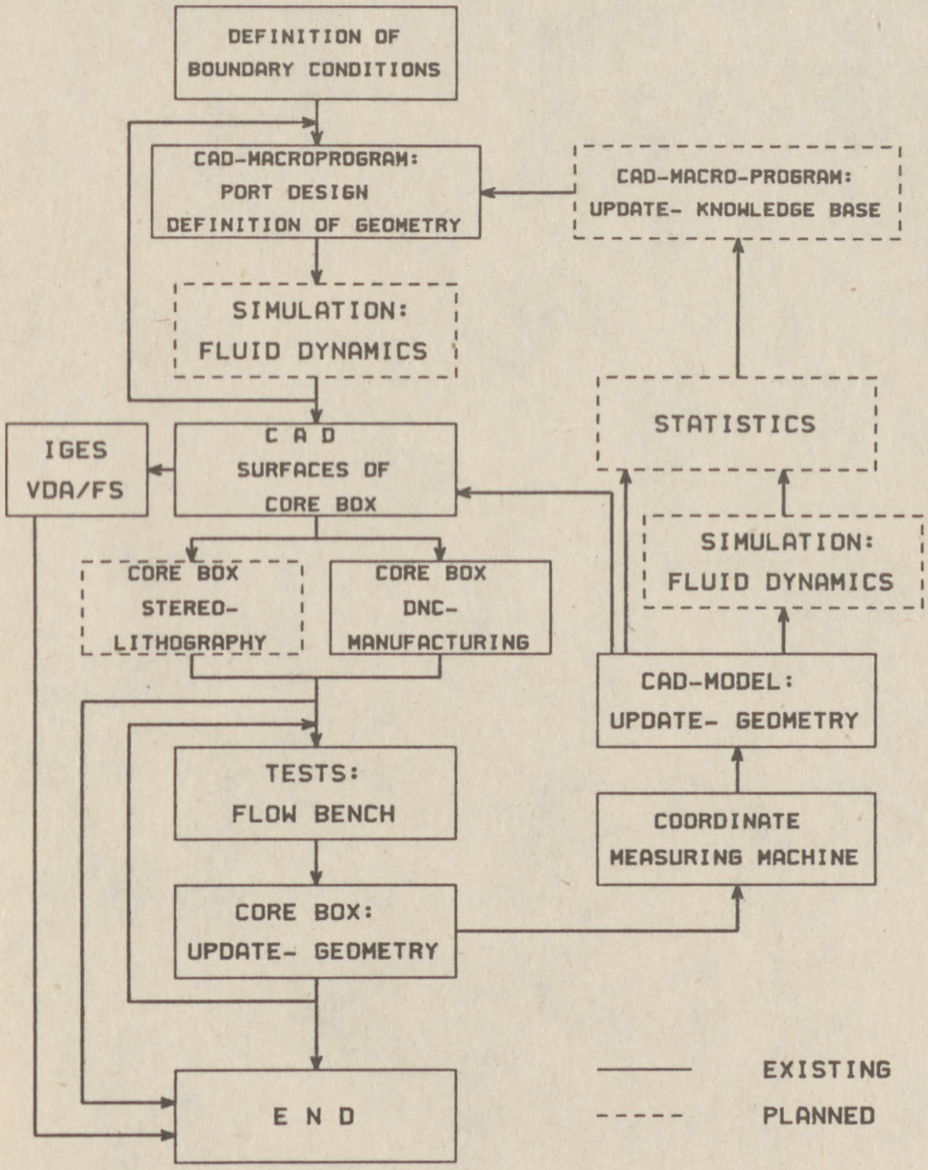
FIG. 1

INTEGRATION OF CAD INTO AVL- ENGINEERING- SOFTWARE- ENVIRONMENT



AVL GRAZ-AUSTRIA | C A D / C A E / C A M APPLICATIONS AND CONCEPTS | FIG. 2

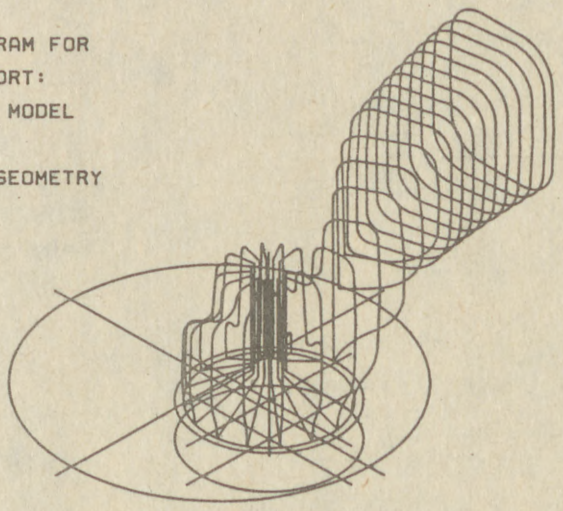
VALVE - PORT - DEVELOPMENT



AVL GRAZ-AUSTRIA | C A D / C A E / C A M APPLICATIONS AND CONCEPTS | FIG 3

MACROPROGRAM / VALVE - PORT

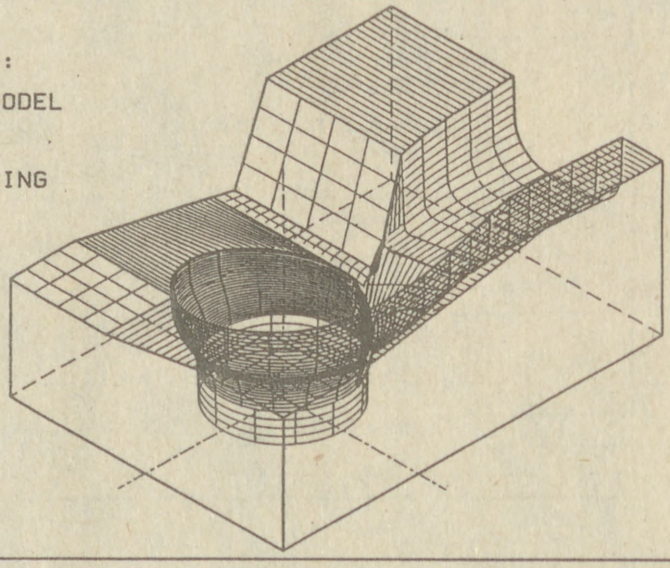
MACROPROGRAM FOR INTAKE PORT: WIREFRAME MODEL OF CALCULATED GEOMETRY



AVL GRAZ-AUSTRIA | C A D / C A E / C A M APPLICATIONS AND CONCEPTS | FIG 4

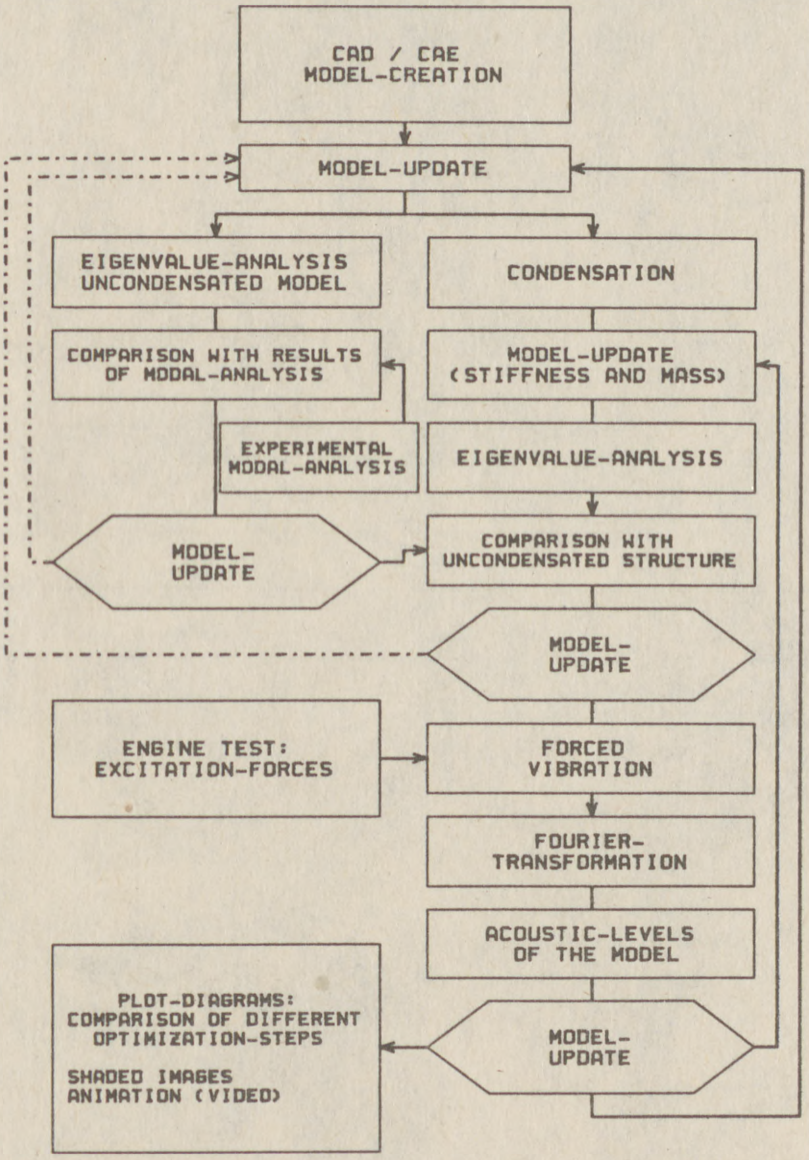
CAM- MODEL / VALVE - PORT

CORE BOX: SURFACE - MODEL FOR MANUFACTURING



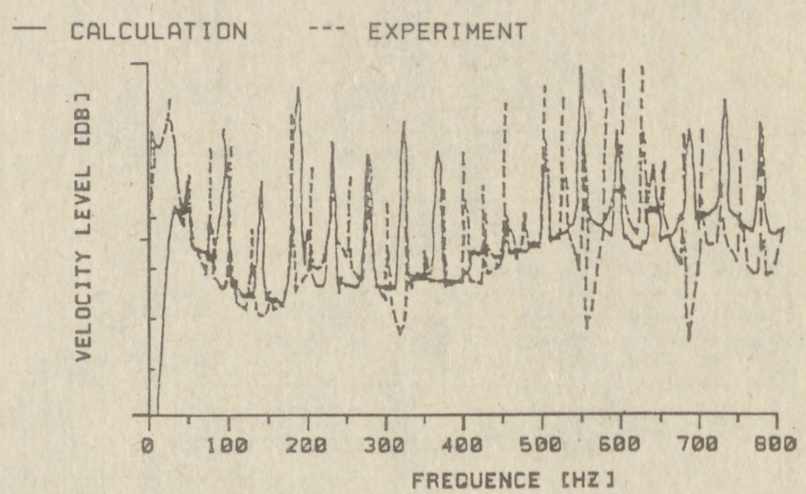
AVL GRAZ-AUSTRIA | CAD / CAE / CAM APPLICATIONS AND CONCEPTS | FIG. 5

DYNAMIC - ACOUSTIC - FE - CALCULATION



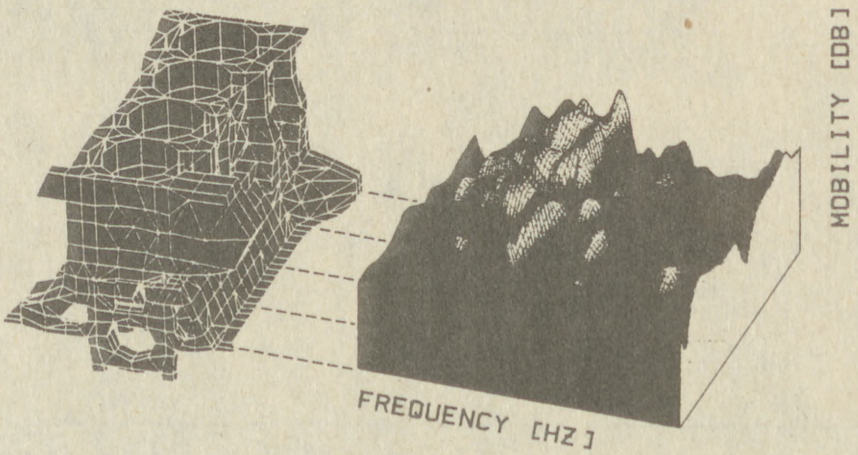
AVL GRAZ-AUSTRIA | CAD / CAE / CAM APPLICATIONS AND CONCEPTS | FIG. 6

DYNAMIC-ACOUSTIC - FE-CALCULATION: COMPARISON ANALYTICAL / EXPERIMENTAL MODEL



AVL GRAZ-AUSTRIA | CAD / CAE / CAM APPLICATIONS AND CONCEPTS | FIG. 7

DYNAMIC-ACOUSTIC - FE-CALCULATION: VIBRATION AND NOISE ANALYSIS OF A CRANKCASE TRANSFER MOBILITY TO THE RIGHT SKIRT



PRODUCTION OF DIAMOND CLUSTERS BY EXPLOSION AND THEIR PRACTICAL APPLICATION

G.V.Sakovitch, P.M.Brylyakov,
V.D.Gubarevitch, A.L.Verestchagin,
V.F.Komarov
(SPA "ALTAI" USSR)

Wide application of synthetic diamonds in technique has stimulated continuous search for more and more rational ways of their synthesis. Recently the USSR and USA have reported /1-2/ about diamond synthesis from carbon of the explosive when it was exploded under the inert atmosphere. In the USSR this process was accomplished in 1982 and at present it has been brought up to the level of pilot-scale production with wide application of produced diamonds for industrial purposes. The diamonds obtained in such a way have a series of specific properties which make possible their non-traditional usage extending the field of application of the valuable material.

Detonationally produced diamonds are characterized by exclusively cubic structure, high level of defects and supersmall particle sizes.

Having based upon X-ray diffraction analysis of the diamond ($Co_{K\alpha 1}$ radiation from plane of 220), the lattice parameter is 0,3562 + 0,0003nm (for natural diamond - 0,3567nm). C^{13}NMR-spectroscopy shows chemical shear of 34ppm, which corresponds to diamond phase of carbon. With the help of the fourth moment method the dimensions of coherent X-ray

dissipation and the parameters of lattice microstresses have been determined. They turned out to be 4-6 nm and 1.0 GPa respectively.

The crystal density in accordance with picknometry under helium is 3,1 g/cm^3. Specific surface evaluated with BET method, makes up 300-390 m^2/g.

Thus, there produced the cubic diamond carbon with highly distorted lattice, having small particle sizes. While trapping and clearing the agglomeration of primary particles into agglomerates having size of several microns (Fig. 1,2,3) have been seen.

The element composition of ultrafine diamond (UFD) consists of : C - 86+88%, H - 0,1-0,4%, N - 2,5-3,7%, O - 8,9-11,4%. The groups consisting of $-C^{-O}-R$, where R is H, OH, CH_3, NH_2, O= ⬡ =O have been detected on the surface with the help of polarography and IR-spectroscopy. Vacuum desorption at the temperature of 673K allows detecting CO, CO_2, CH_4, H_2, and NH_3 in gas phase, with predominant contents of CO_2 and CH_4. When heated above 1373K the diamond graphitization has occurred.

UFD crystals have high sorption capacity and chemical activity. At room temperature they are capable of decomposing aqueous solutions of K_2PdCl_4, $Fe(C_2H_3O_2)_2$ evolving a free metal on their surface.

Because of their small sizes UFD crystals have high sedimentation stability in liquids and selective adsorption capacity.

Such collection of physico-chemical properties reveals a series of non-traditional fields of UFD application.

Wear-resistance increase of metal coatings

Electrochemical and chemical precipitation of metals on the surface of metal matrix from UFD-doped electrolytes, changes the crystal size of precipitating metal and its surface texture (Table 1).

Table 1

UFD influence on the metal crystallite size and its microhardness

Type of coating	Grain size, μm		Microhardness, GPa	
	Starting material	UFD-doped material	Starting material	UFD-doped material
Nickel, electrochemical	3,0-5,0	0,1-0,5	2,8-3,0	4,0-5,8
Copper, electrochemical	2,0-3,0	0,2-0,5	2,0-2,1	3,2
Chromium, electrochemical	0,013	0,009	9,0-11,0	11,0-14,0
Copper, chemical	1,0-0,5	0,1-0,5	2,0	6,5-7,8

In Table 2 there presented the relative reflection intensities of various crystallographic planes (nkl) of precipitated electrochemical chromium-coating, having different

UFD contents in electrolyte, from which it may be found that the maximum disordering of crystallites in the plane of precipitation is observed with UFD concentrations in electrolyte of 8-15g/l. The maximum distortion of chromium lattice parameter is observed over this range of concentration.

Table 2

The influence of UFD concentration in electrolyte on the surface texture and crystal lattice parameter of electrochemically precipitated chromium

UFD concentration in electrolyte g/l	Relative reflection intensities from plane 110	200	211	220	222	310	Spacing, nm+0,0001
0,0	1	22	9	12	100	5	0,2891
3,0	1	22	5	4	100	1	0,2891
8,0	28	82	39	25	100	6	0,2901
15,0	66	100	46	28	45	10	0,2897
25,0	1	23	10	1	100	0	0,2893
40,0	1	0	0	1	100	0	0,2892

The obtained data give evidence of improving depreciation of metal coating structure, which results in increasing wear-resistance of such coating. This is illustrated in Tables 3-7.

Table 3

Test results of chromium-diamond coated drills

Diameter of drill, mm	Material to be machine worked	Efficiency of wear-resistance increase, times
0,8...1,2	glass-reinforced laminate	2,7...3,3
1,0...2,0	glass-reinforced laminate	10...20
1,5...2,5	steel	1,5...1,7
3,5...10,0	steel	2,0
6,1...10,0	stainless steel	1,8...3,0
7,2...8,5	steel	1,5...1,8
10,0	stainless steel	1,9
20,0	iron	6,0...8,0

Table 4

Test results of chromium-diamond coated drills

Diameter of milling cutter mm	Material to be machine worked	Efficiency of wear-resistance increase, times
8...10	brass	2,3
10	steel	2,0...4,0
11	steel	2,0
12	stainless steel	1,4

Table 5

Test results of chromium-diamond coated threading tool.

Type of tool	Material to be machine worked	Efficiency of wear-resistance increase, times
Taps		
M3-M4	steel	2.0...3,0
M6	steel	1,8
M8	steel	3,5
M10	steel	1,8...5,6
M10	Iron	2,0
M12	stainless steel	1,9...5,0
M16	steel	2,0...12,0
M20	steel	3,2

Table 6

Test results of pressing tools with chromium-diamond coating (relative wear-resistance in comparison with tools strengthened by azotization, carbonization, chrome-plating and application of special steels).

Material to be pressed	Efficiency of wear-resistance increase, times
Iron and stainless steel, powder	9...15
Radiotechnical ceramics, powder	4...5
Plastics, powder	2...3

Table 7

Test results of chromium-diamond coated stamping tool (dies, female dies) with sheet stamping

Operation	Material to be machine worked	Efficiency of wear-resistance increase, times
Cold extruding	steel	1,6...1,8
	copper, aluminium	2,0...3,0
Stamping	fibreglass-reinforced plastic	1,6...2,4
	brass	2,0...4,0
Drawing	brassed steel	2,8...3,0
Forming	steel	1,4...1,8

We associate the nature of increased wear-resistance confirmed by numerous types of different tool testing with various modes and materials, as it has already been mentioned, with higher amorphous state of the precipitating metal structure. Its ductility and adhesion to matrix are increased also. SEM photographs of chromium and chromium-diamond coating conditions with bending substrate are shown in figures 4-5. If the usual coating cracked, showing crystallite plates, then chromium-diamond coating has shown tiny cracks, characteristic of ductile metal.

Wear-resistance material

Last decade is rich in reports on application of ultrafine solids as lubricant dopings, improving tribotechnical properties of the latter. For these purposes various materials have been used: molibdenum disulfide, graphite, copper, polytetrafluoroethylene etc. There are attempts of using diamond for these purposes.

We have produced crude UFD, consisting of approximately equal fractions of diamond phase of carbon (UFD) and ultrafine carbon in graphite phase. Because of small particle sizes, specific crystal forms (Fig.3) and high adsorption capacity, its addition in motor and machine oils essentially increases their tribotechnical features. See fig.6.

In the result of crude UFD addition into the oil the friction coefficient and volume temperature in attrition zone have been decreased. In terms of selective adsorption there observed the lowered oil viscosity and at the same time the discontinuity, the distortion of oil film ("dry friction") begins at more high speeds of relative sliding. The best anti-scuff properties of doped oils are ensured.

Doped oils turned out to be suitable for precision machine tools and at present we have tried out them at machine tools of various firms (Table 8). At this event the oil consumption is decreased by 2.

Table 8

The application results of I-50A oil at machine tools of various firms

Manufacturer	Country	Machine Tool type
MATRIX	GB	milling (NO -66)
CAMPUTEN SJLJ	Italy	grinder (SU-RBS/14)
MANO	FRG	Jig milling (MH 800 P)
BOKO	FRG	Universal vertical-drillmilling (WF3-TNC L35)
NAGEL	FRG	Superfinish (KS/RS 1203, 2003)
KAPPXCO	FRG	grinder (KS/RS 1203/2003)
Magerle AG	Switzerland	surface grinding (FPA-12-52)
STUDER	Switzerland	grinder (30)
Mitsui Seiki	Japan	Jig-grinding (CG BN)
TOYDA-Koky	Japan	circular grinding (G OMG 006-32 63)
MAKINO	Japan	profile grinding (G C2)

Oil, doped with crude UFD, showed good performances when breaking-in car motors both carburettor and diesel. Breaking-in time when obtained expected parameters on different motors, is minimized by 2...10, the quality of running in is improved. The similar results are observed, when service breaking-in car motors. Service run-in over 10-15 thousand km has minimized oil consumption. After such service there appears the effect of increased wear-resistance of attriting couples. The above-mentioned statements allow us to contend about perspective application of produced UFD.

Summary

Recently the cubic ultra-fine diamond has been obtained from the explosive carbon by charge blasting in the pressurized chamber under the inert atmosphere. The present work reports on the wide range of the effective UFD-application to increase tools' and machine-parts' wear-resistance, to improve the oils anti-friction properties. The obtained results allow us to save high-speed steel, to substitute hard alloys by steel, to produce more cheap strengthened coatings, to substitute the oils to be imported for the precision machine tools by the domestic ones.

The List

to the report "Production of Diamond Clusters by Explosion and their Practical Application"

by G.V. Sakovitch et al.

Fig.1 SEM-micrograph of UFD

Fig.2 SEM-micrograph of UFD

Fig.3 SEM-micrograph of UFD

Fig.4 Chromium-diamond coated plate under angle bending (45°)

Fig.5 Chromium-coated plate under angle bending (45°)

Fig.6 Tribologic wear features of the Steel 60xB2C roller under friction with bronze BrOF-0615 pawl-roller being oil lubricated

(a) with the crude UFD-addition

(b) without addition

REFERENCES

1. A.I. Lyamkin, E.A. Petrov, A.P. Ershov, G.V. Sakovitch, A.M. Staver, V.M. Titov, DAN USSR, 1988, 302, n3, pp.611-613.

2. N. Roy Greiner, D.S. Phillips, J.D. Johnson, Fred Volk, Nature, 1988, n333, pp.440-442.



Fig. 1.

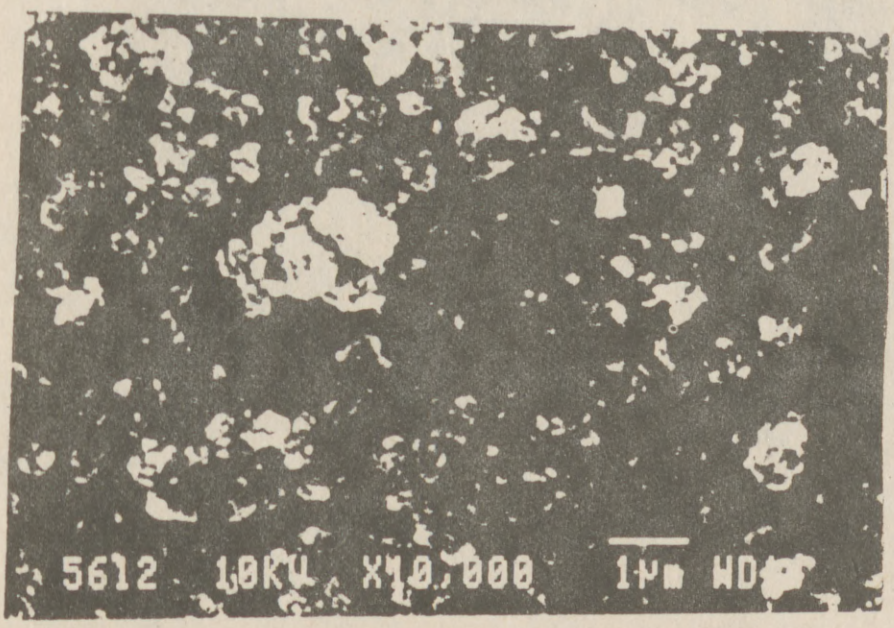


Fig. 2.

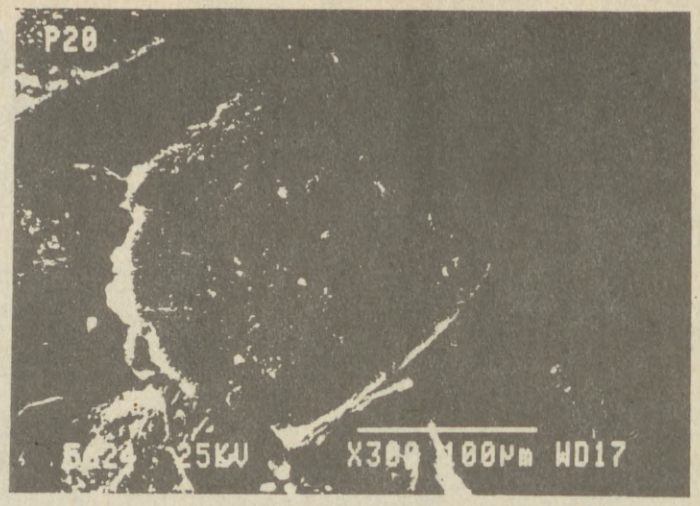


Fig. 3.

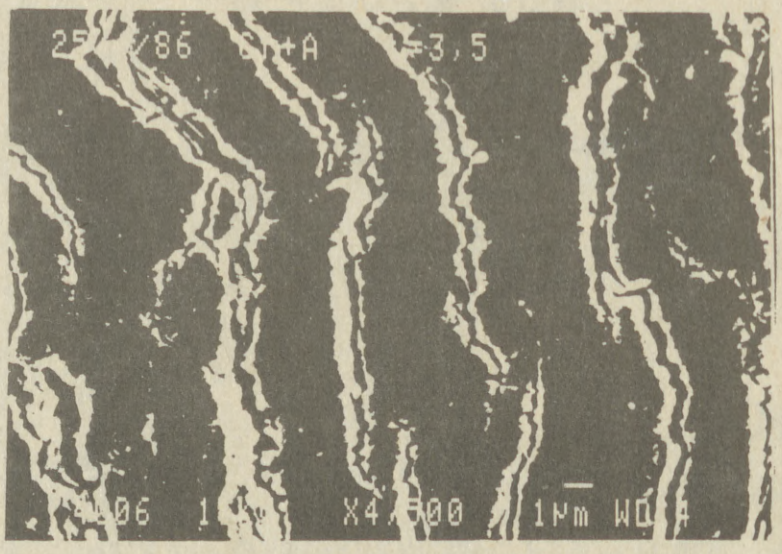


Fig 4.

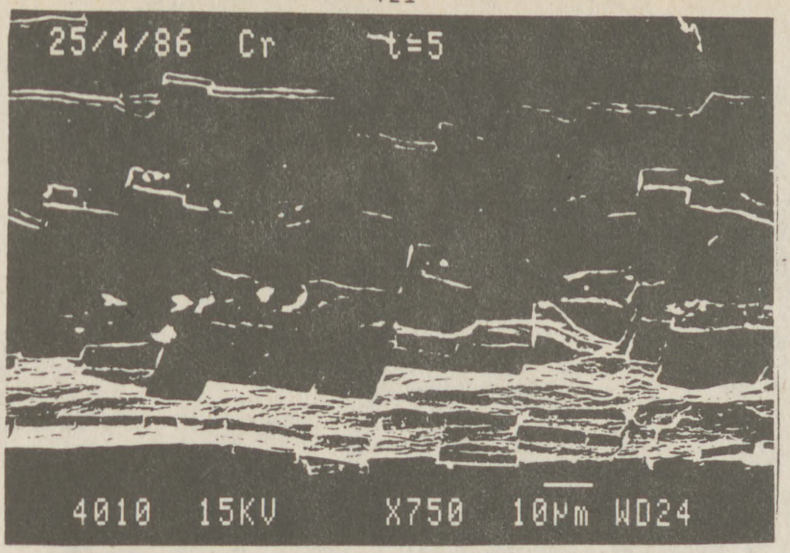

25/4/86 Cr t=5
4010 15KV X750 10μm WD24

Fig. 5.

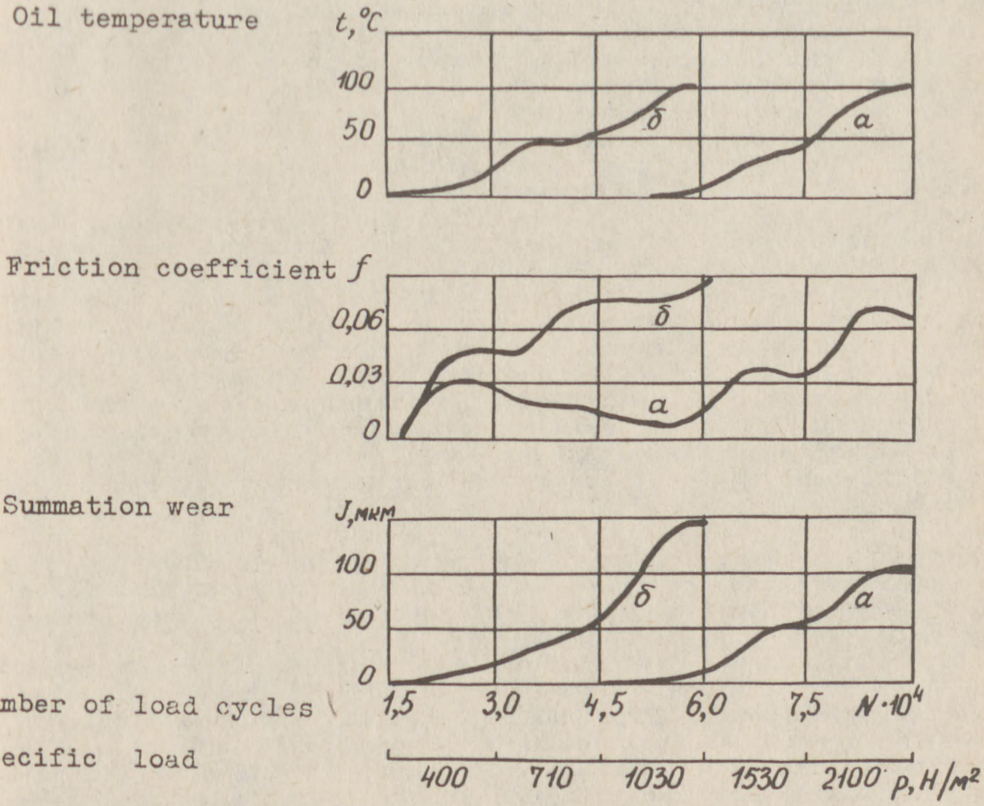

Oil temperature
t,°C
100
50
0
δ
a
Friction coefficient f
0,06
0,03
0
δ
a
Summation wear
J,мкм
100
50
0
δ
a
Number of load cycles
1,5
3,0
4,5
6,0
7,5
N·10⁴
Specific load
400
710
1030
1530
2100
p,H/м²

Fig.6

GENERAL REQUIREMENTS FOR INSTALLING CIM

Schlattmann, J.; Jorden, W.: Universität-GH-Paderborn, Laboratorium für Konstruktionslehre (LKL), Pohlweg 47-49, 4790 Paderborn, West Germany

1. Introduction

Obviously the invention of CIM opens up new dimensions regarding the flexibility of production and therefore the possible diversification of products to be manufactured. This will become even more important as the customer gets more and more interested in individual products. This demand can be kept up with by means of computer integrated manufacturing.

This paper will show some basical perceptions regarding the installation of CIM under close consideration of strategical and systematical points of view. Much attention has to be paid toward the connexion of subsystems and the expansion of basic systems, respectively. A well organized approach will consist of considering organisatorical demands and technical demands as well. This type of logistical system development of CIM will be shown by means of guidelines. These guidelines are to be verified by examples. The guidelines have been set up in order to support the process of solution finding and to avoid unsuitable solutions. Furthermore they represent a first strategical approach which will lead to overall more suitable solutions. In connection with suitable methodologies they become quiet important in the process of solution finding. Also the process of solution finding regarding the installation of CIM systems will become more clearly defined if such strategical methods are being employed. Regarding the usage of AI (artificial intelligence) systems as a supporting tool it becomes very important to provide the data flow, experience, etc. in a systematical type of way. The development of guidelines as well as the determination of important strategical points of view regarding the installation of CIM have been developed during our research work at the Laboratory of Design of the University of Paderborn and within the assistance of industrial projects.

2. Modelized considerations of CIM-realisation

For a goal oriented consideration of the processes taking place within a CIM-system a modelized representation of the system is important.
Any CIM-system can be visualized as an funnel turned upside down. This picture can be more or less detailed depending on its penetrating depth. This implies that all inputs and outputs can be registered, as it is done for black-box illustrations.
Incomming informations, orders, tasks etc. are fueling as inputs the funnel. Then, within the funnel operations take place according to well defined laws and regularities so the output will consist of the desired results. The laws and rules to be obeyed can be physical constraints, technical necessities or

even business and management oriented points of view. There are also, besides the setup and configuration rules of such a system priority rules. These priority rules are very common within the area of production planning and control (PPS) which is a subsystem of CIM systems.
There, the PPS-system allows an easy implementation of priority-rules. The system itself, however, does not support the evaluation of the effects regarding the usage of rules.
Meanwhile, a lot of research work has been done, partly by using simulation models, to evaluate priority rules. Here, mostly simple basical rules have been evaluated so far, as it has been shown to be rather difficult to judge the value of combined, highly complex rules (see also /1/). The rules can help to achive an optimized manufacturing process. So the SOT (shortest operating time) rule seeks for minimizing the repuired operating time.
The FIFO (first in - first out) rule seeks to consider the temporal sequence of the tasks to be carried out. Combining these two rules is impossible, even though this may be desired within an flexible and individual customers service.
This shows how essential it becomes to develop a systematical approach strategie for designing an CIM-system.
Basically, the structure of a plant can be divided into different levels, compare fig. 1.

Any of these levels are connected hierarchially and demand a suitable supporting planning and controlling structure.
In order to set up a CIM strategie, a precise analysis of the structures of the manufacturing plant is essential. Provocative, one may ask: "Why talking CIM, where in many firms the automation in distincive areas as CAD/CAM etc. has not even taken place, yet". But the answer is as simple as that:
"Who nowadays starts thinking of a CIM-realisation, can think, plan and design an overall concept. He can consider the integration of stand alone solutions (CAD/CAM etc.) and protect himself against setting up incompatibility barriers, later on", rule # 1.
In general one can state about CIM: CIM is a philosophy, generally individual for any firm. It is an interdisciplinary task.

In the first place CIM is, besides the technical necessities, a strategie and therefore a management task, where the overall planning has to take place goal oriented (strategical) rather than as a Top-Down-type of approach, rule # 2.
Meanwhile the concept has to be supported by the lower levels, fully.
What's about the technical aspects of CIM: Within a producing plant there are enormous needs for integrating steps, compare fig. 2.

Fig. 1: Hierachy of communication within manufacturing with a schematical sketch of planning and controlling structures.

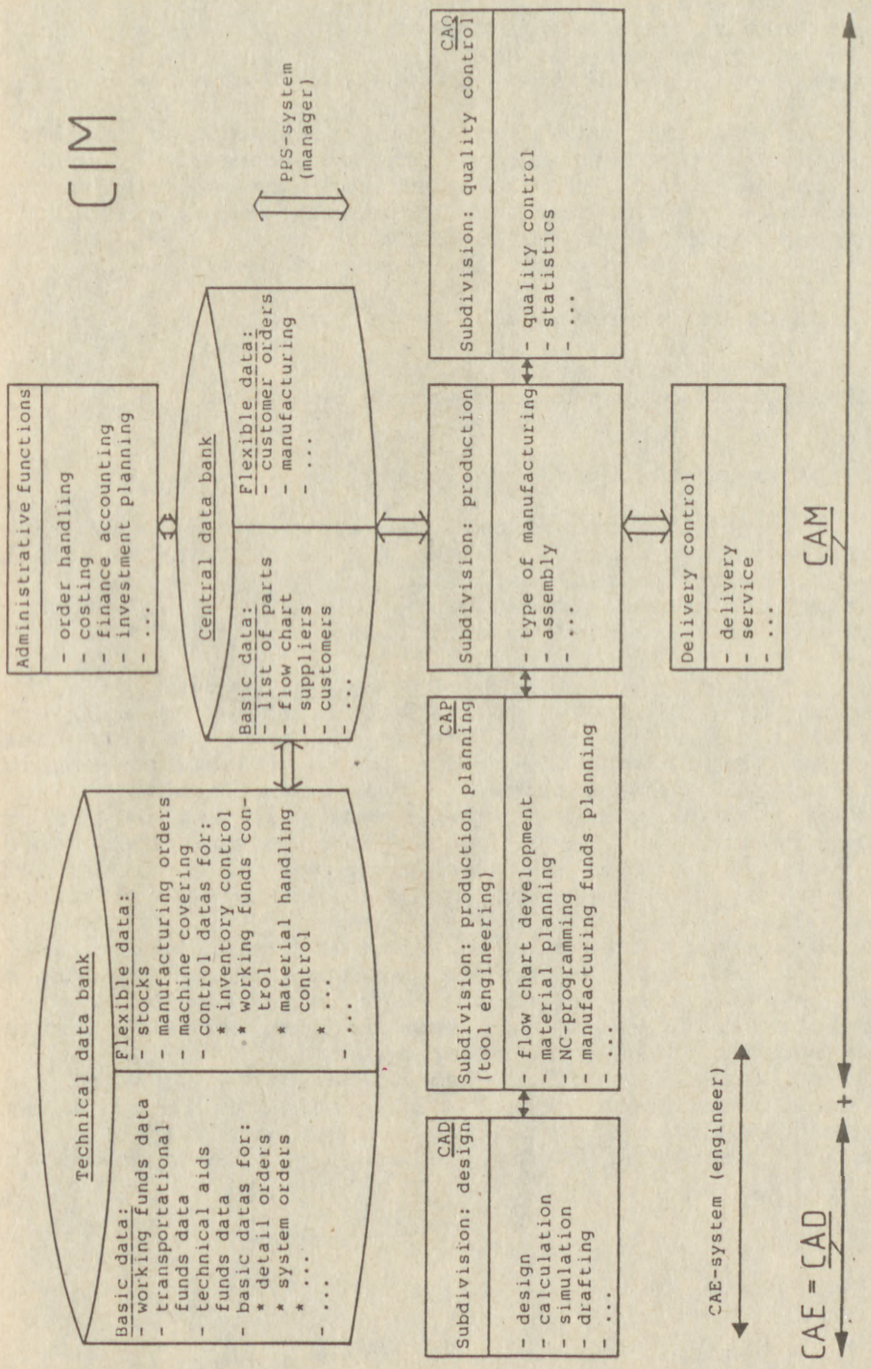


Fig. 2: Cim-Modula and their network within the manufacturing process, example.

The different areas, before referred to as "stand alone solutions" have to be connected together.
This includes supply and delivery as well as design and quality control.
Setting up the computer network gets difficult due to the earlier mentioned highly specialized systems, computer controllers, etc. which results in different computer configurations and architectures and therefore to incompatibilities within the different stand alone units. (CIM-Modula)
The following steps are to overcome these problems.

In the area of technical problems:

- Standardization of interfacing, rule # 3.
- Standardization of computer programmes, rule # 4.
- etc.

In the area of organisatorical problems:

- The goal oriented methodological approach (principle of Taylor including separating the overall tasks into subtasks (structuring of the task)), rule # 5.
- Implementing artificial intelligence including the structuring of knowledge, experience, data flows, etc, rule # 6.

3. Rules as a tool within the problem solution process

Rarely, in the area of system technique, a discussion will occur regarding the application of design rules or general rules of proceeding, respectively. Normally, more attention is paid to a analysis or goal oriented system consideration. Frequently, more emphasis is put on the analysis and design of stand alone systems within CIM, rather than on applying design rules or, generally spoken, methodological priority rules which include a step by step type of approach within the solution finding procedure.
By neglecting these systematical aids one may overlook possible probleme solutions. So, the search for the optimal solutions ist already at the very beginning restricted to a subset of possible solutions. To avoid this problem more emphasis should be put on a methodological type of approach.
Figure 3 shows a systematical sketch of knowledge aquiring and knowledge application mechanisms. It is subdivided into 5 steps which are segmented into different levels and phases.
The five steps, mentioned in fig. 3, are to be broken down in more detail.

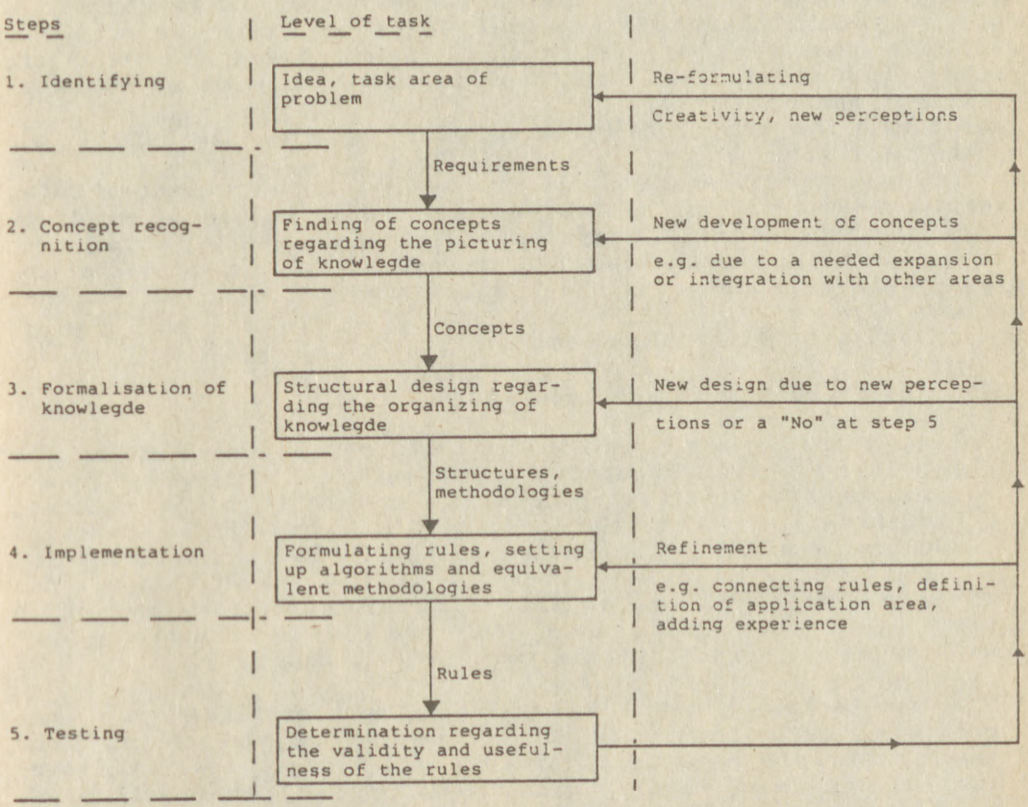


Fig. 3: Schematical sketch of knowledge aquiring and knowledge applying mechanisms.

So, for instance, the different working levels, within the 5 steps, have to be accompanied by adequate control- and decision levels. For the sake of simplicity they are not shown in Figure 3. Also, possible repeating loops (e.g. optimization by iterative steps) have not been considered.
Within the control level documentation (data storing) supervision and initiating the different working phases have to take place. The above presented modelized knowledge aquiring scheme shows the main structure and has to be adapted to the particularities of a certain manufacturing plant.
In particular, the presented scheme needs to be refined within the previous mentioned steps.
The figure intentional transfers the methodological principle to an evident basical scheme. This is to illustrate the sequence of operations. In general, this model could also be used as a basis for setting up an expert system.
The above described type of approach is aimed to support especially the unexperienced "young" engineer and will enable him

to handle complex, rather difficult to survey tasks. Within a team, applying these systematical rules is quiet normal, but, they are sometimes applied without being aware of their effects. This means, that this tool is not been used in the most efficient manner, possible.
Therefore, the achieved solution will be most likely not the optimal solution.
In the following there are some rules are to be presented in an exemplary manner. They are to support the invention of a structured development of CIM systems. They also describe the type of approach for installing a CIM-system. In the meantime applying this methodological tool makes the way to go more transparent.
Rules for installing a CIM system:

- Compare rules # 1 to # 6, see above.

- Define your list of requirements not before checking on the complete system or manufacturing plant, respectively, (overall approach) and weight your steps according to the existing rationalisation potential (possibly by means of an external consultant for this will ensure an objective examination).

- The CIM data handling requires data-management-systems which have to be kept up to date (For example: a phone book not kept up to date is of almost no value for the user).

- The manufacturing plant has to be CIM compatible, e.g. the products, data banks and the structure of the company and their coworkers have to fit into a CIM-system. This is important as, at least when it comes down to the operational phase of planning the CIM-system one will detect the missing of suitable products, data banks and personnel.

- One has to allow enough time for the strategical phase of CIM planning. This is due to the fact that the invention of CIM will change the organisatorical network of the plant. Especially within interfacing the different functional blocks, compare fig. 1 and fig. 2, the lack of knowledge regarding organisatorical and personnel problems will occur. Therefore insight into these problems has to be gained at an early stage of planning (Increased motivation of coworkers).

- Without proper preparation a complete CIM system can not be set up. This will be shown by three examples:
  (a) Lacking a product design which allows automatic assembly no computer integrated manufacturing will be possible.
  (b) Whereas within robot programming "Teach-in" systems are still widely used CIM requires off-line programming and the direct use of manufacturing datas.
  However, this may result in a positioning accuracy ten times less then for on line programming. This is because a compensation of elastical deformations in a vertical articulated robot system is not or at least not sufficiently solved.

(c) A management and business related problem:
By applying conventional operating efficiency calculation overhead and direct labour costs are easy to calculate. But the increased flexibility due to the invention of CIM can not be measured by the well known formulas. Here more information has to be gathered in order to develop suitable calculation theories.

- The men-machine (computer-dialog)-system has to be chosen carefully according to the special requirements, for these systems are still due to be improved.

- A goal oriented and systematical support by standardization will guarantee high flexibility. This also means a certain protection of the investments since for instance existing software could be used even when new hardware is aquired.

- A distribution of intelligence has to take place. This does mean, regarding the CIM-system, an enormous sturdy against the effects of disturbances, has to be existing see also the example for central/decentral control. This requires an exact structuring of the intelligence used for supervision, coordination, and control of the manufacturing. Without such an resolute structure it is hardly possible to adjust the system to different production set ups

- By applying universal proceeding chains potentials of rationalisation can be used for instance by applying new, improved chain links, which are newly presented on the market.

- The personel has to be of great influence in the future. Therefore CIM should be seen as a tool and not as goal on the way towards the plant of the future. The reason for this is, that otherwise the psychological demands get to high as the liberty of action will be narrowed down even more.

4. Conclusion

Frequently, within the realisation of a CIM system, customers are offered "off the shelf" standard products as custom tailored systems. In praxis, however, this high demands can't be satisfied by such a system. In most cases much work and time has to be invested for adapting the CIM system to the particular requirements of the firm. A way out can be found by the engineer if he approaches towards the realisation of CIM in a systematical and methodological manner.
This type of approach makes the solution finding process more transparent.
Within the step-by-step-method, first the components of CIM should be used as stand alone systems, but one has to ensure the compatibility of the different systems and has to look for easy interfacing. This basical set up is then to be completed by adding further functions. The proper sequence of applying the earlier stated rules can not be done in a check-list type of manner. They can't even seen isolated but they are to be seen as a whole. Sometimes it will occur that some rules are

asking for contradictory decisions. In these cases an optimized solution can be found by seeking for an compromise.
The rules presented in an exemplary manner are nevertheless a handsome approach towards installing a CIM system systematically and goal oriented. It is important to expand the presented rule-system in more detail. By structuring the rule system a very handy tool can be developed and a first approach towards an expert-system has been made. But, however, research and devolopment will be an ongoing and necessary element to solve the many still existing problems.

/1/ Wiendahl, H.-P.; Lüssenhop, T.: Wirkung von Prioritätsregeln - Eine kritische Betrachtung. VDI-Z 131 (1989), No. 1, Page 36 -

Adaptive Control of Production by Simulation Technique

by

Jochen Rempel, Dipl.-Ing., SimTec, Gesellschaft für Fertigungsplanung und Qualitätssicherung mbH, Pappenstraße 36, D-4100 Duisburg 1, FRG,

Marli Schmidt-Weinmar, Dipl-Phys., SimTec GmbH Pappenstraße 36, D-4100 Duisburg 1, FRG,

Günter H. Schmidt-Weinmar, Prof. Emerit., Dr.sci.nat., Dipl.-Phys., Dept. Electr. Engineering, University of Alberta, Edmonton, Alberta, Canada T6G 2E1, and SimTec GmbH, Pappenstraße 36, D-4100 Duisburg 1, FRG.

Decisionmaking, dialog, and control in production systems which contain a number of partially autonomous production cells are to be supported by computer simulation. For demonstration we simulate such a production system on a personal computer and show how the results obtained provide effective decision support to the central coordinator given the available material and personnel resources of the day. Editing the input to the simulation, the item-dependent production targets are assessed in an almost conversational mode.

Conventional production planning and control systems contain substantial devices for organizing materials and delivery dates but do little to plan the sequence and time of occurrence of events by which production is to proceed under the contraints of capacity and available resources. Likewise, control of production is insufficiently supported by those systems. These shortcomings affect not only the quality of the overall time frame for the planning of any significant production events but also the quality of control at all levels of production since the overall planning is to provide the primary time reference for the whole production program.

In conventional production planning and control systems, control of production is perceived as central control based on the premises that (Ref. 1)

- the total production program can be resolved in every detail, possibly at an early stage, and
- planning proceeds successively in such a way that the results of any planning stage are input to the subsequent stage.

Usually no feedback exists with this kind of planning.

Production with Partial Group Autonomy

To orient production towards customers' orders,

- smaller lot sizes,
- shorter delivery times,
- short throughput times,
- frequent retooling, shorter retooling times, and
- raised quality standards

are required.

Besides, there are significant changes in the social environment today; people are looking for more flexible working hours, a more demanding job content, and attractive work settings. All those factors demand that we look for concepts that give production a high degree of flexibility.

The best known prototype today for the organization of work in more human ways than by division of work (Taylorism) is the production cell (Ref. 2); a group of collaborating people follow the produced items through (some part of) the production line and retain some degree of autonomy in the way they schedule, at the production site, the required events. Group working is being employed with success in many industries, for example at the automotive assembly lines of the Swedish car makers Volvo and Saab (Refs. 3 & 4).

Compared to a shop floor organized by division of work, a production organized by working groups and oriented towards customers' orders needs fewer communication and control links. For a production cell with partial autonomy there usually is only one transfer of an order to the cell for each batch of items being produced and only one confirmation of the transfer to a central coordinator. Thus the role of the traditional central control in, e.g., controlling delivery dates, is reduced to performing certain coordinating functions, while the group of people in the production cell perform by themselves all the required short-term planning and controlling functions.

This delegation of responsibility generally improves the flexibility of production. It can also enhance the motivation, the expertise, and the creativity of personnel. However, it also creates some demand for suitable tools by which the potential conflict between the individual working groups and the production as a whole can be negotiated. For example, targets for delivery dates, throughput etc. will still have to be set by a central coordinator and be adhered to by the production system. Here, innovative planning and control tools are required, which do not attempt to extend control from a central planning office down to the shop floor but rely only on a minimunm of information exchanged between the production cells and the central coordination. Thus some dialog between the working groups and the central coordinator has to be established. At the Saab assembly line, for example, personal computers are being used for this very purpose (Ref. 4).

Innovative planning and control devices are desirable for production cells with partial autonomy in particular in view of some modified short-term-planning needs. For example,

- Factors as, e.g., **personnel**, **tools**, or **devices**, which can significantly influence the quality or delay the production, have to be brought into the planning and control system.

- There is a growing need to react quickly and efficiently to

revisions of the initial production plan by, e.g., splitting of work sequences, assigning orders to auxiliary machines, or speeding up the processing of an order.

- Planning and control has to proceed in terms of new units since the units by which central production planning and control departments operate are not necessarily suitable at the production level. For example, for filling a furnace to capacity we better plan in production units determined at the production site rather than in a central planning office.

Adaptive Production Control by Simulation

A planning and control support system suitable for a production system with partial autonomy must combine some discretionary powers with some capability for the prediction of events and their evaluation in order to furnish an effective decision support.

From the strategic planning to the short-term production planning and control, alternative courses of events can be tried out and evaluated by computer simulation. Given the present state of the art in personal computer technology, a simulation-based planning and control system can be updated automatically on line or manually and be used as decision support in an almost conversational mode. For example, simulating one work day of a production line with 50 processing steps requires in the order of 1 minute using a personal computer with 286/386 processor and coprocessor. Simulation technique implemented in the support of production planning and control offers the following possibilities.

Time Reference: The course of events in time can be described by computer simulation; thus predictions of such events and the times of their occurrence can be made. Such predictions are necessary to establish a dialog between a semi-autonomous production cell and a central coordination.

Generation of Alternatives: Alternative sequences of events in time ("scenarios") can be generated by computer simulation. Different sequences of events generated may correspond to, e.g., a number of different options for the group to operate a number of different machines, or to a number of different working shift schedules, or to other timely conditions through which production proceeds. These simulated alternative sequences of events are evaluated and the results given to the cell personnel and/or the central coordinator for decision support.

Evaluation of Alternatives: Alternative event schedules which correspond to, e.g., different sequences of orders can be evaluated, in particular for planning horizons of short and medium length. Such evaluations are done, for example, in terms of the throughput times, or of the quality in balancing loads to capacities, or of the fidelity with which delivery dates can be projected, or of the safety of certain materials' provisions. The results of these evaluations support the decision by the group in favour of one generated scenario, to which the group commits itself at some point in time. The production cell will report to the central coordination some status information corresponding to the chosen scenario.

Dialog: Following the concept of an object-oriented production with decentralized control by partially autonomous working groups, different planning targets resulting from the group personnel on the one hand and the

central coordination on the other hand have to be adjusted mutually by way of a dialog. A dialog based on the results of simulating and evaluating different courses of events under certain production constraints leaves a significant amount of discretion to the group of the production cell. All required coordinating activities remain with a central coordinator who, for example, issues to the production cells any requests based solely on realistic, simulation-based corner data.

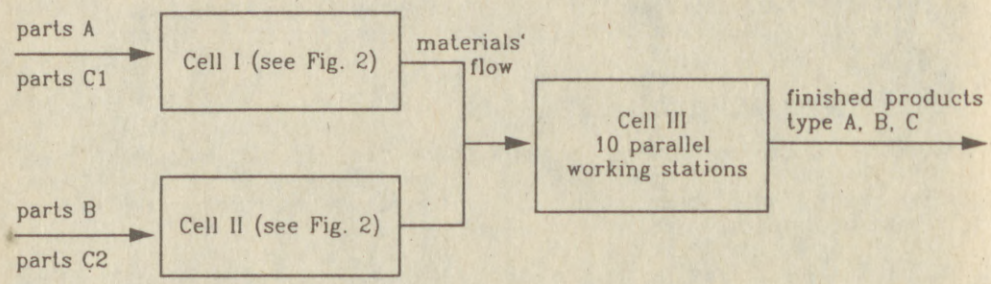


Fig. 1. Flexible production system used for simulation in the example presented.

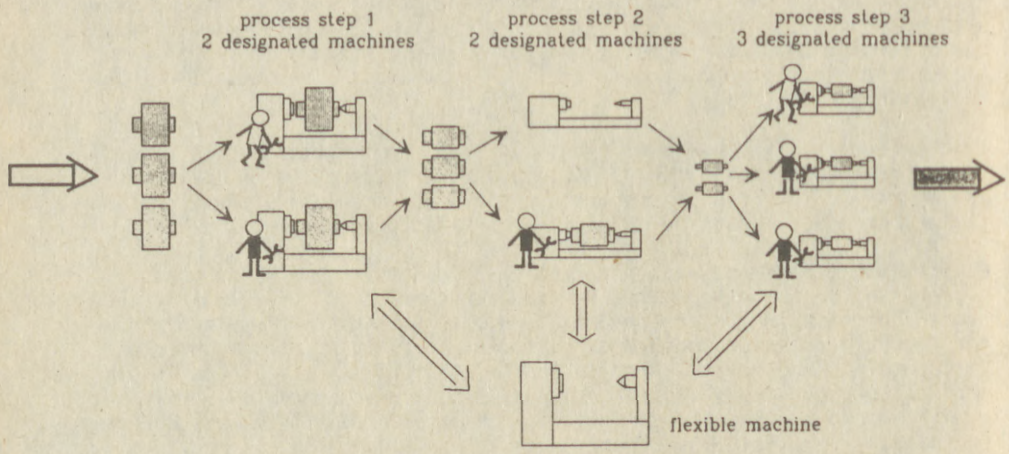


Fig. 2. Layout of the production Cells I and II (see Fig. 1). Shown are six personnel present, two of them can work more than one machine if needed.

Example

We now demonstrate the use of simulation technique by the example of a flexible production system with three partially autonomous production cells (see Fig. 1), which are answering to a central coordinator. The layout of the cells I and II is shown in Fig. 2, which also shows some personnel present as an example. Cell III consists of 10 workstations in parallel. Every 4 minutes one batch of raw parts of either type A or C1 (B or C2) is loaded into

Cell I (Cell II). Parts A and B are processed independently and yield the finished products A and B. Parts C1 and C2 are processed independently in cell I or cell II, resp., then assembled at the entry to cell III where they are called unfinished parts C which leave the cell as finished product C. At each processing step, the processing time depends on the type of batch to be processed and fluctuates randomly with a triangular distribution function for the probability density (see Table 1).

For our presentation we envisage as **fixed** the organisational **structure** of the production system including the processing times given in Table 1. At the **disposition** of the coordinator are

- the **composition** of batches of raw materials **loaded** into the system in terms of type, and
- the number and the qualification of the **personnel present.**

The central coordinator works with and modifies the table shown in Fig. 3, which is the input to the simulation-based planning and control system. Scenarios are simulated in order to support the central coordinator in the decision which type of batches to process at a given day with the personnel present in order to meet production targets. The role the qualifation of personnel plays in this context will be particularly addressed by the presented scenarios (see Table 2 and Fig. 5).

Length of Production Time (minutes)									
Cell I:	**product A**			**product C1**					
Step 1	7.0	9.0	11.0	8.0	9.0	12.0			
Step 2	6.0	8.0	10.0	7.0	9.0	11.0			
Step 3	12.0	15.0	18.0	13.0	14.0	17.0			
Cell II:	**product B**			**product C2**					
Step 1	6.0	10.0	13.0	7.0	9.0	10.0			
Step 2	5.0	9.0	11.0	7.0	8.0	10.0			
Step 3	10.0	16.0	18.0	13.0	15.0	19.0			
Cell III:	**product A**			**product B**			**product C**		
	20.0	25.0	30.0	10.0	15.0	20.0	25.0	30.0	35.0

Tab. 1. Length of production time (minutes) for the flexible production system in the example presented.
The length of the production time is stochastic; the values shown are the minimum, peak, and maximum of the triangular distributions.

Input to Cell I

Number of machines for:

step 1: 2 step 2: 2 step 3: 3

Number of flexible machines (step 1..3): 0

Personnel and their qualification

Name	present	step1	step2	step3	flex.
A	Y	Y	-	-	-
B	Y	Y	Y	-	-
C	Y	-	Y	-	-
D	Y	-	Y	Y	-
E	Y	-	-	Y	-
F	Y	-	-	Y	-
G	-	-	-	-	-
H	-	-	-	-	-

Ratio of input A/C1: 55/45

Input to Cell II

Number of machines for:

step 1: 2 step 2: 2 step 3: 3

Number of flexible machines (step 1..3): 1

Personnel and their qualification

Name	present	step1	step2	step3	flex.
A	Y	Y	-	-	-
B	Y	Y	-	-	-
C	Y	-	Y	-	-
D	Y	-	Y	-	-
E	Y	-	-	Y	-
F	Y	-	-	Y	-
G	Y	-	-	Y	-
H	Y	-	-	-	Y

Ratio of input A/C1: 70/30

Input to Cell III

Nunmber of personnel assigned: 8

Fig. 3. Simulation input table for edition by the central coordinator. The values shown correspond to the scenario Sc. 7.

Simulation Model

The production system shown in Figs. 1 and 2 was modeled as a network of nodes, activities, queues, personnel, and resources using the SLAM II simulation language (Ref. 5). Where desirable, the SLAM II code was appended by some user-written FORTRAN functions. SLAM II allowed us to model all processing times as stochastic activities (see Table 1). In a SLAM II simulation model, the entities carry attributes so that, e.g., a number of batches of different types can be modeled flowing simultaneously through the production system on batch-dependent routes.

Results

The results shown in Figs. 4 and 5 are obtained by simulating the production system shown in Figs. 1 and 2 on a personal computer AT with 386 processor; for details of the simulated scenarios, see Table 2. The simulations and the evaluations of the results are designed so as to assist the central coordination in assessing the number of batches of finished products A, B, C under certain constraints given by the personnel present at a given day.

Scenarios Sc. 1 to Sc. 5 are to explore the capacity of the system in regards to the production of products A, B, and C. All personnel are present.

Scenario Sc. 1. Without any set target for product C, approx. 100 batches of products A and B can be produced per day.

Scenarios Sc. 2 to Sc. 4. The composition of the input is changed by increasing (decreasing) the number of batches of type C (type A or B, resp.) loaded into the system.

Description of Scenarios			
Scenario	Personnel in Cell: I / II	III	Remarks
Sc. 1	8 8	10	only A only B
Sc. 2	8 8	9	A/C1 = 70/30 (ratio of products loaded B/C2 = 70/30 into the system)
Sc. 3	8 8	9	A/C1 = 50/50 B/C2 = 50/50
Sc. 4	8 8	8	A/C1 = 30/70 B/C2 = 30/70
Sc. 5	8 8	7	only C1 only C2
			Scenarios 6 to 9: 2 personnel absent in cell I, 1 personnel absent in cell III
Sc. 6	6 8	8	
Sc. 7	6 8	8	Cell I: 2 operators change machines if needed
Sc. 8	7 7	8	1 operator transfers from cell II cell I
Sc. 9	7 8	7	1 operator transfers from cell III to cell I
			Scenario 10: 3 operators absent form Cell I 6 operators assigned to Cell III Priority to produce B and C.
Sc. 10	5 8	6	Cell I: 3 operators change machines if needed

Tab. 2. Description of the scenarios simulated in the example presented. Unless stated otherwise, each operator works one machine.

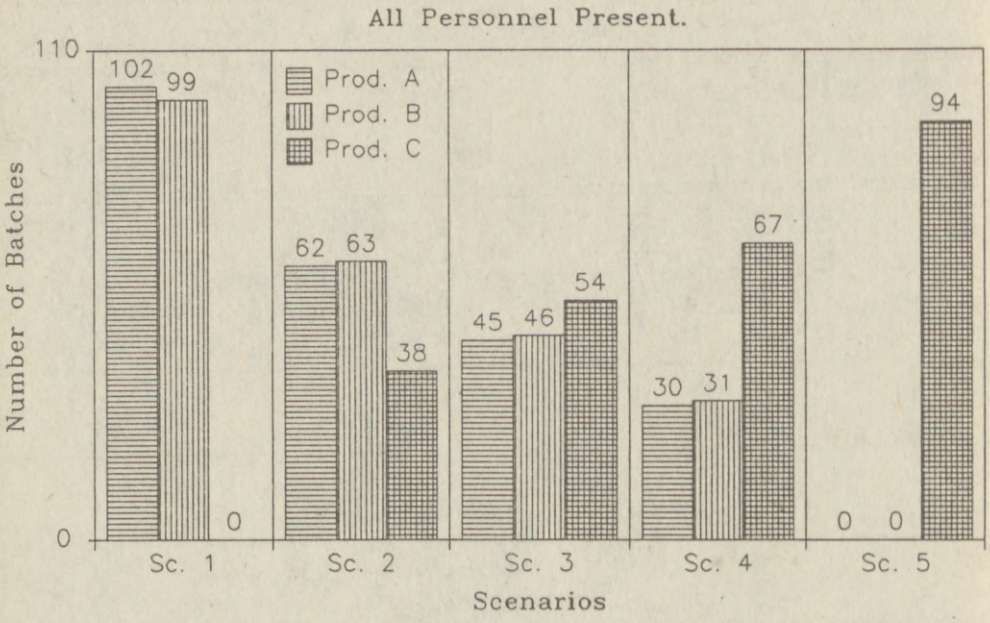


Fig. 4. Daily production levels for products A, B, and C. The scenarios are chosen to explore the capacity of the system, see Table 2.

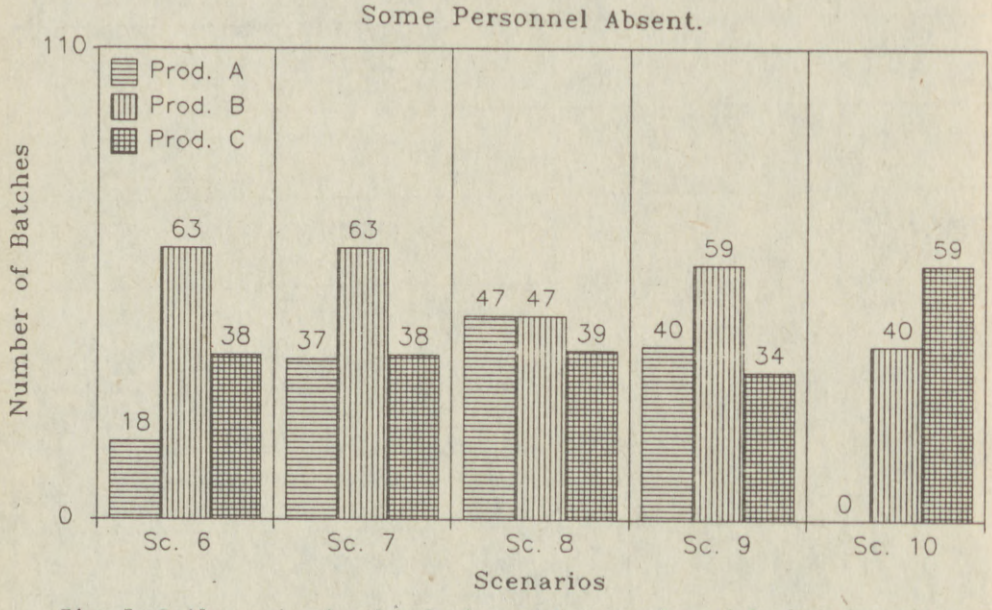


Fig. 5. Daily production levels for products A, B, and C given targets for products A and C and constraints by personnel availability, see Table 2.

Scenario Sc. 5. Without any targets set for products A and B, approx. 95 batches of product C can be produced per day.

Scenarios Sc. 6 to Sc. 9 are to assess the effect of absence of personnel on production targets. The following targets are set for the given day: At least 40 batches of product A and at least 38 batches of product C are to be produced.

Scenario Sc. 6. Cell I: 2 operators absent; the remaining 6 operators are not qualified to change between machines if needed.
Cell III: 1 operator absent.
Although the target for product C is met, only 18 batches of product A are produced.

Scenario Sc. 7. The absences are the same as in Scenario Sc. 6, but of the remaining 6 operators in Cell I, 2 operators are qualified to change between machines if needed (see Figs. 2 and 3).
The target for product C is met, but production level for product A is still short of 3 batches.

Scenario Sc. 8. The absences are the same as in Scenario Sc. 6. To relieve the load on Cell I, one operator transfers from Cell II to Cell I.
The targets for both products A and C are well met.

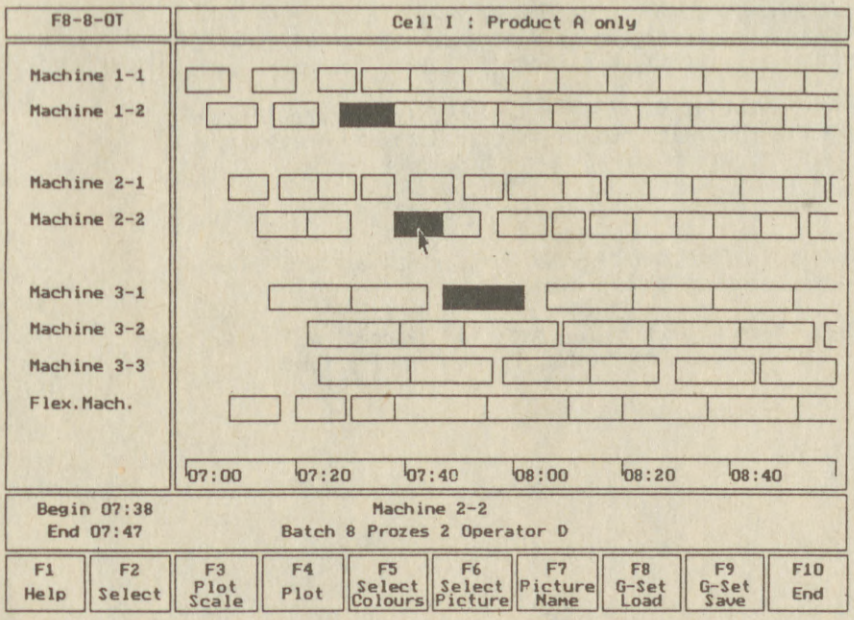


Fig. 6. Gantt-Chart obtained by simulating the materials' flow through Cell I.
The progress of every batch through the cell can be followed on the screen by selecting a color code. Additional information on a particular batch in progress as, e.g., the process step and the operator in charge of it, can be displayed by "clicking" on the respective field in the Gantt-Chart.

Scenario Sc. 9. The absences are the same as in Scenario Sc. 6. To relieve the load on Cell I, one operator **transfers** from Cell III to Cell I.
The target for product A is met, but production level for product C is short of 4 batches.

Scenario Sc. 10 is in order to find the production level for product C without producing product A under the constraint of some absent personnel, in particular in Cell I.

Scenario Sc. 10. Cell I: 3 operators are absent. Of the remaining 5 operators, 3 operators are **qualified** to **change** between machines as needed. Only 6 operators were available for assignment to Cell III.
Thanks to the qualifications of the 3 operators in Cell I to change between machines as needed, 59 batches of product C are produced. This compares favourably with the 94 batches of product C produced when Cell I had all 8 personnel present. Without 3 of the remaining 5 operators being qualified to change between machines as needed, only 48 batches of product C would have been produced.

References

1 *Die integrierte Auftragsabwicklung bei Fertigungsinseln, -Grobplanung, Feinplanung, Überwachung*, Th. Ruffing, AWF-Fachtagung Fertigungsinseln, Ausschuß für Wirtschaftliche Fertigung e.V. (AWF), Bad Soden/Ts., FRG, December, 1988.

2 *Fertigungsinseln, Methode, Umsetzung, Praxis und Erfahrung*, AWF-Fachtagung, Ausschuß für Wirtschaftliche Fertigung e.V. (AWF), Bad Soden/Ts., FRG, December, 1989.

3 *Menschliche Fabrik*, Wirtschaftswoche, 13.10.1989, p. 80.

4 *Saab Acts to Take Drudgery Out of Car Making*, Int'l Herald Tribune, November 18-19, 1989.

5 *SLAM II, Network Models for Decision Support*, A.A.B. Pritsker, C.E.Sigal, R.D.J. Hammesfahr, Prentice-Hall, 1989.

NEW METHODS OF COMPUTER-AIDED DATA ACQUISITION FOR CAD IN FACILITIES PLANNING

Prof. Dr. sc. techn. Hans Schmigalla
Dipl.-Ing. Hans-Dieter Beckmann
Dr.-Ing. Harald Schreiber

Friedrich Schiller University Jena
Dept. of Technology
E.-Thaelmann-Ring 32
JENA
DDR-6900

1. Problem

With CAD systems gaining ground in the technology of plant design the discrepancy between computer-aided processing of data on the one hand and conventional methods for data-gathering on the other one is increasing. The trend to increase reconstruction and rationalization projects within facilities planning leads to the development of plant structure data bases (e. g. [BRAC 84]) as well as to the discovery that data acquisition and processing is extremely expensive. Two approaches for a more effective gathering of actual object-place data appear as interesting in facilities planning:

(1) the evaluation of photograms of layouts by means of suitable photogrammetric procedures as well as of object-place data provided by using geodetic approaches and supplementing them by graphic macroes of equipment etc. and
(2) the automated conversion of graphic information taken from existing plans and drawings assuming that they are reliable.

Both the approaches involve the necessity to convert the data gathered into CAD structures which allow the formation of plant structure data bases and manipulation on the CAD system.

2. Selected methods for CAD compatible acquisition of object-place data

2.1. Acquisition by means of photogrammetric methods

Application of photogrammetric and geodetic methods and technologies makes it possible to considerably decrease the time for data gathering at the workplace, to process data by

means of CAD technologies, to reduce data during input and thus to make available the data necessary for the solution of design problems as well as for the establishment of a master file comprising data invariant in distinct projects ([SCHM 85], [SCHM 87], [SCHM 88] and [SCHR 89]).

Layout photogrammetry is the measurement of photographic pictures showing the layout of workshops with the aim of acquisition, storage and processing of object-place data. Together with the application of geodetic methods it is important particularly for the establishment of a master file, e. g. for the establishment of space related information systems for data acquisition and as plausibility check.

Layout photogrammetry is possible with systems used in other forms of application of photogrammetry in industry:

a) classical stereo instruments off-line or on-line coupled with CAD systems of special software for randomly oriented single or pairs of stereo pictures,
b) special digitizer computer plotter combinations using a camera with reseau grid and special software for randomly oriented single pictures.

Under certain circumstances the following type of system can be regarded as efficient:

c) digitizer computer plotter combinations where standard CAD software and any camera available can be used. Picture and object planes are arranged in parallel (e. g. floor level); 2 D evaluation is planned.

This procedure developed for layout photogrammetry (cp. fig. 1) allows CAD compatible 2 D as well as 3 D data analyses.

Picture record is performed on the basis of defined basic control and a control which, in dependence on the strategy of coverage (2 D or 3 D coverage), has an overlap of at least 20 and 60 %, resp. (cp. [SCHM 87], [SCHR 89]).

As a result of the application of layout photogrammetry numerical data bases are developed comprising object- and point-place information in dependence on the strategy of coverage, as well as CAD stored layouts.

The following hard- and software systems have been the focus of

interest until now (cp. [SCHR 89]):

Dimension	input-device	Type of computer	CAD system
2-D	digitizer	DT 90 x 120 RGS	MOD/LAYPHO
2-D	digitizer	IBM-PC/XT	CADdy
2-D	digitizer	IBM-PC/XT,PC1640	AutoCAD
3-D	STECOMETER	SIEMENS 7.530	CADIS
3-D	STECOMETER	IBM-PC/XT,PC1640	AutoCAD
3-D	DICOMAT	IBM-PC/XT,EC1834	AutoCAD

Investigations of the accuracy at constant control distance in longitudinal direction through the workshop, in our example a shop for the production of bulky parts, yielded the following data:

- 2-D (digitizer - CADdy) max. 30 mm
- 3-D (STECOMETER - CADIS) max. 20 mm
- 3-D (DICOMAT - AutoCAD) max. 20 mm.

2.2. Automatic digitization of layouts

The use of visual sensors in connection with a suitable optical system offers a possibility for creating a raster image data structure from existing plans and drawings which allows an automatic evaluation of its information. The signal which is picked up by the sensor and, as a rule, is two level and analogue is transformed into a digital image by spatial resolution and quantization of the signal level. The present state of the art of such input devices is reprented by large area flatbed-, drum- or paper feed scanners ranging to the size A 0, scanning options to conventional large area plotters as well as small area (A 4) scanners for application in desktop publishing. These devices work on- or off-line as peripheral components of graphic workstations, and they scan the original either by points, lines or areas. We do not know of any application of such systems for a CAD compatible processing of graphic originals in the technology of workshop design.

The determinative criterion for development and implementation of algorithms for automatic digitization of graphic originals in designing is the necessity to process various amounts of data. In order to implement such processing with commercial computers the following demands have to be met:

- quick transition from the digital raster image to a primary description of the picture by means of an on-line procedure together with further on-line reduction of data describing the picture,
- efficient internal representation of data by using dynamic storage structures and
- use of algorithms with low time complexity.

Fig. 2 shows schematically the flow of the picture data through a system for automatic digitization of graphic originals. The recording of the graphic original by means of a visual sensor is accomplished in agreement with the demands mentioned above in lines and is called image acquisition. After a simple line oriented procedure for picture pre-processing which is aimed towards elimination of isolated picture elements as well as filling of gaps, there follows picture segmentation. During this stage of processing an outline of the object structures in the picture is generated on the basis of chain codes ([FREE 61], [KIM 88]) which serves as a basis for a procedure of vectorization by means of decomposition into digital line segments ([CREU 82]). The vectorized contours coded as polygones are then used for calculating the center line ([MART 87], [SCHI 89]), so that as a result of segmentation the vectorized line-shaped contours of objects can be seen. All algorithms mentioned above are operated on-line, but differ widely in their time complexity. The following stages of processing of the description and analysis of pictures aim at higher forms of the description of picture elements on the basis of geometrical elements and their embedding into a task oriented project specific context. AI methods are particularly suitable for that, especially for the representation of knowledge about the picture elements to be expected in form of reference models on the basis of frames or semantic nets.

From the data obtained so far, an IGES data base is generated. The IGES supported functional extent as well as its wide range of application (cp. [GENG 88]) predetermines this standard as a suitbale and neutral data interface for the transmission of graphic data to any CAD system available.

3. Final remarks

The methods presented for computer aided data acquisition supplement the conventional procedures for analyzing and processing graphic planning data for CAD. Their application

leads to a considerable lowering of the acquisition times with simultaneous increase in the reliability of the data, and thus it is a precondition for the efficient establishment and maintenance of data bases for planning.

References:

[BRAC 84]
Bracht, U.
Werksstruktur-Datenbanken zur rechnerunterstützten Fabrikanalyse und -planung - Konzept und Realisierung. -
In: Rechnerunterstützte Fabrikplanung, Tagung Düsseldorf, 22. 23. März 1984. - Düsseldorf: VDI - Verlag, 1984. - pp. 9 - 24

[CREU 82]
Creutzburg, Egbert; Hübler, Albrecht; Wedler, Volker
On-line Erkennung digitaler Geradensegmente in linearer Zeit. -
In: GEOBILD '82; Wissenschaftliche Beiträge der Friedrich-Schiller-Universität Jena. -
Jena: Friedrich-Schiller-Universität, 1982. - pp. 48 - 65: 5 refs.

[FREE 61]
Freeman, Herbert
On the encoding of arbitrary geometric configurations. -
In: IRE Transactions on Electronic Computers. - New York, NY
EC-10 (1961) 2. - pp. 260 - 268: 13 figs., 4 tabs., 1 refs.

[GENG 88]
Gengenbach, U.; Mittelstaedt, M.
CAD-Schnittstellen - Stand und Entwicklungstendenzen. -
In: Datenverarbeitung in der Konstruktion 1988. 3. CAD und Informatik: Kongreß/VDI-Ges. Entwicklung, Konstruktion, Vertrieb. -
Düsseldorf: VDI-Verlag, 1988. - pp.169 - 181: 5 figs., 13 refs.

[KIM 88]
Kim, Seong-Dae; Lee, Jeong-Hwan; Kim, Jae-Kyoon
A new chain coding algorithm for binary images using run-length codes. -
In: Computer Vision, Graphics, and Image Processing. - Duluth, MN
41 (1988) 1. - pp. 114 - 128: 12 figs., 6 refs.

[MART 87]
Martínez-Pérez, M. Pilar; Jiménez, Javier; Navalón, José, L.
A thinning algorithm based on contours. -
In: Computer Vision, Graphics, and Image Processing. - Duluth, MN
39 (1987) 2. - pp. 186 -201: 13 figs., 11 refs.

[SCHI 89]
Schirmer, H.; Fuchs, S.
An algorithm for the recognition of line objects. -
In: Computer Analysis of Images and Patterns. Proceedings/Voss, Klaus; Chetverikov, Dmitry; Sommer, Gerald (Eds.). -
Berlin: Akademie-Verlag, 1989. - pp. 157 - 162: 6 figs., 2 refs.

[SCHM 85]
Schmigalla, H.; Schreiber, H.
Photogrammetrische Informationsgewinnung zum Aufbau von Objektdatenbänke für die Werksanalyse und - projektierung. -
In: Rechnerunterstützte Fabrikplanung, Fachtagung Fellbach, 24. u. 25. Oktober 1985. - Düsseldorf: VDI - Gesellschaft, Produktionstechnik (ADB), 1985. - pp. 125 - 141

[SCHM 87]
Schmigalla, H.;Schreiber,H.
Rechnergestützte Analyse von Layoutmeßbildern In: Bauplanung - Bautechnik . - Berlin 41(1987)5.- pp. 216 - 218

[SCHM 88]
Schmigalla,H.;Schreiber, H.
LAYOUT-SURVEY - ein Verfahren zur Analyse von Layoutmeßbildern in der Betriebsprojektierung. - In: Rechnerunterstützte Fabrikplanung, Fachtagung Fellbach, 24. u. 25. Oktober 1985. -
Düsseldorf: VDI - Gesellschaft Produktionstechnik (ADB), 1988. - pp. 113 - 135

[SCHR 89]
Schreiber, H.
Untersuchungen zur CAD-kompatiblen Layoutphotogrammetrie und -vermessung. -
1989. - 96 pp. - Jena, Friedrich Schiller University, Dept. of Technology, Doctoral Thesis

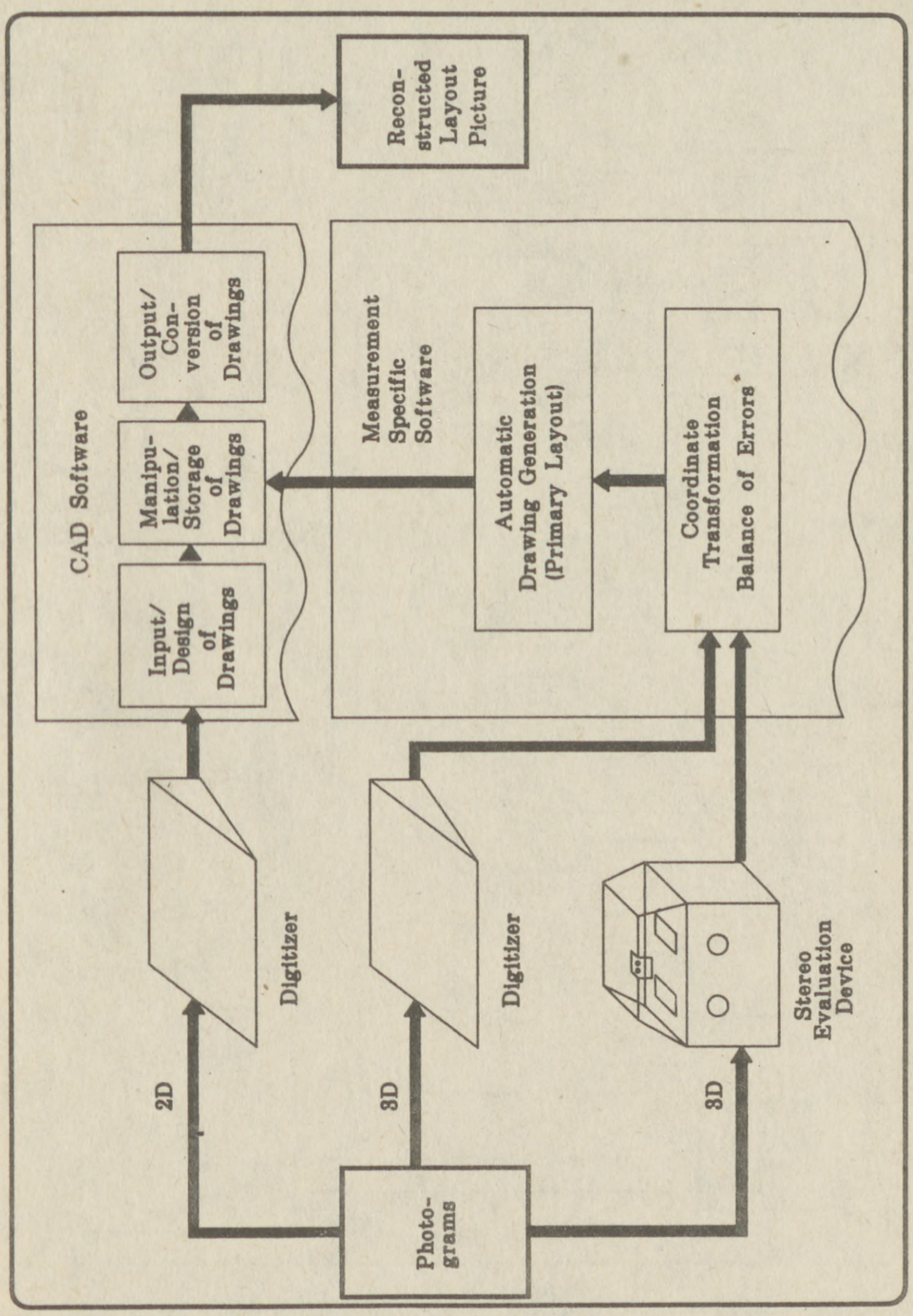


Fig. 1: Procedure for Layout Photogrammetry

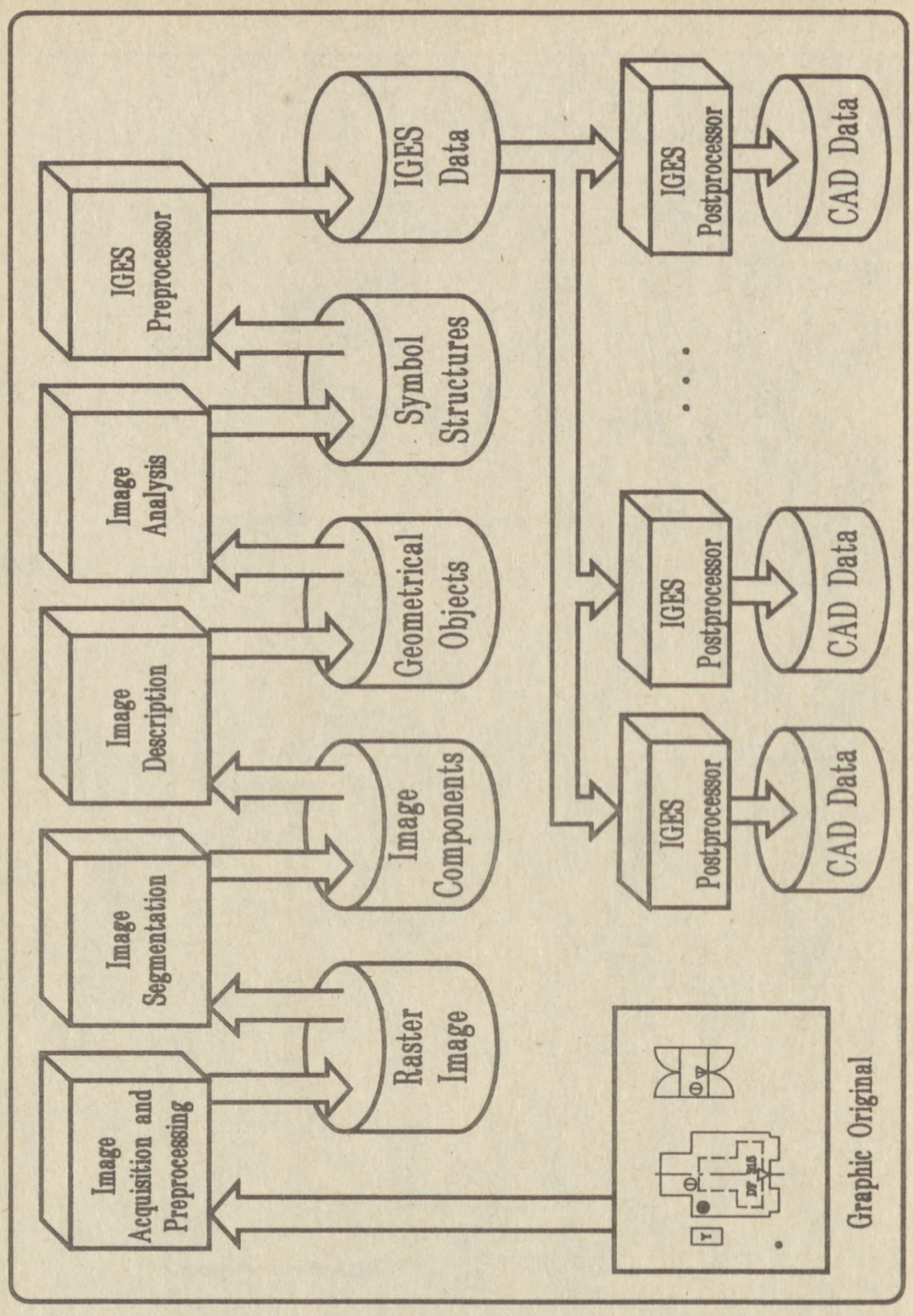


Fig. 2: Automatic Digitization of Graphic Originals

GRAPHICAL PROCEDURE FOR PROGNOSIS OF THE CUTTING-TOOL RELIABILITY, ON FLEXIBLE AUTOMATIC LINES, BASED ON THE NUMBER OF WORK PIECES MACHINED WITH PARTICULAR TOOLS

Professor S. St. SEKULIĆ, Ph. D.

Department of Mechanical Engineering
Faculty of Technical Sciences
University of Novi Sad
Novi Sad, Yugoslavia

1.0 Introduction

The tool situation can be described using a simple state function as follows

$$x(t) = \begin{cases} 1 & \text{tool available} \\ 0 & \text{tool on failure} \end{cases}$$

where the random function is time dependent.

The tool failure time (the time interval when failure occured), as we know depends on the number of different factors and represents a wery complex parameter. Complexity of the geometrical shape under dynamic and heat load influenced the cutting tool failure. We must respect the fact, that in certain work shop conditions, if we have to determine the cutting tool reliability we must have the evidence of the replacement time.

The basic characteristics of the cutting process are:

1. Work piece material
2. tool material
3. working conditions distributed over the cutting run.

The third characteristic is base on the elements of machining conditions (the elements of chip cross sectional area, cutting speed, tool life, tool geometry (shape), cutting fluid and has hard dependence on dynamic system state: machine tool - fixture - cutting tool - work piece).

Based on the proceding we may draw the conclusion that the tool failure is not a constant but represents a random process, where we are able to make prognosis with statistical methods and law of probability.

The reliability of cutting tool is most commonly defined by means of the following basic characteristics:

- the reliability function (the probability in between time failure),
- the probability distribution function of time failure
- frequence of time failure,
- failure intensity.

The recent investigations showe that the function of cutting tool failure distribution is liable to the Weibull distribution:

$$F(t) = 1 - \exp\left[-t/\eta\right)^{\beta}] \qquad (1)$$

and the reliability is

$$R(t) = 1 - F(t) = \left[\exp - (t/\eta)^{\beta}\right] \qquad (2)$$

The frequence failure is

$$f(t) = dR(t)/dt = \beta/\eta\ (t/\eta)^{-1} \cdot \exp - (t/\eta)^{\beta} \qquad (3)$$

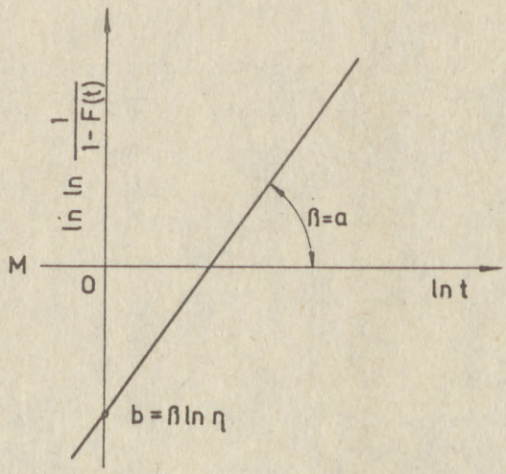


Fig. 1.

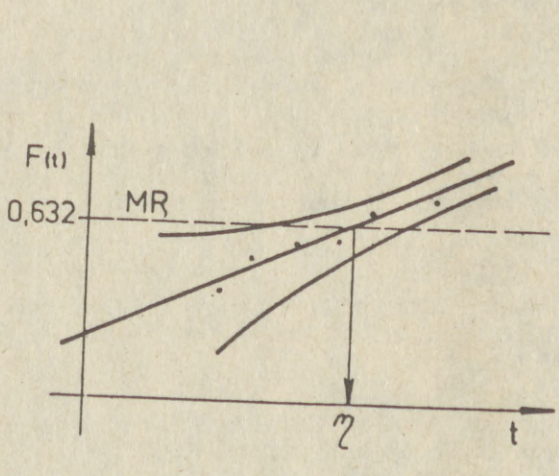


Fig. 2.

and the intensity of failure is

$$\lambda(t) = f(t)/R(t) = \beta/\eta(t/\eta)^{\beta-1} \qquad (4)$$

In the case of Weibull distribution the mean time to failure we find using Gamma function

$$T_m = \eta\Gamma[(1/\beta) + 1] \qquad (5)$$

From the equation (1) we have:

$$1/[1 - F(t)] = \exp (t/\eta)^{\beta} \qquad (6)$$

after double logarithming we obtain

$$\ell n\, \ell n[1/1 - F(t)] = \beta\ell nt - \beta\ell n\eta \qquad (7)$$

By replacement

$$y = \ell n\, \ell n[1/1 - F(t)] \text{ and } x=\ell n\, t \qquad (8)$$

we obtain the liner equation

$$y = \beta x - \beta\ell n\eta \qquad (9)$$

with slope angle β and intercept $b = \beta\ell n\eta$ (Fig. 1).

Therefore, the determination of Weibull distribution parameters cna be carried out by the determination of slope angle β and section $\beta\ell n\eta$ in the grid defined by equation (8) (Weibull probability paper).

The value of the parameter of scale can be directly determined from the probability paper given in the logarithmic scale, drawing a vertical line in the intersection point of the approximatics straight line and mediana for which is $\ell n\ \ell n\ [1/1-f(t)] = 0$ or $F(t) = 0{,}632$ (Fig. 2).

The hypothesis of distribution can be accepted if all points obtained by experiments are in the confidence limits.

2.0 Data colection and processing

Colection of data about cutting-tools failure originated during production process, in observed operation, could be done in the most simple manner via number of machined work pieces. When the number of work pieces, after which failure caming is founded, the time to failure in that case is equal to the product of time in wich rise the chip, on work piece and number of work pieces z, i.e.

$$T = z\, t_s = z\, i\, \ell/s\, n$$

where the following symbols are: i number of passes, ℓ lenth of cutting, s feed and n number of revolution.

How is valid for observed operation

$$C = i\, \ell/s\, n=\text{const.}$$

we have

$$T = C\, z$$

Therefore, if with the view to determination reliability we observe N cutting tools and if failure occur after machining

$$z_1, z_2, z_3, \ldots, z_i, \ldots, z_n$$

work pieces, the corresponding times to failure are

Table 1.

j	z_j	T_j	5%	MR	95%
1	7730	408	0,465	6,107	23,840
2	10380	548	3,332	14,796	36,436
3	11310	597	7,882	23,578	47,009
4	12100	639	13,507	32,380	56,437
5	12480	659	19,958	41,198	65,019
6	13120	692	27,125	50,000	72,875
7	13280	701	34,981	58,811	80,042
8	13480	711	43,563	67,620	86,492
9	13800	728	52,991	76,421	92,118
10	14060	742	63,564	85,204	96,668
11	14270	753	76,160	93,893	99,535

Table 2.

j	$x_i = \ln T_j$	$100-(MR)_j$	$y_i = \ln \ln \frac{1}{\frac{100-(MR)_j}{100}}$
1	6,0112672	93,893	-2,7643928
2	6,3062753	85,204	-1,8318205
3	6,3919171	76,422	-1,3134173
4	6,4599045	67,620	-0,9383666
5	6,4907235	58,802	-0,6330040
6	6,5395860	50,000	-0,3665129
7	6,5525079	41,189	-0,1199115
8	6,5666724	32,380	0,1201174
9	6,5903010	23,579	0,3679804
10	6,6093492	14,796	0,6475290
11	6,6240652	6,107	1,0280949

$$T_1, T_2, T_3, \ldots, T_i, \ldots, T_n$$

and by that $z_{i-1} \gtrless z_i$ i.e. $T_{i-1} \gtrless T_i$ are valid.

For determining the parameters of Weibull's distribution of failure the graphical method, by medial ranks, is sugested.

For that purpose, the time values about failure must be sorted in series according to expression

$$T_{j-1} < T_j$$

After that determination of medial ranks is done by appropriate tables or calculation by formula

$$MR = (j - 0,3)/(N - 0,4)$$

The table is also used to determine the position of the lower and uper confidence limits (5% and 95%) for a required confidence level α (for instance $\alpha = 0,05$).

On the basis of the data given in the table the points obtained by experiments and the confidence limits are ploted on the Weibull probability paper, and the points obtained by experiments are connected by strainght lines in the manner to minimize the deviation of all the points.

Hereafter from the point F(t) = 60% a strangh line paralel with aproximate line must be drawn and on the uper auxiliary scale parameter of shape β could be read off and after that scale parameter η on the t partition.

2.1 Example

In the order to determination of the cutting-tool reliability, the its failure was observed on the operation, rough machining of the hole on the operation, rough machining of the hole on the pistons, using coanterborer ϕ 19 mm, with two cutting edges by cemented carbide kind K10. The diameter of the hole before boring was ϕ 17 mm.

Cutting condition: number of revolution n = 1800 min^{-1} (cutting speed v = 1,8 m/s), feed s = 0,2 mm, lenth of cut in pistons hole ℓ = 19 mm.

The failures of the cutting tools have been arisen after

12480	13480	10380	12100	7730	14270
13120	14060	13280	13800	11310	

machined holes.

The times of failures were sorter in advancing order in table 1, wich contains data concted for medial ranks and confidence interval limits, too.

Complete graphical method is presented on the figure Fig. 3.

Pure graphical procedure, using standard Weibull's probability paper, enables fast data processing, but higher values of the shape parameters β, difficulties are appeared in relation to its reading off, becouse of the large slope of streight line. In this cases the parameters β and η must be determined using graphoanalitical procedure, wich will be exposed as follows.

Starting from the equation

$$y = ax + b \qquad (9')$$

and using the least squere method that gives

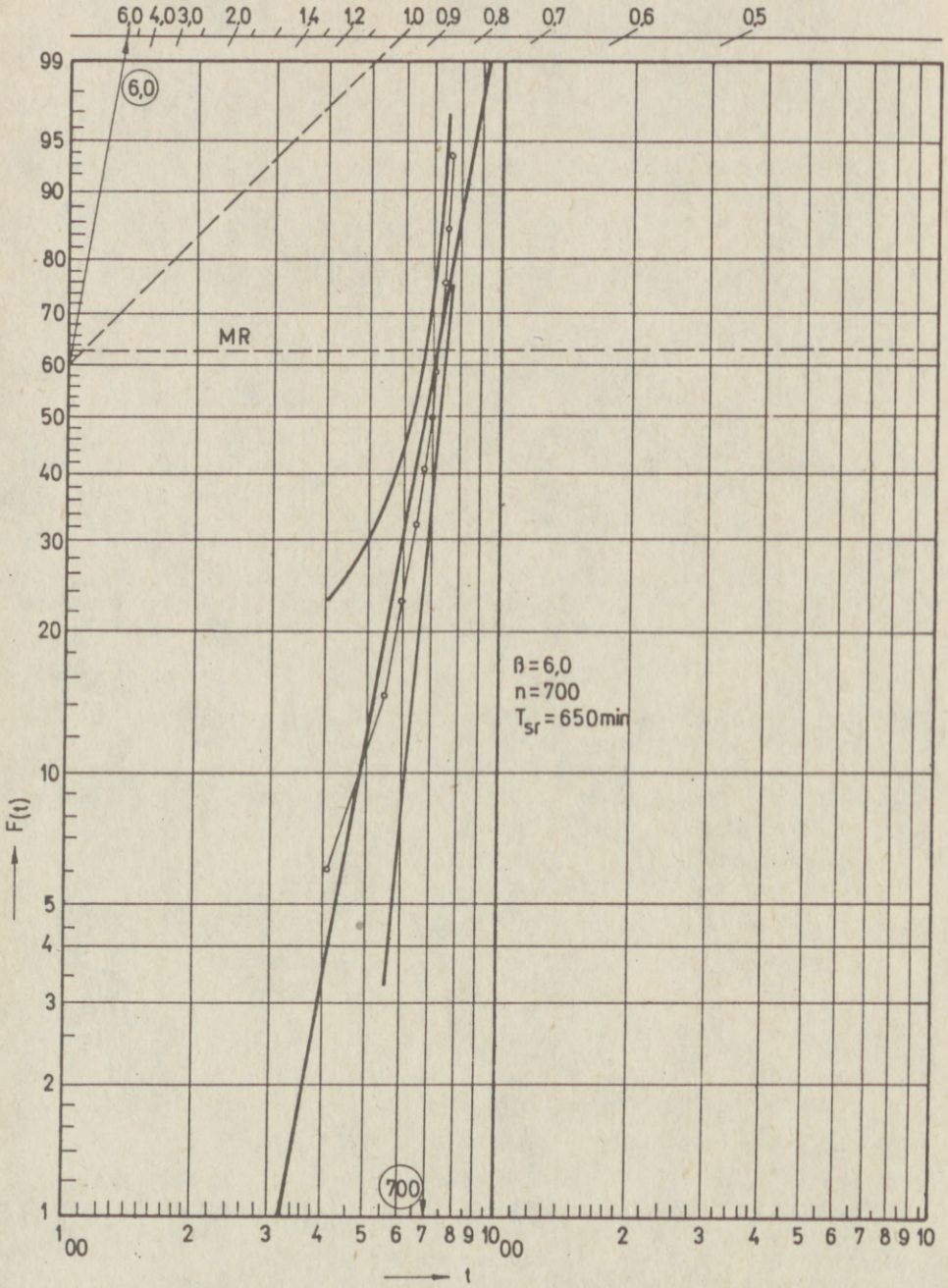

6,0 4,0 3,0 2,0 1,4 1,2 1,0 0,9 0,8 0,7 0,6 0,5
99
95
90
80
70
60
50
40
30
20
10
5
4
3
2
1
6,0
MR
β=6,0
n=700
T_{sr}=650min
700
F(t)
100
2 3 4 5 6 7 8 9 10
1000
2 3 4 5 6 7 8 9 10
t

Fig. 3.

$$(\Sigma\Delta_i^2)_{min}$$

where Δ_i is the error of the ith observation. From the condition of minimum the normal equations are

$$\Sigma(x_i y_i) - a\ \Sigma(x_i)^2 - b\ \Sigma x_i = 0 \qquad (11)$$

$$\Sigma y_i - a\ \Sigma x_i - N \qquad b = 0$$

and consequently

$$A_1 a + B_1 b = C_1$$
$$A_2 a + B_2 b = C_2 \qquad (12)$$

where

$$A_1 = \Sigma(x_i)^2 \ ; \quad A_2 = \Sigma x_i = B_1$$

$$B_2 = N; \quad C_1\ \Sigma(x_i y_i); \quad C_2 = \Sigma y_i$$

The solutions for the above system are

$$a = \frac{D_a}{D} = \begin{vmatrix} C_1 & B_1 \\ C_2 & B_2 \end{vmatrix} \Big/ \begin{vmatrix} A_1 & B_1 \\ A_2 & B_2 \end{vmatrix} = \frac{C_1 B_2 - C_2 B_1}{A_1 B_2 - A_2 B_1} \qquad (13)$$

$$b = \frac{D_b}{D} = \begin{vmatrix} A_1 & C_1 \\ A_2 & C_2 \end{vmatrix} \Big/ \begin{vmatrix} A_1 & B_1 \\ A_2 & B_2 \end{vmatrix} = \frac{A_1 C_2 - A_2 C_1}{A_1 B_2 - A_2 B_1} \qquad (14)$$

The constants $A_1,\ldots,C_2$ may be found in the appropraiate tables. The constant a and b are determined by substitution,

$$\beta = a \qquad \text{and} \qquad \eta = \exp\,(b/\beta) \qquad (15)$$

When the parameters β and η are known, the probability function of failure F(t), the reliability R(t), the frequence of failure f(t) and the itensity $\lambda(t)$ of failure can be calculated by equations (2) to (4).

The mean time to failure is calculated by expression (5).

With regard to the above mentioned, the distribution function parameters of failures can be determined on the colected failures of the cutting tools T_j and to them corresponding medial ranks $(MR)_j$.

On the basis of expressions (7) to (15) we have

$$x_i = \ell n\ T_j \quad \text{and} \quad y_i = \ell n\ \ell n\ \frac{1}{|100-(MR)_j|/100} \qquad (16)$$

and the least squere method gives (table 2)

$$\beta = a = 5{,}95980$$

and

$$\eta = \exp(b/\beta) = \exp(-39{,}07265/5{,}95980) = 703{,}476 \text{ min.}$$

By the substitution of values of β and η into expressions (1) to (5) the

Table 3.

i	t_i	R(t)	F(t)	f(t)	λ(t)
1	350	0,9845219	0,0154781	0,0041498	0,0002656
2	400	0,9660191	0,0339809	0,0046535	0,0005151
3	450	0,9326216	0,0673784	0,0050542	0,0009238
4	500	0,8774785	0,1225215	0,0052837	0,0015579
5	550	0,7940073	0,2059927	0,0052592	0,0024995
6	600	0,6788014	0,3211986	0,0048992	0,0038483
7	650	0,5356583	0,4643417	0,0041931	0,0057238
8	700	0,3787382	0,6212618	0,0031928	0,0082663
9	750	0,2311433	0,7688567	0,0020877	0,0116392
10	800	0,1162761	0,8837239	0,0011202	0,0160303

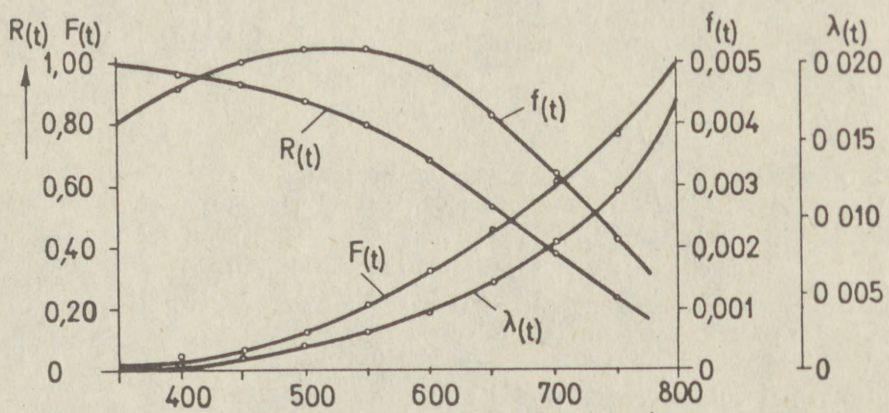


Fig. 4.

following probability function F(t), reliability R(t), frequence f(t), intensity of failure λ(t) and mean time to failure T_m

$$F(t) = 1 - \exp\left[-(t/703{,}4760)^{5{,}9598}\right] \quad (17)$$

$$R(t) = \exp\left[-(t/703{,}4760)^{5{,}9598}\right] \quad (18)$$

$$f(t) = (1/118{,}03685)(t/703{,}4760) \cdot \exp\left[-(t/703{,}4760)^{5{,}9598}\right] \quad (19)$$

$$\lambda(t) = (1/118{,}03685)(t/703{,}4760)^{4{,}9598} \quad (20)$$

$$T_m = 703{,}4760\ \Gamma(1/5{,}9598 + 1) \quad (21)$$

$$T_m = 652{,}3 \text{ min}$$

In order to drawn the relationships (17) to (20) it is necessary to divide the time period Δt in which the failures are expected into time intervals δt so that

$$\Delta t/\delta t = k = \text{const.} \; ; \; 5 \leq k \leq 10$$

For each time delimiter of the intervals the values are calculated according to (17) to (20) using the table 3. The diagram on Fig. 4 is made on the basis of table 3.

5.0 CONCLUSIONS

On the basis of the foregoing the following conclusions could be drawn:

- the suggested methodology allow the determination of cutting-tool reliability for all the types of production,
- the methodology proposed, based on the medial rank, enables the determination of the cutting-tool reliability using the small amount of failure data,
- pure graphical procedure, based on standard Weibull's probabilistic paper, application enables fast data processing and
- by higher values of the shape parameters the difficultes rise by reading off, and in this cases the graphoanalitical procedure are sugested.

REFERENCES

1. SEKULIĆ S., Statistical formulation of cutting tool reliability in a working conditions, Proc. XXI EOQC-Vama '77, Stream C, 2570270, 1977
2. SEKULIĆ S., Determination of tool quantum for application on the basis of tool reliability, Int. J. Prod. Res., Vol. 16, No. 1, 51-61, 1978.
3. SEKULIĆ S., Cost of cutting tools and total machining costs as a funktion of the cutting tool reliability in automatic flow lines, Int. J. Prod. Res., Vol. 20, No. 2, 187-200, 1982.
4. SEKULIĆ S., Methodologies for determination of cutting tool reliability, Drugie miedzynarodnowe sympozijum NERZEDZIA '84, Politechnika krakowska, Krakow-Janovice, 160-164, 1984
5. SEKULIĆ S., Determination of cutting tool reliability on flexibile automatic flow lines, Toward the factory of the future, Proc.of the 8-th Int. conf.onprod.Res.-ICPR'85,august 1985, Stuttgart,163-168, 1985

3-D SOLID MODELING FOR SWEPT VOLUME OF NC TOOL MOVEMENT

Yoshiyuki SHIROMA*, Koichi IWATO**
Yukinori KAKAZU+ and Norio OKINO++

* Department of Electronic and Information Engineering, School of Engineering, Hokkaido Tokai University, Sapporo, 005, JAPAN
** Seiko Instruments Inc. koto-ku, kameido, Tokyo, 136, JAPAN
\+ Department of Precision Engineering, Faculty of Engineering, Hokkaido University, Sapporo, 060, JAPAN
++ Department of Applied System Science, Faculty of Engineering, Kyoto University, Kyoto, 606, JAPAN

Abstract: This paper presents a method for generation of the swept volume formed by the movement of the NC cutter. A generalized sweeping method is proposed and applied to generate the swept volume. The idea is as follows. An imaginary plane cross-section is set in the middle of the tool path. Then the NC cutter leaves its trace on the plane when the cutter goes through it. Since the trace, called the enveloped pattern, turns out to be a closed curve with maximum profile, it can be used reversely for generation of an entire swept volume. Namely, the enveloped pattern is swept along the tool path to generate an entire swept volume. As a result, the entire swept volume is generated as a set of space points which belong to the inside of the enveloped pattern from the start to the end of the cutter motion. The algorithm of this work has been developed and performed with the CSG-based CAD/CAM system TIPS-1.

1. Introduction

With the advance of NC machine tools, the NC machining has been widely used in manufacturing stage of industrial goods. The NC machining provides simpler, repeatable, and quick ways to cut the desired part out of a block of material. The correctness of the NC code, however, is often uncertain. Thus one of the most important problems to be solved for the NC machining is how to verify the correctness of the NC code. The computer based simulation has been considered to be an actual and a simple ways to verify the NC code, and actually *the point model method* has been applied. In the point model method, the tool path (i.e., the trajectory curve formed by the movement of the cutter control point) is displayed and verified by the know-how and sense of imagination that NC programmers must use when operating the NC machine tool. This method is very simple, inexpensive and actually useful for brief verification of the simple program with the 3-axis motion of the NC machining. It is very difficult, however, to verify the complicated program with the 5-axis motion, because this method cannot take the cutter orientation and the cutting surface into consideration. This is due to the adoption of the point model instead of the solid one of the NC cutter. In order to conquer the disadvantage of the point model method, a solid modeling based NC

machining-process verification is required.

Some attempts have been reported[1][2][3][4] recently for the NC verification. In these attempts, the swept volume formed by the movement of the NC cutter has been handled and displayed by means of rendering techniques such as Scan Line algorithm[1], Z-buffer algorithm[2], Voxel representation[3], and Dexel hardware technique[4]. Though the rendered image of the swept volume is actually useful for visual verifications, the rendered image cannot be used for more advanced applications. For example, it is impossible to do set operations between the rendered image and the internal solid models of its environments even though such operations are often required in the NC machining-process verification. From the viewpoint of modeling consistency, the swept volume should be represented internally in accordance with the ordinary solid shape. Thus this work has been started to aim at verifying the NC machining-process by CSG scheme.

In order to verify the NC machining-process by CSG scheme, the solid modeling of the swept volume formed by the movement of the NC cutter is essential. Therefore, to generate the swept volume, we shall apply a new method[5] based on a generalized sweeping method.

2. Description of the problem

Let us consider now a moving solid object as illustrated in Fig.1. Let P be the moving object, and $t(t_0 \le t \le t_1)$ be a motion parameter which designates time instances of the motion, and the initial and final instances of the motion be designated by t_0 and t_1 respectively. It is assumed that the orientation of the moving object and the moving path are given. Let $P=P(t)$ be a set of space points which belong to the inside of the moving object at the time t. Then the swept volume is considered to be the totality of space points which belong to the inside of the moving object from the start to the end of the motion. Thus the swept volume, denoted by S_v, can be defined as follows:

$$\left.\begin{aligned} S_v &= P(t_0) \cup P(t_0+\Delta t) \cup \cdots \cup P(t_1) \\ &= \bigcup_{t=t_0}^{t_1} P(t), \end{aligned}\right\} \quad (1)$$

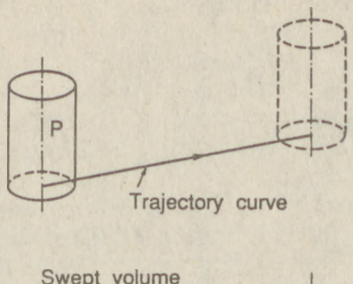
where $\cup$ is a union operator. The problem of generating the swept volume as defined in Equation(1) is considered to be that of determining the envelope which is formed by the movement of the surface of the object. In order to determine the envelope, we shall define the moving object by its bounding surfaces. Then the moving object P can be defined as follows:

$$\left.\begin{aligned} P &= P_1^v \cup P_1^s \cup P_2^s \cup \cdots \cup P_n^s \\ &= P_1^v \cup \left\{ \bigcup_{i=1}^{n} P_i^s \right\}, \end{aligned}\right\} \quad (2)$$

where P_i^s $(i=1,2,\cdots,n)$ are bounding surfaces of P, and P_1^v is the solid shape of P bounded by these surfaces. (See Fig.2.) Then the swept volume S_v can be composed of P_1^v and a couple of swept volumes formed by the movement of the bounding surfaces P_i^s $(i=1,2,\cdots,n)$. Thus the swept volume S_v can also be defined as follows:

$$S_v = P_1^v \cup \left\{ \bigcup_{i=1}^{n} \overline{P}_i^s \right\}, \quad (3)$$

where $\overline{P}_i^s$ $(i=1,2,\cdots,n)$ are swept



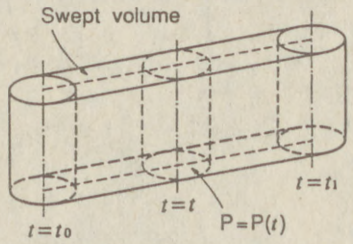


Fig.1. The moving solid object and its swept volume.

volumes of the bounding surfaces P_i^s $(i=1,2,\cdots,n)$, and are called the sub-swept volumes, for convenience. Since each sub-swept volume consists of a set of space points, it can be expressed as

$$\left.\begin{aligned}\overline{P}_i^s &= P_i^s(t_0)\cup P_i^s(t_0+\Delta t)\cup\cdots\cup P_i^s(t_1)\\ &= \bigcup_{t=t_0}^{t_1} P_i^s(t)\,.\end{aligned}\right\} \quad (4)$$

In Equation(3), P_1^v is considered to be the moving object itself at the initial position; namely, $P_1^v = P(t_0)$. Thus the P_1^v can be addressed by the ordinary Primitives. Therefore, the problem to generate the swept volume S_v is reduced to that to generate the sub-swept volumes $\overline{P}_i^s$ $(i=1,2,\cdots,n)$.

Based on our study, if and only if we adopt a solid with the surface of revolution (i.e., sphere, cylinder, ball-end milling cutter shape, and so on) for the moving object, only the characteristic curve is concerned for generation of the sub-swept volume formed by

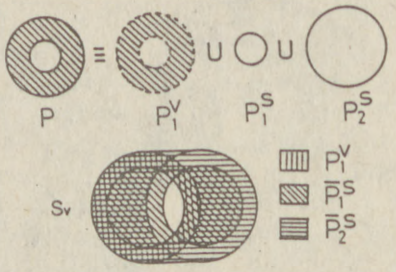


Fig.2. Decomposition of the moving solid object and the composition of the swept volume.

the movement of the surface of revolution. Thus we shall derive the characteristic curve of the NC cutter shape in the next section.

3. Parametric representation of the characteristic curve

Let the family of surfaces be given by $f(x,y,z,t)=0$, where t is the family parameter which is constant for any given surface. Then the characteristic curve of the surface for the parameter t is defined by the simultaneous equations expressed as,

$$\left.\begin{aligned}&f(x,y,z,t)=0\,,\\ &\frac{\partial}{\partial t}f(x,y,z,t)=0\,.\end{aligned}\right\} \quad (5)$$

In order to determine the envelope, the simultaneous equations must be solved by eliminating a family parameter t from them. If the shape of the moving object and its motion are restricted to the simple case, the equations can be solved analytically. In general, it is very difficult, however, to solve the equations analytically. Thus we shall use the parametric representation of the characteristic curve instead of Equation(5) for generation of the swept volume. We assume that the solid with the surface of revolution is adopted for the NC cutter shape.

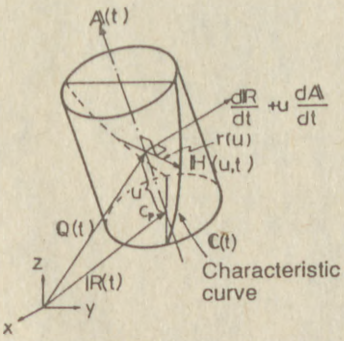


Fig.3. The characteristic curve of the NC cutter.

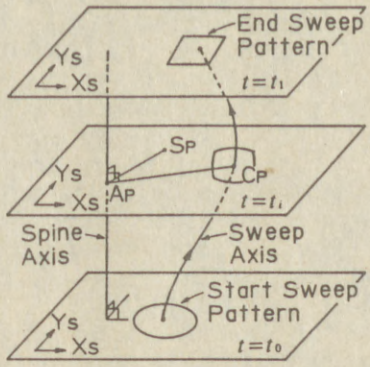


Fig.4. Sweep parameters of the proposed sweeping method.

It is assumed that the position and the orientation of the NC cutter are represented by the trajectory curve of the representative point (i.e., the cutter control point on the axis of the revolution) and by the orientation of the axis of the revolution respectively. Then the characteristic curve, denoted by $C(t)$, can be represented as follows:

$$C(t) = R(t) + u \cdot A(t) + r(u) \cdot H(u,t) , \qquad (6)$$

where,

$$\left.\begin{aligned} Q(u,t) &= R(t) + u \cdot A(t) , \\ H(u,t) &= \frac{\partial Q}{\partial t} \times A \Big/ \left| \frac{\partial Q}{\partial t} \times A \right| , \\ A &\neq k(\partial Q/\partial t) , \quad (k = const.) . \end{aligned}\right\} \qquad (7)$$

Here $R(t)$ is a position vector of the cutter control point C_P, and $A(t)$ is a vector of the axis of revolution. $H(u,t)$ is a vector which is perpendicular to both the vectors $A(t)$ and $\partial Q/\partial t$ as shown in Fig.3. The parameter u designates the distance from the cutter control point C_P to an objective point on the axis $A(t)$, and $r(u)$ is the radius of the NC cutter on the plane cross-section at $u=u$. Theoretically, if the characteristic curve $C(t)$ is calculated from $t = t_0$ to $t = t_1$, the sub-swept volume formed by the movement of the surface of revolution of the NC cutter can be generated. Similarly, if the characteristic curves of both the top and bottom surfaces of the NC cutter are calculated, the corresponding sub-swept volumes can be generated. Actually, there is no established way, however, to generate the sub- and the entire swept volumes directly from the calculated characteristic curve. Therefore, we propose a generalized sweeping method for generation of the swept volume. In the next section, the sweeping method is described.

4. A Generalized sweeping method for CSG-based solid modeling

A generalized sweeping method for the CSG modeling is proposed. For applying this method, three kinds of sweep parameters should be given; *Sweep Pattern*, *Sweep Axis*, and *Spine Axis*[6][7], as illustrated in Fig.4. The roles of each parameter are as follows:

- Sweep Pattern is a 2-D convex closed curve which is defined on a plane cross-section, and is swept through 3-D space. We

refer to the cross-section as the XsYs-plane, where the axes on the plane are denoted by Xs and Ys.

- Sweep Axis is an axis along which the Sweep Pattern is swept in 3-D space, and is considered to be a trajectory curve of a representative point of the Sweep Pattern. We assume that the representative point, denoted by C_p, is positioned at the inside of the Sweep Pattern.
- Spine Axis provides the definition of the XsYs-plane. Namely, normal plane of the Spine Axis is used for the XsYs-plane. The rule how to define the XsYs-plane can be used as a substitute for the Spine Axis, when the Spine Axis cannot be given explicitly.

In the conventional sweeping method, both the Sweep and Spine Axes are unified. In this method, however, these two are separated in order to extend the capability of geometric representation.

5. Definition of the enveloped pattern

Let us consider an imaginary plane cross-section in the middle of the tool path. Let L be the cross-section at the time t, as illustrated in Fig.5. When the NC cutter goes through the cross-section, it leaves a trace on the cross-section. In general, this trace turns out to be a closed profile curve, and the shape and the dimension of the profile curve are varied in accordance with the position of the NC cutter. Let us define the profile curve. We assume that the NC cutter leaves its trace on the cross-section L from $t = t_i$ to $t = t_j$, where

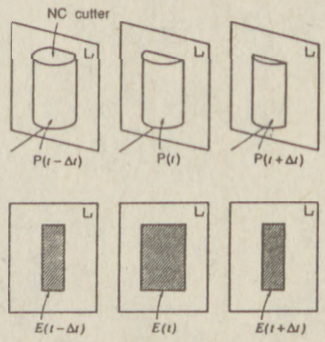


Fig.5. The enveloped pattern.

$(t_0 \le t_i \le t \le t_j \le t_1)$. Let $E(t_i)$ be the profile curve left by the NC cutter at $t = t_i$. Then the union set of all the profile curves on the cross-section L are

$$\left.\begin{aligned} E_p &= E(t_i) \cup E(t_i + \Delta t) \cup \cdots \cup E(t_j) \\ &= \bigcup_{t=t_i}^{t_j} E(t) . \end{aligned}\right\} \quad (8)$$

The union set E_p constructs the 2-D pattern with the maximum profile. This pattern is called *the enveloped pattern*. As the swept volume S_v is composed of the sub-swept volumes, so is the enveloped pattern composed of sub-enveloped patterns left by the individual bounding surfaces of the NC cutter. Let E_i^s $(i = 1,2,\cdots, n)$ be the sub-enveloped patterns corresponding to the bounding surfaces of the NC cutter. Then the enveloped pattern can also be defined as

$$E_p = E_1^s \cup E_2^s \cup \cdots \cup E_n^s = \bigcup_{i=1}^{n} E_i^s . \quad (9)$$

Equations(8) and (9) suggest that there are two methods for the derivation of the enveloped pattern. We adopt the derivation method based on Equation(9) in this work. The sub-enveloped pattern defined in Equation(9) is

composed of traces left by the characteristic curves of the surfaces of the NC cutter. Thus the determined characteristic curve is used for derivation of the sub-enveloped pattern. The enveloped pattern is used as the Sweep Pattern in the proposed sweeping method. Namely, if the enveloped pattern E_P can be derived, the swept volume S_V can be generated reversely by sweeping the enveloped pattern along the tool path. This is the principle of the application of the sweeping method to generate the swept volume.

6. Classification of the shape and the motion of the NC cutter

6.1 The NC cutter shapes

The prepared NC cutter shapes are illustrated in Fig.6; namely, a sphere, a cylinder and the ball-end milling cutter. A cylinder can be used as the flat-end milling cutter. Since the shape of the ball-end milling cutter is represented by the union set of the sphere and the cylinder, the enveloped pattern of the ball-end milling cutter can be represented by that of the sphere and the cylinder.

6.2 The NC cutter motion

The motion of the NC cutter is classified on the following assumptions:

- The tool path is given as the trajectory curve of the cutter control point C_P.
- The motion of the NC cutter is represented by that of the axis of revolution $A(t)$.
- The trajectory curve and the cutter motion are given in the local coordinate system fixed to the NC cutter.

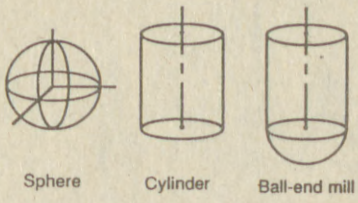


Fig.6. The NC cutter shapes.

Then the motion of the NC cutter is classified as,

(A) The case where $dA/dt = 0$,

(B) The case where $dA/dt \neq 0$.

The case (A) means that the direction of the NC cutter is always constant during the motion. Reversely, in the case (B), the direction of the NC cutter varies during the motion. These two cases are classified in detail as follows:

$$(A-1) \ : \ A \cdot (dR/dt) = 0 \ .$$

$$(A-2) \ : \ A \times (dR/dt) = 0 \ .$$

$$(A-3) \ : \ \begin{cases} A \cdot (dR/dt) \neq 0 \ , \\ A \times (dR/dt) \neq 0 \ . \end{cases}$$

$$(B-1) \ : \ \left(A \times \frac{dR}{dt} \right) \times \frac{dA}{dt} = 0 \ .$$

$$(B-2) \ : \ \left(A \times \frac{dR}{dt} \right) \cdot \frac{dA}{dt} = 0 \ .$$

$$(B-3) \ : \ \begin{cases} \left(A \times \dfrac{dR}{dt} \right) \times \dfrac{dA}{dt} \neq 0 \ , \\ \left(A \times \dfrac{dR}{dt} \right) \cdot \dfrac{dA}{dt} \neq 0 \ . \end{cases}$$

These classified motions are illustrated in Fig.7 respectively. Hereafter, we refer to the case (A-1) as the (A-1) motion, and the other cases are referred to in the same form. The (A-1) motion means that the NC cutter moves in a direction perpendicular to the axis $A(t)$. The (A-2) motion means that the NC cutter moves in a direction to the axis $A(t)$. The (A-3) motion is the general case where $dA/dt = 0$ except the motions

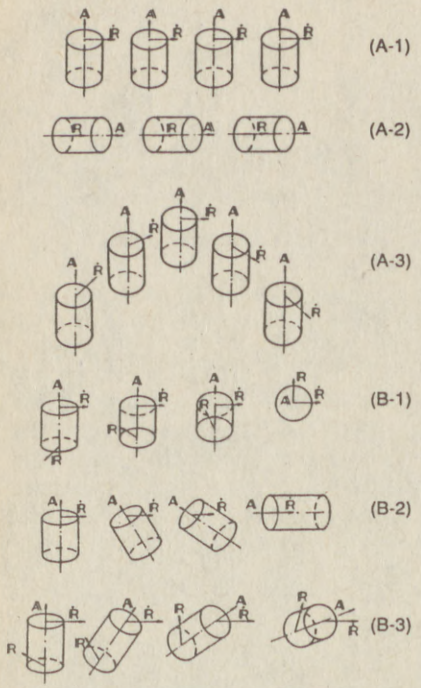


Fig.7. The classified motions of the NC cutter.

(A-1) and (A-2). In the (B-1) motion, the NC cutter falls down in a direction perpendicular to the tangent of the tool path during the motion. The (B-2) motion means that the NC cutter falls down in a direction to the tangent of the tool path during the motion. The (B-3) motion is the general case where $dA/dt \neq 0$ except the motions (B-1) and (B-2).

7. Derivation of the enveloped pattern

7.1 Settlement of the XsYs-plane

The rule how to define the XsYs-plane is used instead of the Spine Axis in this work. Here we shall clarify the rule. Let us consider now the NC cutter at the time t, as illustrated in Fig.8. Let $\dot{\mathbf{R}} = d\mathbf{R}/dt$ be a tangent vector of the tool path at the control point Cp. A

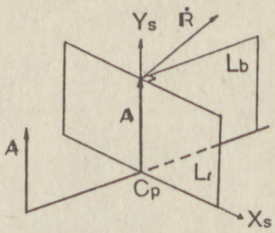


Fig.8. Settlement of the XsYs-plane.

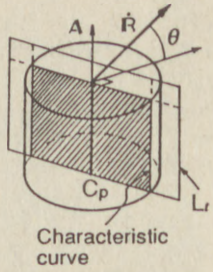


Fig.9. The sub-enveloped pattern of the cylindrical surface.

plane, denoted by Lb, is defined so as to include the vector $\dot{\mathbf{R}}$ and the axis $A(t)$. Then a plane Lt, which includes the axis $A(t)$ and is perpendicular to the plane Lb, can be defined and is used as the XsYs-plane, where the control point Cp is considered to be the origin of the plane and $A(t)$ is used as the Ys-axis. Thus the Xs-axis is set in a direction perpendicular to the Ys-axis.

7.2 The enveloped pattern for the case where $dA/dt = 0$, $A \cdot (dR/dt) \neq 0$, and $A \times (dR/dt) \neq 0$

We shall derive the enveloped pattern for the case where the tool path is a straight line in the (A-3) motion.

Let a cylinder be the flat-end milling cutter, and Lt be the XsYs-plane at the time t, as illustrated in Fig.9. Let θ be the angle between the vector $\dot{\mathbf{R}}$ and the top surface of the cylinder. When the vector $\dot{\mathbf{R}}$ directs to the upper side of the top surface of the cylinder, the sign of θ is positive. Reversely, if the vector $\dot{\mathbf{R}}$ directs to the lower side of the top surface, the sign of θ is

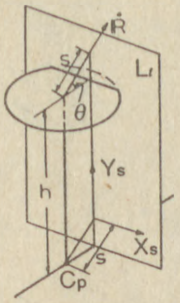


Fig.10. Derivation of the sub-enveloped pattern left by the top surface of the cylinder.

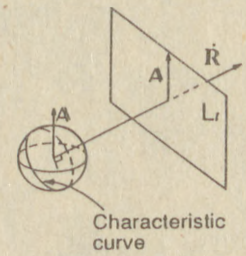


Fig.11. Characteristic curve of the sphere.

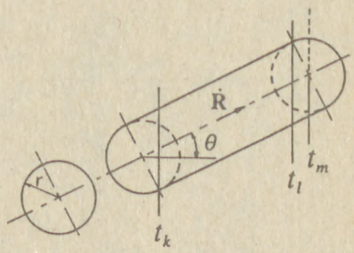


Fig.12. The swept volume formed by the linear movement of the sphere.

negative. In the case mentioned above, the characteristic curves of the cylindrical surface are straight lines, and appear as the intersection lines of the cylinder and the XsYs-plane. Thus the sub-enveloped pattern left by the cylindrical surface becomes a rectangle, as shown in Fig.9. (See the shaded area.)

Let us derive the sub-enveloped pattern formed by the top surface of the cylinder. In order to express the sub-enveloped pattern, a parameter s is introduced. This parameter distinguishes the proceeded distance of the cutter control point Cp during the time Δt. The top surface of the cylinder at $t = t - \Delta t$ leaves a trace on the XsYs-plane at $t=t$, as illustrated in Fig.10. Then the sub-enveloped pattern of the top surface of the cylinder is expressed as

$$\left.\begin{aligned} Y_s &= h + s\cdot\sin\theta \quad , \\ X_s &= \pm\sqrt{r^2-(s\cdot\cos\theta)^2} \quad , \end{aligned}\right\} \quad (10)$$

where r is the radius of the cylinder, and h is the distance between the control point Cp and the top surface of the cylinder. In Equation(10), if the objective sub-enveloped pattern is left by the top surface of the cylinder at $t = t - \Delta t$, then $s = -|s|$. Reversely, if the objective sub-enveloped pattern is left by the top surface of the cylinder at $t = t + \Delta t$, then $s = |s|$. By eliminating the parameter s from Equation(10), the sub-enveloped pattern is obtained as follows:

$$X_s = \pm\sqrt{r^2 - \left(\frac{Y_s - h}{\tan\theta}\right)^2} \quad , \qquad (11)$$

where $\tan\theta \neq 0$. As a result, the sub-enveloped pattern of the top surface of the cylinder is an ellipse.

The characteristic curve of the sphere with radius r appears on the plane perpendicular to the vector $\dot{\mathbf{R}}$, and is a circle with radius r, as illustrated in Fig.11. Thus the swept volume formed by the linear movement of the sphere becomes a cylinder as shown in Fig.12, where the direction of the axis of the cylinder is the same as the vector $\dot{\mathbf{R}}$. But this cylinder does not include the remained volume at the initial and final positions of the sphere. In Fig.12, the sub-enveloped pattern of the sphere becomes an ellipse within the moving section from t_k to t_l, and its equation is as follows:

$$X_s^2 + (Y_s\cdot\cos\theta)^2 = r^2 \, . \qquad (12)$$

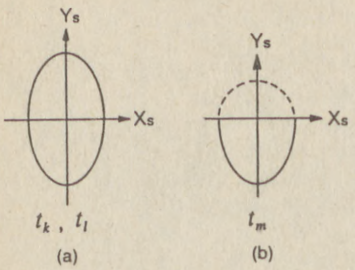


Fig.13. The sub-enveloped pattern of the sphere.

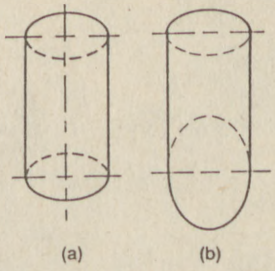
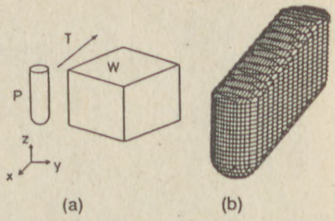


Fig.14. The derived enveloped patterns of the flat-end and the ball-end milling cutters.



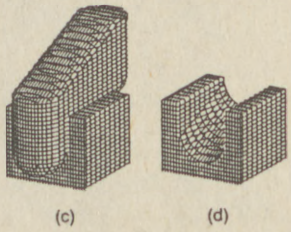


Fig.15. The swept volume of the ball-end milling cutter and its interference with the workpiece.

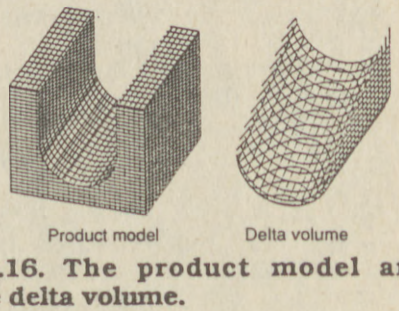


Fig.16. The product model and the delta volume.

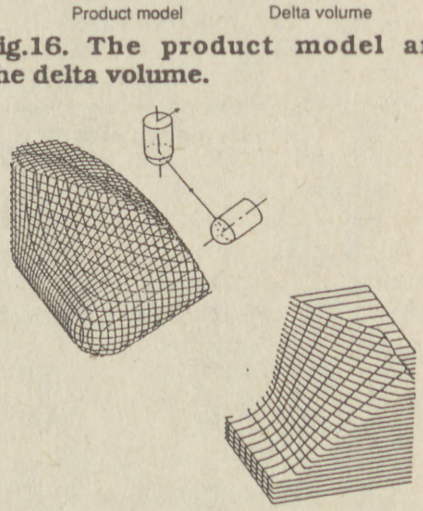


Fig.17. The example of the (B-1) motion.

Fig.13-(a) shows this sub-enveloped pattern. When the moving sphere is positioned nearby the terminal point of the motion (for instance, at t_m in Fig.12), the sub-enveloped pattern of the sphere is constructed by a circle and an ellipse, as illustrated in Fig.13-(b). Consequently, the enveloped patterns of both the flat-end and ball-end milling cutters are shown in Figs.14-(a) and (b) respectively. This derivation method is applicable to the other cases.

8. Experiments

In order to prove the correctness of the derived equations and to verify the effectiveness of the applied method, the computational algorithm has been developed and performed with the CSG-based CAD/CAM system TIPS-1[8] on the HITAC-M280 computer. Fig.15 through Fig.17 show examples of the 3-D solid model of the swept volume formed by the movement of the NC cutter. Fig.15-(a) shows the NC cutter P, the workpiece W and the tool path T. The swept volume S_V formed by moving the NC cutter along the tool path can be generated as shown in Fig.15-(b). Actually, this swept volume was generated by sweeping the enveloped pattern along the

straight line. The interference between the swept volume and the workpiece can be calculated and displayed as shown in Fig.15-(c). If the swept volume is subtracted from the workpiece, we can get the machined part as shown in Fig.15-(d). Similarly, if the product model is subtracted from the machined part, the delta volume being removed can be obtained as shown in Fig.16. As these geometric model are represented consistently by CSG scheme, the interference between the NC cutter and its environments can be calculated not only for visual verifications but also for the quantitative one. The NC cutter motion used in Figs.15 and 16 is the case (A-3). The example of the (B-1) motion is shown in Fig.17, where the straight line is used as the tool path.

9. Conclusion

A method for generation of the swept volume formed by the movement of the NC cutter is presented. A generalized sweeping method is proposed and applied to generate the swept volume. In the applied method, the enveloped pattern is introduced and used as the Sweep Pattern. Namely, the entire swept volume is generated by sweeping the enveloped pattern along the tool path. The enveloped pattern is composed of traces left by the characteristic curves of the surfaces of the NC cutter. Thus how to derive the enveloped pattern from the characteristic curve is clarified. The computational algorithm of this work has been developed and performed with the CSG-based CAD/CAM system TIPS-1. From the experiments, it is clear that the method applied to generate the swept volume is effective enough, and that the generated swept volume can be handled just like the ordinary Primitives. As the swept volume has the same internal representation with the ordinary Primitives, it can be used not only for visual verifications of the NC machining-process but also for more advanced applications.

References

[1] Jerard, R.B. et al., "Methods for Detecting Errors in Numerically Controlled Machining of Sculptured Surfaces," IEEE CG & A, Vol.9, No.1(1989), pp.27-39.

[2] Wang, W.P. and Wang, K.K., Geometric Modeling for Swept Volume of Moving Solids," IEEE CG & A, Vol.6, No.12(1986), pp.8-17.

[3] Kishinami, T., Kanai, S., and Shinjyo, H., "An Application of Voxel Representation to Machining Simulator," J. of J.S.P.E., Vol.55, No.1(1989), pp.105-110. (in Japanese)

[4] Hook, T.V., "Real-Time Shaded NC Milling Display", Proc. SIGGRAPH '86, Vol.20, No.4(1986), pp.15-20.

[5] Shiroma, Y., Kakazu, Y., Iwato, K., and Okino, N., "Basic Researches on N/C Machining Simulator (Modeling of Cutter Movement Trajectory)," Trans. JSME, Vol.50, No.452, Series C, (1984), pp.697-706. (in Japanese)

[6] Shiroma, Y., Watabe, H., Kakazu, Y. and Okino, N., "A Study on 3-D Solid Modeling of Fillet Volume by CSG Representation - On the Fillet of Intersection Line between Two Quadratic Surfaces -," J. of J.S.P.E., Vol.53, No.2 (1987), pp.116-122. (in Japanese)

[7] Shiroma, Y., Kakazu, Y. and Okino, N., "Blended Free-Form Primitives for CSG modeling," Proc. ICPE '88 BEIJING, Beijing, CHINA, September, (1988), pp.287-293.

[8] Okino, N., Kakazu, Y., and Kubo, H., "TIPS-1 : Technical Information Processing System for Computer-Aided Design, Drawing and Manufacturing," Computer Languages for Numerical Control, Hatvany, J. ed., North-Holland, Amsterdam, (1973), pp.141-150.

CIM INNOVATION PROCESS IN THE F.R.G.

Dr.-Ing. Dietrich Stams
Kernforschungszentrum Karlsruhe GmbH
Projektträger Fertigungstechnik
Postfach 36 40
D-7500 Karlsruhe 1

1. Introduction

In the F.R.G. the CIM innovation process started in many companies with many different approaches depending on their special situation, their aims and their tasks.
The Commission of the European Communities, the governments of many European countries and also the government of the F.R.G. are running programmes to initiate and accelerate these innovation processes.

This paper is to show the reasons and perspectives of this development and the ideas and concepts of the F.R.G. government CIM-programme. The results and experience gained so far shall be indicated. The goal of this paper is to contribute to the discussion of development, cooperation and promotion of CIM within Europe.

The view-point of this paper is based on the work of the author. He is the head of the management agency which is responsible for organizing and running this F.R.G. CIM-programme. This agency is a department within the Kernforschungszentrum Karlsruhe and consists of 25 scientists and 15 accountants. The financial budget of this programme is about 500 Mio DM for the runtime of 5 years from 1988 - 1992.

2. The reasons and perspectives of the CIM innovation process in the F.R.G.

In the F.R.G. more than 30,000 enterprises move in the field of consumer and investment goods production.
The small and medium sized companies are playing a dominant role as the following figures show:

	Size of the companies/numbers of employees[1]				
	< 199	200 - 499	500 - 999	> 1000	Sum
Number of companies	25,951	3,111	980	693	30,735
Total number of employees	1,554,329	953,883	682,721	1,914,176	5,105,109

The market situation for consumer and investment goods has changed from a sellers' market into a customers' market. Only those companies have a chance to survive which are able to find and realize solutions with a maximum benefit for their customers in the shortest time.

The consequence for these companies is a fundamental change of the requirements for manufacturing in the direction of

- more customer specific offers that are better and elaborated in more detail in a shorter time with accurate information about delivery time and price conditions as before
- design and manufacturing of such customer oriented solutions
- shortest and absolutely reliable time for delivery
- quality as expected by the customer
- a very good after-sales-service
- considerable price range.

In the past, big batches with lowest prices gave the best basis for competition. This has led to high specialism within the enterprises, very detailed sharing of functions vertically between planning and execution, and horizontally between the different steps of planning or of execution. - Perfect Taylorism, that was the best solution.

Now smaller batches must be produced and much more work must be done for the planning and organization in shortest and guaranteed time scales. This leads to new and better optimized solutions with less specialism, less detailed sharing of functions, more integration together with high quality and flexibility in planning and execution.

Resulting from this is the statement that the most important impact of today's discussion of **"CIM"** is moving away from Taylorism going in the direction of I = **INTEGRATION** of functions.
And the most serious problem of CIM is the misunderstanding of keeping the organization that was optimum for the past (see above) but that is wrong for the present and future, and to freeze this improper organization by implementing C = **COMPUTER** as the supposed means for solving all problems.

The conclusion is the following:
Firstly, one has to understand the new requirements coming from the market and to improve the structure of the enterprise, and secondly, to use computers for a better handling of information in the new structure; that is the potential of CIM. And the problem is to understand and to use this potential.
A second serious problem is that the staff of small and medium sized companies is normally overcharged by the task of planning and implementing CIM-systems. And these companies are - as we have seen above - the most enterprises in the F.R.G.
A third problem is the lack of standards to build up CIM-systems out of modules. This is necessary to get optimum solutions for very different tasks using the best offers and combination of the different modules and to be able to go forward with integration step by step over long time periods because of the high amount of money and man-power needed for this development.

3. The concept of the F.R.G. government CIM-programme

Some of the basic principles of the F.R.G. research and technology policy are
- to create proper frame conditions for a good development of society, of labor and of the enterprises within society in the F.R.G. and in Europe
- to strengthen the individual initiatives and power of the enterprises
- to keep the balance of industrial structures between big, small and medium sized companies
- to strengthen the infrastructure and to improve the co-operation between research and industry
- to accelerate innovative processes
- to support technology assessments
- to initiate and - if necessary - support developments which will create new humane workplaces
- to support developments which create European co-operations.

Based on these principles and on the requirements and problems of the CIM innovation process the CIM-programme of the F.R.G. government has the following main areas

A) CIM technology transfer
B) CIM standardization
C) CIM indirect-specific funding
D) Cooperative future-oriented research projects, especially EUREKA-FAMOS projects
E) Technology assessment

A) CIM technology transfer - "CIM-TT"

As we have seen, the efficiency of the enterprises must change towards more customer related individual products and services with the aim to create the highest benefit for the customer.
This needs more flexible and more in-depth planning and production. Integration, reorganization and, after this, optimum use of integrated computer systems are the main lines of a long term innovation process. This is not yet common knowledge in the F.R.G., but there are advanced enterprises which are on the way to this kind of innovative process.
Another lack of knowledge is in the field of CIM-components like networks, communications, data bases or in the field of CIM implementation strategies and staff qualification.

The European Community is running the so called ESPRIT programme where ESPRIT stands for European Strategic Programme for Information Technology. A lot of basic technology has been developed within this programme and should be transferred to a broad scale of industry. But nevertheless, for the time being it is rather risky and difficult to start CIM projects for the most companies in the F.R.G. Nearly all the working processes have to be considered and eventually changed.

Recognizing the situation that CIM is a very complex technology and that the knowledge of this technology is spread over a not well known number of CIM supplying and CIM applying enterprises, CIM-consultants, research institutes and associations the first aim of the CIM-programme is to activate this knowledge, concentrate it, make it available and start a collective learning process. This is called CIM-TT.

A CIM-TT-Infrastructure was established with the following characteristics:

- Regional: 16 centers spread over West Germany from Kiel in the north to Munich in the south, Berlin in the east and Saarbrücken in the west.
- Interdisciplinarity: 30 institutes are included in this 16 centers, reaching from manufacturing technologies over economics to social science.
- Quality: all universities and Fraunhofer-institutes which are important in this field are participating.
- Demonstration fields in these centers: all market relevant CIM hardware and software is present
- Connections are established to suppliers, consultancies, labor and engineers associations, chambers of commerce.
- Coordination of the work of these centers by the management agency in the Kernforschungszentrum Karlsruhe: documentations and modules for seminars have been worked out for the main topics of CIM as:

- CIM planning, that contains
  - strategic enterprises planning
  - reorganization of the enterprises
  - personal qualification and planning
  - implementation strategies
- CIM components, that contains
  - data bases
  - communication components and systems
  - interfaces
  - simulation tools
  - expert systems
- CIM integration paths
  - CAPP centered integration
  - CAD centered integration

  and other integration paths.

This CIM-TT system is running since middle of 1988; the main experience is: companies urgently need general information for their orientation and, as much as possible, practical demonstrations and exchange of experience between different appliers. Another urgent need is: seminars and discussion for the staff of individual companies related to their specific problems. The CIM-TT approach is going to cover these needs.
A collective learning process of both CIM-TT-centers and companies which execute CIM-projects could be started, which reduces uncertainty and encourages and helps the enterprises to make well prepared steps in direction of well understood CIM.

B) CIM standardization

Integrating the information processing of the functions within the enterprise needs a concept of modularization and interfacing. Due to the fact that the different modules are produced by different CIM component suppliers it is very important to standardize this modularization and interfacing. The F.R.G. government CIM programme funds basic research to support this standardization work.

C) CIM indirect-specific funding supports

- in the special industrial sector of about 4,000 companies which produce manufacturing equipments
- the innovation of their own production process by CIM projects

Both these conditions are called "specific". "Indirect" means that the state hereby does not intend to "direct" selection and influence the kind of funded projects.

This industrial sector of 4,000 enterprises was chosen because of 3 reasons. Firstly, it is very export oriented and will only be able to survive if it is highly innovative. Secondly, this sector is the "supplier of productivity" for the whole area of 30,000 consumer and investment goods producing industry. Thirdly, for a considerable support of a single company funds of several hundred thousands of DM are the lowest sum. A budget is available for several thousands but not for ten-thousands of companies.

1,800 of 4,000 companies asked for subsidies to run their CIM project. Of these, 1,200 were right in time before the funds - 300 Mio DM - were distributed, so that these 1,200 get the support for their CIM project at maximum 300,000 DM (40 % of their expenses).
The detailed regulations for the projects and their financing are such that the enterprises
- have to do a planning phase to study the possibilities and benefits of integration in the sense as discussed before
- have to work with their own staff at minimum with 6 man-months
- get funds for
  - own staff - minimum 6, maximum 24 man-months
  - purchasing integration software modules
  - substitution for non-integratible software
  - consultancy
  - staff qualification measures.

The experience - gained until now - shows that these conditions are helpful. Sufficient and good planning including the strategical, organizational and personal aspects is the first central problem to be solved. It is done more intensively because help for this is provided. The second problem is the qualification of the inhouse staff. Also, this is done better with the help of the programme.
This kind of funding in general is helpful to gain more understanding of the main CIM problems and to make steps towards solving them.

D) Cooperational future oriented research projects

Such projects are selected by special criteria and priorities; therefore they are called "direct" funded projects. A main part of these projects are the EUREKA-FAMOS projects.

EUREKA is a joint initiative of 19 European countries (EC & EFTA) in cooperation with the Commission of the European Communities with the goal of meeting the challenge of modern technologies, improving Europe's competitiveness on the world markets. It was founded in 1985. Its basis is combining European resources, its purpose to initiate cooperative high technology, non-military projects for the development of products, systems, services with a world wide potential.

Within EUREKA the EUREKA "Umbrella Project FAMOS" is an initiative of 17 of these 19 countries together with the CEC in the field of in German "Flexibel Automatisierte Montage Systeme"or in English "Flexible Automated Assembly Systems".
The reason for this initiative is the fact that assembly has become the bottleneck of production in many areas:

- typically 40 % share costs
- often less than 10 % automation

CIM is one of the main tools to improve this situation. The aims of this initiative are:

- less jobs moving to non-European countries
- products and production once lost are brought back
- power for competition is recovered in lost areas especially in strategically important fields.

The FAMOS Working Group was founded by the governments of these 17 countries together with the CEC. It provides help during preparation and running of projects in this field of flexible automated assembly.

The orientation towards technology was worked out first. The result is the so called "FAMOS Reference Model" which consists of a 3-dimensional matrix with

3 horizontal surfaces
- planning
- system
- process

4 vertical columns
- product
- assembly sequence
- assembly equipment
- assembly monitoring

15 application fields
- domestic appliances
- electronic and electrical industry
- food industry
- automotive industry
- wood and furniture industry
- mechanical engineering

etc.

The initiative of the different FAMOS projects comes from industry and research. The FAMOS Working Group gives advice, help and - if possible - nation funds. The result until now:

- 30 projects running for 1 - 3 years
- 40 projects in preparation

The experience of FAMOS projects until now:

- growing understanding between the European parties
- "European surplus" by integrating the specific resources of the European countries
- first significant results mainly based on CIM technologies.

The FAMOS Working Group prepares a EUREKA-FAMOS exhibition on the Hannover Industrial Fair in spring 1991 to show these achievements.

E) Technology assessment

It is well known that innovational processes have many effects on the future development of human work, and the environment, and resources and energy consumption or other main areas of social life.
In the past time one recognized that we have the possibility to apply new technologies in different ways, which may have more or less positive or negative influence on the future developments.

The task of the technology assessment projects carried out in the CIM-programme is to give recommendations for optimum innovation processes and give early indications for possible problems which may occur in the future, the main projects are:

- Changes in work conditions by chained manufacturing systems with modular structure
- Computer aided manufacturing control systems in small batch size manufacturing. Effects on the situation of labor and ways of approaching a humane work design
- Integrated procedure for investment decisions and supervision for complex manufacturing systems
- Effects of product planning and control systems in small and medium-sized enterprises - instructions for designing technology, organization, and personnel economics
- Integrating use of a computer aided technology and qualification structure in mechanical manufacturing - preconditions and approaches for qualification assurance on shop floor level
- Preconditions and approaches for a humane work design in computer aided design and planning processes
- Analysis of effects concerning the indirect-specific funding of CAD/CAM applications
- Analysis of effects concerning the indirect-specific funding for the development of industrial robots, handling systems, as well as of the surrounding intelligent periphery
- Contributions from social sciences to the "CIM-Technology-Transfer" Initiative
- Project groups for joint analyses of effects within the Federal Manufacturing Technologies Programme 1988 - 1992
  1. "Evaluating the indirect specific funding of CIM application"
  2. "CIM implementation and structural innovations in work organization"
  3. "Qualification oriented work organization in development and design as a basis for coping with the introduction of CIM and with product innovation"

I will close with a summary of the main aspects.

1. The change from a sellers' market into a customers' market requires from the enterprises the ability to cover the needs of their customers in the best way possible. This requires an increased ability of planning in all stages of the production process.
   This begins with the elaboration and offer of different appropriate optimized solutions which solve the customer problems in the time requested and ends with an after-sales-service which is an adequate answer to all the problems which may occur to the customer during the application of these solutions. To achieve these ability is the challenge to the enterprises.

2. CIM has an important potential to enable the enterprises to achieve this improvement.
   This requires the full use of the potential of CIM. This means
   - firstly integration within the planning process and between planning and production
   - secondly implementing computer as a powerful tool to support the integration of the planning and production process.

3. The main number of enterprises are medium and small and do not have the expertise to make use of the complete CIM-potential. Therefore the CIM innovation process is being promoted and supported

   - by establishing 16 CIM centers which provide basic information on CIM
   - by supporting research wich promots the CIM standardization process
   - by giving funds for CIM projects especially for creating know-how in the own company, and intensive planning of integration.

4. A great number of companies joined this initiative and is running their CIM project. A collective learning process has begun. It can be expected that during the next 5 years about 1/3 - 1/2 of the companies in the production field will innovate their production processes by using CIM technology.

5. The innovation of assembly towards flexible automation is a special problem with a lot of CIM aspects. In many sectors of production 40 % of the costs are "produced" by assembly, whereas only 10 % of the assembly process are automated.
   A broad European cooperation of 17 countries was started under the "umbrella" of the joint EUREKA-FAMOS initiative.
   30 projects are running. The same number of projects is in preparation.
   The results achieved until now are very promising.
   This initiative will create a reasonable contribution to a joint Europe.

(1) Source: Statistisches Jahrbuch 1988 für die Bundesrepublik Deutschland

DR. NICOLA TODOROV, DR. DIMITAR MATEV
CENTRAL MACHINE TOOL RESEARCH INSTITUTE, BULGARIA

PROBLEMS OF THE COMPUTER INTEGRATION MANUFACTURING IN THE MACHINE BUILDING

A modern tendency in the contemporary development of industry is the transformation of the main approach in the design of management and control of production systems - from the decomposition and distinct separation of the main control and information subsystems towards their mutual interaction, mutual influence and infiltrating.

In firm "ZMM", on the teritory of its Sofia production complex for machine tools, consisting of two research institutes, a powerful plant and a small, modern factory, is planned to be created a computer integrated manufacturing (CIM) system.

The cruical prerequisites for the decision for implementing the CIM philosophy in this production complex are:

1. The presence on one teritory of powerful design and production capacities covering the whole cycle of marketing, designing, process planning, production and expedition of complex products such as machining centres, special machine tools, automatic transfer lines (ATL) and flexible manufacturing systems (FMS);

2. A modern manufacturing shop floors, including one middle-ranged and one small FMS for prismatic parts, one large FMS for rotational parts, a FMS for cutting;

3. The realization of the management, control and information functions on a modern computer technique;

4. The presence of powerful contemporary-equiped CAD/CAM/CAPP laboratories in the research institutes and in the plants;

5. The existence of projects for modernizing of the management information system (MIS) in the main production plant as well as of the casting shop floor, the main warehouse etc.

6. The presence of highly educated and highly qualified staff able to deal with the hazardous tasks of designing and managing of CIM.

As a strategic goal for the further development and prosperity of our production complex we have established - the cruical reducing of the creation cycle of the products as well as increasing 3-4 times the amount of production and its quality while deminishing the cost of the machine tools, flexible machining cells, ATL and FMS.

The analysis of the foreign and home experience shows that for achieving of this goal must be solved the following six basic tasks:

1. Reducing the development cycle of the products;
2. Increasing the market flexibility of the production;
3. Reducing all the stocks in the warehouses;
4. Improving the correctness in fulfilling the obligations according to the contracts by the suppliers and by the customers as well;
5. Increasing the flexibility inside the plant;
6. Improving the quality of the production.

All the problems which arise during the development of the concept for introducing the CIM philosophy in the Sofia machine tool production complex can be grouped in three main sets.

The first group includes the investment problems. It was calculated that in order to solve all the above mentioned main tasks the firm "ZMM" must invest capitals almost equal to the fixed capital formation of the main plant. In the now-existing economic conditions in Bulgaria it is impossible to receive such investments even from the government. As a result of this rigid limitation in the corner of our project was put the step-by-step approach for implementing the CIM concept. The following four principal stages were fixed:

1. Further development of CAD and CAPP (introduction of additional workplaces, creation of graphical and information libraries, automation of other activities etc.) in the research institutes and in the CAD/CAM laboratory in the main plant. Development of the office reference subsystems (personal management, marketing, accounting, material and article inventory etc.) in the MIS. Creating of local area networks (LAN) with their own databases in the two research institutes, in the CAD/CAM laboratory and in the middle-range FMS for prismatic parts in the plant as well as building up an

asynchronous line between the CAD/CAM centres of the machine tool research institute and the small factory for forming tools.

2. Implementing of an integrated engineering system for design of original assemblies and articles. Implementing of office management subsystems (production and business planning, cost calculation) in the MIS as well as connecting of the CAD/CAM/CAPP with the MIS in the main plant. Implementing of a system for monitoring of the production quality as a part of the CAQ control system. Installing of optic lines for the LANs. Creating of a gate connection to the national package-commutation network BULPAK with an interface X.25.

3. Creating of a full-scale integrated engineering system supporting all the CAD/CAPP/CAM activities on the territory of the production complex. Creating of integrated databases. Implementing of the rest of the management and control subsystems (tool management, labour accounting, production control etc.) in MIS. Implementing of computer aided quality control process planning. Connecting the MIS of the plant with the CAD/CAPP/CAM and CAQ systems. Development of the full-range network in the Sofia production complex covering all comprising units as well as installing of special gate devices supporting a connection through the network BULPAK to all partners outside the complex.

4. Further development of the information, standard and technical support of the design and production of machine tools in full corespondance with the CIM philosophy.

After a detailed analysis of several models of CIM the generalized CIM model proposed by Harington [1] was chosen. This model (shown on fig.1) allows the step-by-step introduction of the different computer aided activities which can function as independent subsystems and in the same time are mutually connected and ready for infiltration due to the standard information interfaces.

In this way a satisfactory solution of the investment problems was proposed. It allows to invest available capitals in separate independent information or material systems which can start functioning immediately and in the same time realize in a definite aspect the CIM concept.

The second group of problems is connected with the need of performing certain drastical organizational reforms. Some of the problems here appear as a result of some limitations of the centrally planned economy and they will be eliminated with the introducing of a market-oriented economy. Never-the-less the success of the organizational reforms is highly dependent upon the personal activity of the ruling staff in the Sofia production complex. Another problem connected with the personal qualities of the high managers is the required ability for forecasting the development of the machine tool science and market as well as the capacity for strategic goals correct definition providing a beneficial progress of the whole production complex.

This kind of problems is planned to be solved by an appropriate programm of training for all the ruling strata.

The third group of problems includes the problems concerning the information management. These problems can be divided into three subgroups:

-information exchange problems,
-standartization problems,
-network problems.

The difficulties in the building up of a production management information system have a hardware and software origin:

-in the different subsystems uncompatible hardware is used,
-there is uncompatibility in the signal interchange between the different local control devices - CNC, programable controllers etc.,
-there exist variable transmiting enviroments,
-there is no unification in the creation of information,
-the different computers have different basic software, e.g. operating systems,
-for the realization of the application software are used different programming languages,
-the structure and the control of the information (databases) are application-oriented and so on.

For the recent development of the production systems was typical the information reticance of the "islands of automation". That was an obstacle for achieving a maximum effectivness in the exploitation of the existing manufacturing machines. The natural conclusion is that for achieving a real flexible and

reliable production system we must have such an effective management of the information flow through the chain "marketing-design- production-expedition" as we have reached in the management of the material flow in FMS. The basic idea of the CIM philosophy is to provide an available and suitable for handling information which is created and stored in different subsystems for use in other subsystems which in their turn have the appropriate mechanism for its effective and rational use.

The nature of CIM is so complex that even the notion for the possible interfaces is hazardous. It is further complicated by the necessity of covering of all the functions in all the strata of the production management. On fig.2 and fig.3 are shown the inner information interfaces of the CAPP and CAM systems. These figures give an idea where and how the information is created in the systems. The Harington CIM model includes direct (PPS --> CAM, CAPP --> CAM etc.) and indirect (CAD --> CAPP --> CAM) straight links between the subsystems as well as feedbacks (CAM --> CAPP, CAD --> CAPP --> CAQ --> CAD).

On this stage of CIM design we have chosen this approach for solving the information interchange problems - definition of the origin and the kind of all the information, definition of the necessity for this information in other subsystems and finally optimising the information flow. For instance, let us look at the problems arising in the information exchange between CAPP and CAM. In CAPP is created all the informaton concerning the process plans, the routes and in general the manufacturing of the product in CAM. The structure and content of this straight information flow was defined already in the manual manufacturing. There exist a number of documents for it - process plan card, route cards, schemes, specification for tools and fixtures, assembly card etc. The information in this documents is defined in the creating subsystem and/or function and in most cases is redundant and insufficient simultaneously for the consumer subsystem. For instance, most of the information in the document "Route card" is duplicated in the document "Process plan card", both are created in the CAPP system and contain 128 requisites and never-the-less for the need of the array "Article data" in the CAM system (the information and control system of an FMS for prismatic parts) these two documents are insufficient and a third document "Shop floor route card" is used.

The second problem in this subgroup of problems is the absence of documents and standards defining the "feedback", i.e. the inverse information flow. If we take the same systems CAPP and CAM, the technologist in most cases has no or only too general information about the manufacturing unit (e.g. availability of machine tools, tools, fixtures, even about the capability for manufacturing).

As it is seen from the figures we see the solving of this subgroup of problems in defining of all origins of information, all consumers of information, analysis of the content and structure of it and on that basis optimizing the information flows in the whole system.

The second subgroup of problems origins from the first - lack of national standards for the information exchanged in production system functioning on the principles of CIM.

And the third subgroup of problems is connected with the investment problems as well as with the information exchange problems. The road to solution here was paved by the appearance of the MAP/TOP standards and the production of the corresponding net hardware.

For the correct choice of proper network were carried on analyses of:

-the kind and amount of information circulating in the system,

-the kind of hardware and software used in each subsystem,

-the functioning mode of the network and

-the availability of netware.

The chosen solution was partly described earlier. As a local area network (LAN) was chosen one compatible with ETHERNET and netware compatible with DECNET. The LAN from that kind have sufficient capacity and allow connection of a number of devices without decreasing the productivity when using common resources. The netware provides integration of hardware compatible with that produced by IBM and DEC companies. There exists a software creation possibility for realization of remote communications through the public set with the interface X.25 as well as for emulation of networks from the kind SNA.

In conclusion the designers' conviction is that the implementing of the CIM philosophy in the machine tool production with the existing prerequisites will lead to a totally new production enviroment in the machine building as a whole and to higher economical results.

L I T E R A T U R E

1. Koch J.H., Irgang R. CIM-Schlagwort oder Strategie? Industrie- Anzeiger, No18, 4.3.1986.

2. Todorov N., Matev D., Dimitrov D. Some Information problems of the CAD/CAM Integration in Computer Integrated Manufacturing System. Proceedings of the 1st Conference "CAD - Hardware and Software", Gabrovo, Bulgaria, 28-30 Nov.1989.

3. Computer Integrated Manufacturing System for the Production of Components and Assemblies for Machine Tools, Automatic Transfer Lines, Flexible Manufacturing Cells and FMS. Technical Report, CMTRI(CNIIMM), Sofia, June 1989.

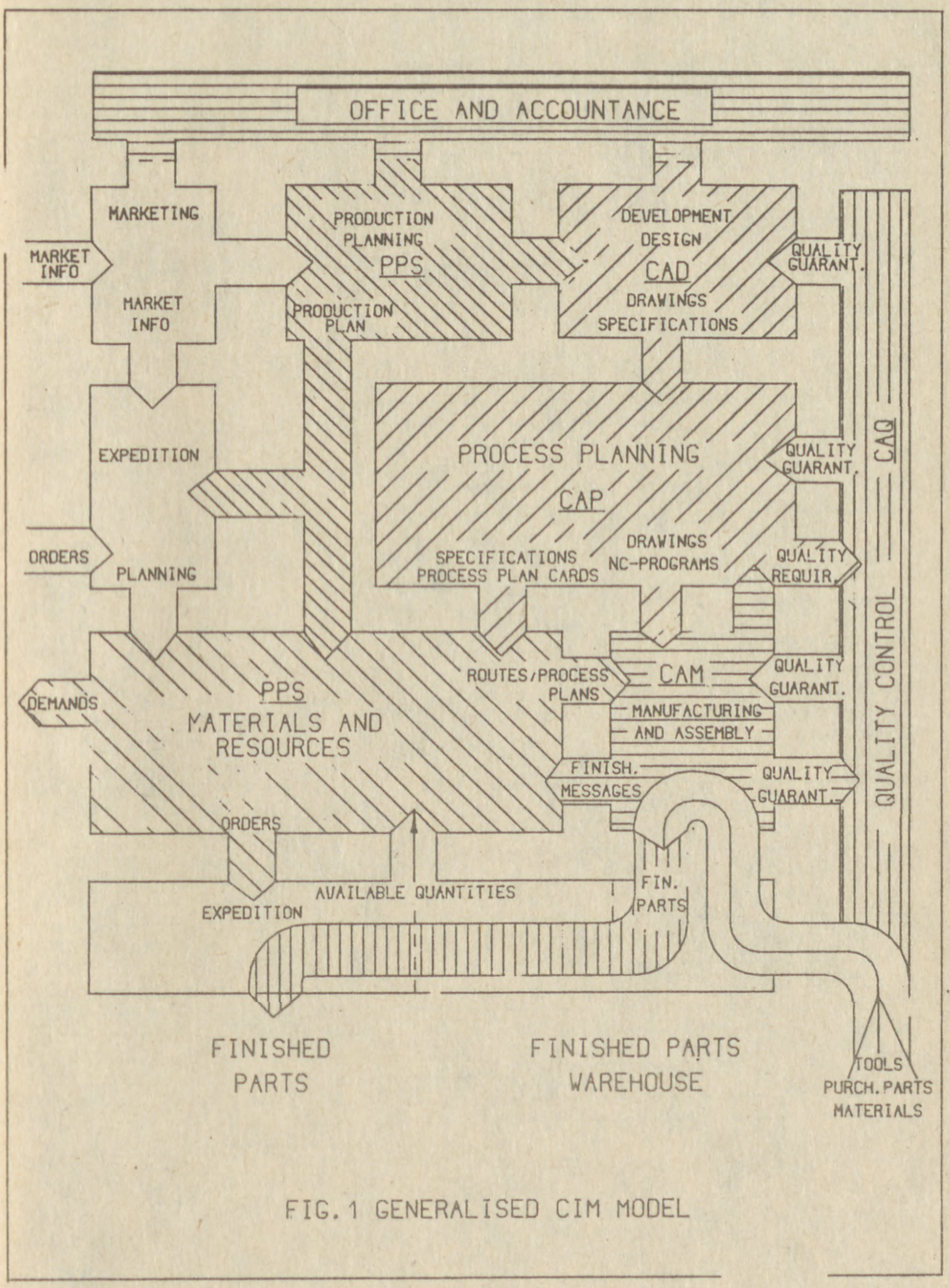
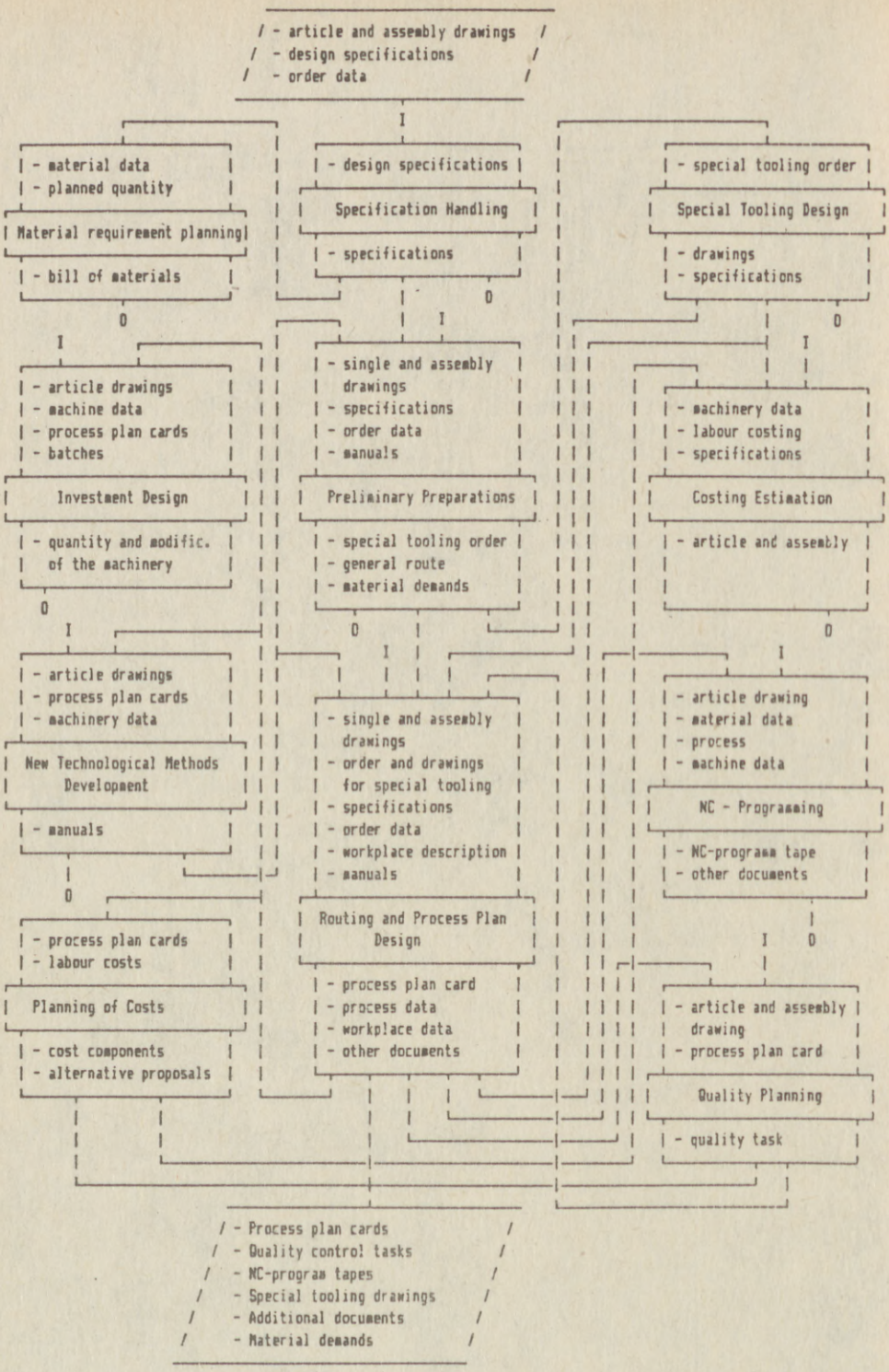


FIG. 1 GENERALISED CIM MODEL


- article and assembly drawings
- design specifications
- order data
- material data
- planned quantity
Material requirement planning
- bill of materials
- design specifications
Specification Handling
- specifications
- special tooling order
Special Tooling Design
- drawings
- specifications
- article drawings
- machine data
- process plan cards
- batches
Investment Design
- quantity and modific. of the machinery
- single and assembly drawings
- specifications
- order data
- manuals
Preliminary Preparations
- special tooling order
- general route
- material demands
- machinery data
- labour costing
- specifications
Costing Estimation
- article and assembly
- article drawings
- process plan cards
- machinery data
New Technological Methods Development
- manuals
- single and assembly drawings
- order and drawings for special tooling
- specifications
- order data
- workplace description
- manuals
- article drawing
- material data
- process
- machine data
NC - Programming
- NC-programm tape
- other documents
- process plan cards
- labour costs
Planning of Costs
- cost components
- alternative proposals
Routing and Process Plan Design
- process plan card
- process data
- workplace data
- other documents
- article and assembly drawing
- process plan card
Quality Planning
- quality task
- Process plan cards
- Quality control tasks
- NC-program tapes
- Special tooling drawings
- Additional documents
- Material demands

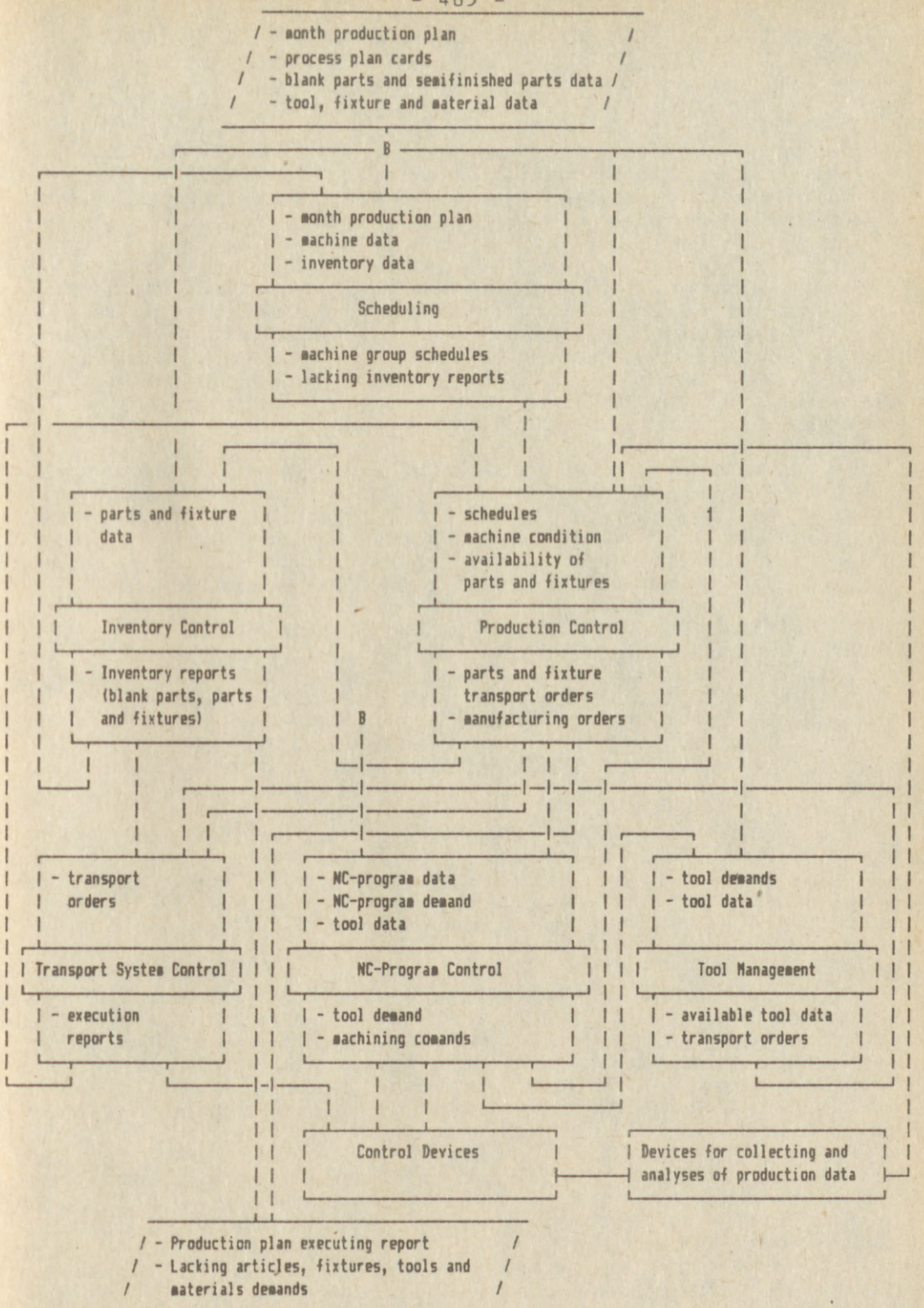


Fig.3 Inner information interfaces in the CAM system

Influences on the economic efficiency of CAD/CAM systems

Sándor Vajna, Weinheim

ABSTRACT
The economic benefits of a CAD/CAM system depend not only on hardware and software performance, but also on staff qualification level and the organization of CAD/CAM activities within a company. A number of such influences and their impact on business efficiency are discussed, and proposals made for maintaining efficient usage.

1. INTRODUCTION

In the introduction of a CAD/CAM system numerous manual processes in product defining areas are replaced by computer-aided processes. Moreover, tasks can be controlled that are insoluble without computer support. Investments in the introduction of a CAD/CAM system are therefore investments in rationalization and expansion. In the prospective determination of business efficiency one assumed initially that CAD/CAM usage would lead to an increase in productivity, resulting in an improvement in profitability and market position, based on enhanced-product quality, increased flexibility and shorter delivery times.

Nowadays it is accepted that CAD/CAM systems are necessary to sustain present business levels (*Diagram 1*). Many customers require computer processing of their orders and the transfer of production data in digital form. Companies that cannot fulfill these requirements lose market share. As a result, decisions concerning the introduction of CAD/CAM technology are made primarily on strategic grounds. In this contribution a number of influencing factors and their effect on the efficiency of CAD/CAM usage are discussed.

2. CONFIGURATION POSSIBILITIES FOR CAD/CAM SYSTEMS

The application of CAD/CAM systems is nowadays decentralized. The advantage is that the requirements of each user can be individually satisfied, without the necessity of user-sharing. Each workstation can be equipped with the precise software required by the user. This customization cuts costs and leads to increased user acceptance and efficiency. Should the system fail, only the particular user is affected. The department's capacity is to a large extent retained. Expansion can be achieved in small stages, and resultant investments closely monitored.

The disadvantage of a decentralized configuration is high support and service costs for hardware and software (both with new versions of CAD/CAM software, as well as with customized supplementary software). This factor alone often requires the setting up of a central support group on companies with their own computer installations. This support group contributes only indirectly to profitability, and resultant costs must be apportioned to user departments.

In a centralized configuration with one mainframe and connected terminals the situation is just the opposite. The main advantage is the reduced cost of each terminal. Apart from local terminals, hardware is required only for decentralized performance. Software licences relate usually only to the mainframe and not to individual workstations, whereby rates are graded according to the number of workstations per licence. The software version available to all workstations is standardized. This results in lower maintenance costs and simplified software service.

The disadvantage is that the user must share the system's capacity with others, and that varying response delays with similar problems become noticeable. As a result order processing times can no longer be calculated exactly. Should the mainframe fail, no user can continue working. All these factors mitigate against acceptance. All the software that is required in individual areas, even the smallest application, must be available at the mainframe. Investment in expansion is only manageable up to that point in time when the central

mainframe's own capacity limits are reached, because additional capacity involves either investment in an extension or in a second or replacement mainframe.

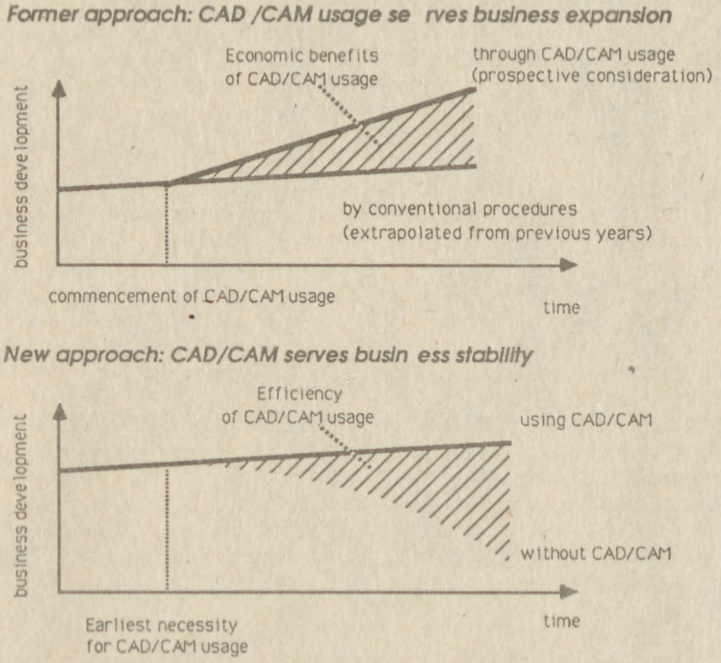


Diagram 1: Requirements for the economic necessity of CAD/CAM systems

The advantages of both organizational structures should therefore be combined. The usage of workstations should be decentralized. For particular departments a computer should be used as a background system. This computer stores all the software used in a particular department, whereby centralized and inexpensive servicing of new versions of basic and supplementary software can be carried out on a departmental level. For fail-safe reasons the CAD/CAM basic software is available as well on the workstations. New versions are transferred as required from the background computer. The background computer controls the LAN and the peripheral equipment that is used by all users. Should this background computer fail, the workstations can function alone. Application packages that are infrequently used are not stored locally, but are loaded as required from the background computer for which they are acquired once only.

3. HARDWARE AND SOFTWARE STANDARDIZATION

By the introduction of new hardware and software the following procedures for a uniform and inexpensive to service CAD/CAM configuration, that is easily adaptable to new requirements, is recommended:

- decentralized configurations with capacity appropriate to the particular task will be implemented. These systems will be connected with each other on the basis of departmental network, that will be controlled by the department background system.

- Standard hardware will be used. "Standard" implies that numerous software applications must be available for this hardware. Because of higher maintenance costs and the increased risk of failure, special hardware (generally in connection with the software of a particular manufacturer) will not be installed. The use of standard hardware offers the advantage that it can be expanded and exchanged as often as business requires. A configuration with too

many hardware platforms is cost-intensive, because each new hardware involves the attention of two people as know-how specialists for operation and service.

- Only standard operating systems will be used. In this connection it is important to distinguish between an operating system that functions with all computers of a particular manufacturer, and one that is compatible with the computers of a number of manufacturers. In the former case there is the danger of being too dependent on one particular manufacturer; in the latter it must be investigated from which point in time a normed operating system (e.g. Unix) can be applied within a company.

- Uniform computer configurations will be used within a company. Components will be defined with which each implementable configuration can be put together. Within the concept of modularity the diversity of components should be minimized.

With this cost-saving procedure quick and flexible interchangeability of hardware and software within a company is ensured. The number of staff required for service and maintenance is determined solely by the number of systems installed. In connection with a normed operating system, hardware from different manufacturers can be used to reduce costs.

4. APPLICATION OF MODULARIZED SOFTWARE IN LIBRARIES

Now that many suppliers have divided their high-performance and expensive software into inexpensive and inter-connected modules, that can be purchased individually, it is worthwhile to make use of modularized CAD/CAM software. Here it is important to make sure that the stored data base is not lost, and that data consistency, irrespective of the module used, remains intact. In this way , individual adaptation to the problem definition is possible. The user can begin with an inexpensive basic module, and acquire further modules as his field of application expands.

With decentralized configurations only the basic software is located locally. For example, 2D- and 3D-wire-frame modellers and surface modellers, plotter software, storage software, generation of macros, and the possibility of running programmes of the application program language. All further modules and the customized supplementary software are stored in libraries, from where they can be loaded on the workstations as required. In this way centralized and inexpensive maintenance is available. Further cost-saving arises in so much as only a few licences of a supplementary module are acquired. Such modules are those not used daily by every user, such as IGES-processors, software for hidden line generation, and FEM-systems. It is accepted that only a limited number of users can work simultaneously with the software. In practice this has not proven disadvantageous.

5. SOFTWARE LICENSING POLICY

As a rule, with decentralized systems one licence per workstation is required. This is particularly recommendable where considerations of cost have led to a division of software between basic software (everywhere there is a workstation) and supplementary software (on the background computer). One should make sure that the supplier offers rebates for multi-installation of the same software module. With a centralized configuration the licence is granted for the mainframe. Where a centralized system is converted into a decentralized system, transfer of the software licences from the mainframe to the workstations is necessary. In order to save avoidable costs, one should get the supplier to guarantee that the number of transferable licences is identical with the maximum number of connectable CAD/CAM terminals.

There is often the possibility to acquire a site licence instead of computer-related licences. A site licence is of particular value where CAD/CAM applications are not distributed over several sites, and where many workstations either already have uniform software facilities or will shortly acquire them.

6. SPEED OF CAD/CAM SOFTWARE DEVELOPMENT

Each year one or two new main versions of CAD/CAM software appear either with increased performance or as corrected versions. Despite the current high performance level of the software, only an average of 10-15% of all possible CAD/CAM activities can now be carried out computer-aided. The proportion of those activities that can be executed with a CAD/CAD system increases in pace with further development of the software, so that the number of fields of applications within a company grows.

If the speed of software development is too high (and that is the case by more than one main version per year), then there is a real danger that there are too many faults in the new version. With users these faults can result in loss of performance. Testing and release of the new software, further user training , as well as the conversion of supplementary software and digital archive to the new version proves difficult under pressure of time. The time required for changeover to the new version of a 3D CAD/CAM system is around 2 man-weeks for testing and release, and some 6-10 man-weeks for conversion.

7. ONGOING TRAINING OF USERS

The economic application of CAD/CAM systems is only then guaranteed when the users are always able to make maximum use of the available functions and tools in their daily business. Many users need at irregular intervals further training in order to refresh their skills and knowledge. An immediate influence of newly acquired functions on productivity is, by reason of the user's learning curve, not possible. There will be a temporary decline in productivity (**Diagram 2**).

With new versions of CAD/CAM software further training of users is required. As with basic training, this should take place away from the place of work, carried out by the CAD/CAM department. In order to ensure that the user makes use of the new functions in the solution of daily problems, that the pressure on application departments resulting from staff absence is not too intense, and that training costs remain at an acceptable level, further training should not take place more than once a year, even when more than one new version appears each year.

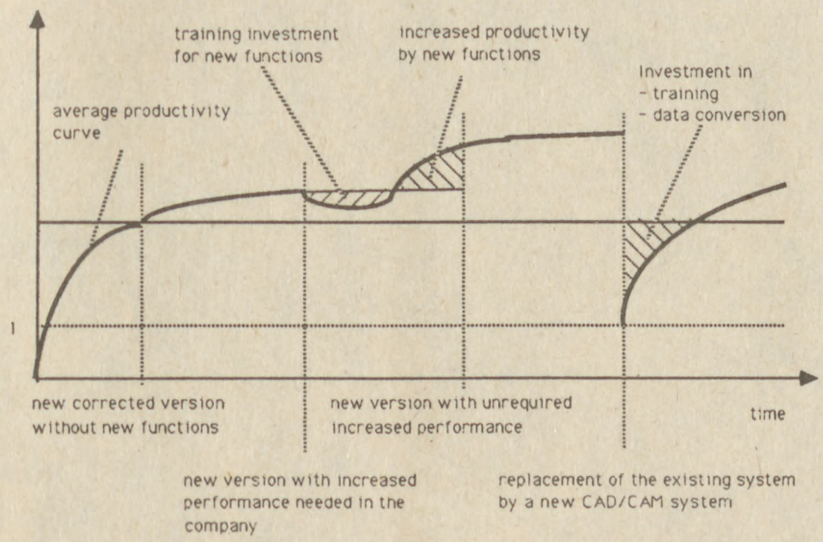


Diagram 2: Influence on productivity of new versions and change of system

The time spent on further training is dependent on the number of available training places, on each of which not more than two users should be trained for a period of one week. Only ongoing training, based on daily tasks, is conducted on site by the CAD/CAM department .

Trouble-free application of CAD/CAM technology requires a constant high level of technical support on the part of the CAD/CAM department. Experience shows that effective support is achieved with a ratio of 10 - 15 users per specialist, at appropriate cost.

8. SERVICE STRATEGY

Maintenance costs amount to between 0.8 and 1.2% of the purchase price per month. Maintenance comprises not only preventative exchange and free repair of defective components (supplier service), but also, in particular, the regular up-dating of both equipment and programmes in the course of further developments (preventative maintenance), servicing with application problems, as well as a supplier-guaranteed minimum system availability.

Ease of system maintenance and low repair frequency tend to encourage a neglectful attitude towards maintenance, which is then only demanded when serious problems such as system malfunction occur. This attitude pays off only short-term, and then only superficially. In such cases the hardware manufacturer will provide no guarantee of minimum availability, will carry out no preventative maintenance, and, when faults occur, will favour those customers with service contracts. The result is often considerable costs for extended downtime and higher spare parts prices. The software supplier provides the user with no support. For further software developments and updating the user without a service contract will be faced with a bill for the full purchase price of a new licence. One should therefore be aware, that to neglect maintenance is also to forego regular up-dating of equipment and programmes, to fail to participate in general further developments, and to dispense with such benefits as networking and data exchange with other systems.

In large companies the following cost-saving measures can be looked into: firstly, the possibility of separating hardware and software maintenance should be considered, and well as the opportunity of obtaining the same service from a third-party at lower cost or better conditions. Where the hardware comprises few components, enough qualified staff are available, and one is prepared to stock the most important components on site, on-call service may be preferred. On malfunction the components are exchanged and repaired either in-house or by the manufacturer without pressure of time. Continuing up-dating of equipment is however, in this case, not possible. Whether or not this approach is economic can only be judged on the basis of actual figures.

9. CHANGES IN STRUCTURAL AND OPERATIONAL ORGANIZATION

Because of the functional separation of product-defining areas into development, design and scheduling, in order processing the integrating characteristics of the common component model in the CAD/CAM system are not used. Each department creates its own data base and uses a copy of the supplying department's data as input data for its own activities. Often different CAD/CAM systems are used in different departments. Repetitive data preparation with resultant redundant data bases and possible input mistakes are the consequence. Delays in order processing follow. Rationalization achievements in individual departments are frustrated, and multiple storage of the same data bases makes a simple updating service impracticable. It is therefore imperative to find alternative organizational structures that harness the full performance and rationalization potential of CAD/CAM applications.

This is best achieved with a uniform organizational structure. The component model in the CAD/CAM system provides the integrating core. First of all it is necessary to switch from an organizational structure based on functions to one based on product families. Within such an organizational unit the whole development of a product family can be processed. Where an organizational separation between production and product-defining departments is necessary (e.g. plant size, different locations), the interface is found at production release. Such an organizational unit is named EIZ (engineering idle-zero workplace, **Diagram 3.**

From a work-organizational point of view this indicates a number of employees who together handle a number of successive work stages. Each employee has access to all work within the EIZ. Within the company the EIZ is autarch, that means, it has all information, materials and production data that is required to carry out, monitor and control its work, as well as full decision-making control. The EIZ is a full profit-centre and operates independently on the market. Work-separation is minimized in an EIZ. Work practices are process-orientated and market-aware. A product manager is responsible for order processing.

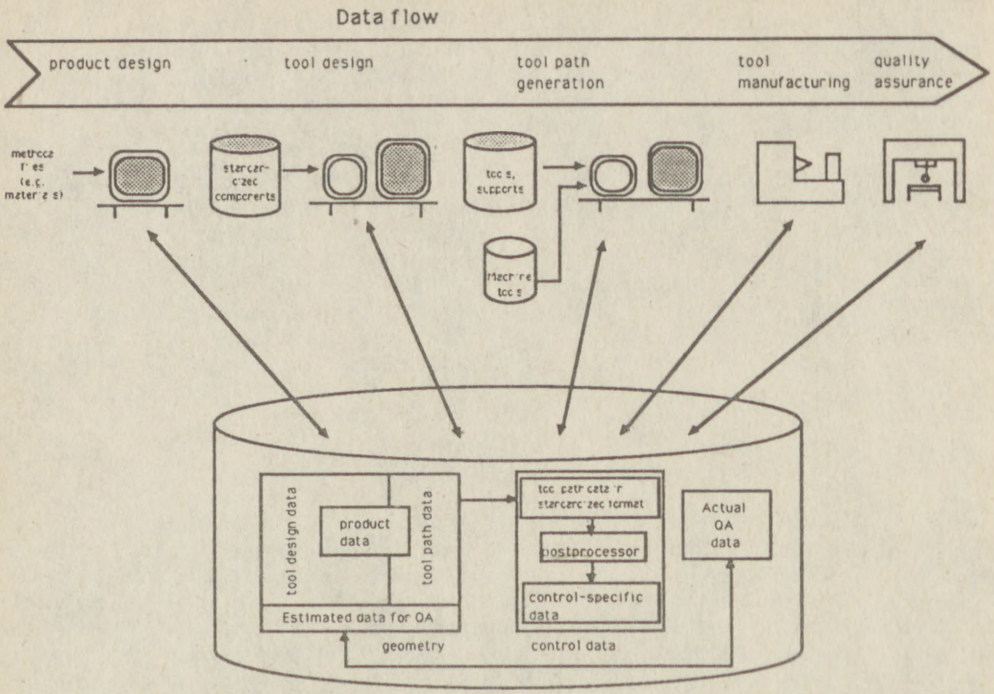


Diagram 3: EIZ with component model as integrating core

This job enlargement leads to an increased employee identification with the appropriate product ("I made it"), and, consequently to greater job satisfaction. This, coupled with the common component model, and fewer errors, contributes towards a reduction in throughput time. The organizational and spatial units result in a close and beneficial working relationship between the particular employees, in effect, a permanent cross-checking in every phase of product definition. The question of economic viability is easily answered, where a single costing point in the EIZ controls all stages in the product creation process, and the usual controlling methods can be applied.

10. SINGLE SYSTEM OR MULTIPLE SYSTEMS?

With increasing use of CAD/CAM technology a company will face the decision, either to remain with a single CAD/CAD system, to install several systems, or to reduce the existing system-mix. The advantages of a single system are the limited operating expenses, arising from lower support costs and simpler maintenance and service. Fewer specialist personnel are required. Overheads are not affected, because they are dependent on the number of workplaces. Supplementary software is generated only once. Disadvantageous is the fact that the overheads charge (especially with powerful systems) can be quite high. The performance requirements of a particular department may not always be exactly fulfilled. There is also the danger of implementing too large systems that are not fully used.

Reasons for a system-mix are either widely-differing fields of application, that cannot be covered with a single CAD/CAM system, an uncoordinated purchasing policy, or the demands of an important customer for a particular system. Such customers often require their suppliers to instal similar systems in order to ensure trouble-free data exchange, especially as far as order processing is concerned.

A system-mix can arise in two ways. Either different hardware and software are used, or simpy different software packages that all run on the same operating system. The advantage is that optimum adaption to the problems of individual application areas, or customers, can be achieved. The disadvantages are that data exchange between diifferent systems in a company, with the interfaces currently available, is extremely time-consuming, and that supplementary software needs to be redundantly developed and serviced. Experience shows that two specialists per system are required.

11. PROLONGATION OF USAGE TIME

In prospective economic viability one assumes daily use of the CAD/CAM system within the parameters of flexible working time (10 hours daily/2,500 hours annually). As soon as the system is running one should investigate if it is possible to extend the usage time without changing the flexible working hours. In many companies, flexible working time runs from 6.30 a.m. to 5.30 p.m., so the usage time can be easily extended to 12 hours daily (3,000 hours annually) without having to introduce new time-break arrangements for employees.

By extending flexible working time to 14 hours daily (3,500 hours annually), an increased return on investment can be achieved. The next stage is the introduction of two-shift usage, so that the usage time reaches 16 hours daily (4,000 hours annually). In the USA two-shift operation is the rule. As the usage time increases the equipment hourly cost-rates decrease, because depreciation, interest charges on capital investment, as well as maintenance and insurance costs are all fixed annual costs. With the present generation of computers, the increase in working capital caused by extending usage times is minimal.

The advantages of extended usage times are, on the one hand, a reduction in throughput time, and, on the other hand, an increase in capacity for the department. Further investment in new workplaces is slowed down. Fluctuations in capacity can also be compensated through changes in usage times. With centralized configurations equalization of usage times result also in better response time behaviour. Longer usage of the systems (and less on-off actuation) leads to reduced susceptibility to malfunction and lower wear and tear, and thus to an increased utilization rate.

Extended usage and increased capacity result in higher personnel costs for both users and technical staffs. Total hourly costs (machine time plus aggregate personnel costs) do not fall at the same rate as machine costs. From the support point of view, one must ensure that at least one systems manager or applications specialist must be on hand throughout the daily usage time to deal with problems. With small installations this is possible when technical staff cover between them the flexible working period; in the case of large installations further staff will need to be employed.

12. REFERENCES

[1] *Grabowski, H., Eigner, M., Hahn, D.*: Auswahl und Einführung von schlüsselfertigen CAD-Systemen, FB/IE 29 (1980)3

[2] *Kaplan, R.*: Don't avoid CIM cost justification,CAE (1988)6, S. 106

[3] VDI-Richtlinie 2216: Einführungsstrategien und Wirtschaftlichkeit von CAD-Systemen, VDI-Düsseldorf, erscheint 1990

[4] *Vajna, S.*: CAD/CAM-Ausbildung: Mit links geht gar nichts - Qualifizieren ist aufwendig, Technische Rundschau Bern 81(1989)36

[5] *Vajna, S.*: Retrospektive Berechnung der Wirtschaftlichkeit von CAD-Anwendungen, Computerunterstützte Technologien in der Fertigungsindustrie, Konradin-Verlag Leinfelden-Echterdingen 5/1986, S. 23/25

[6] *Vajna, S.*: Die Einführung von EIZ - ein notwendiger Schritt zur Rationalisierung in den produktdefinierenden Bereichen, Proceedings of ICED '88 Budapest, S. 362-370

[7] DIN V 66 304, Format zum Austausch von Normteildaten, Beuth Verlag Berlin 1988

[8] *Encarnaçao, J.* et alii: CAD-Handbuch - Auswahl und Einführung von CAD-Systemen. Springer-Verlag Berlin Heidelberg 1984

[9] VDI-Richtlinie 2216: Einführungsstrategien und Wirtschaftlichkeit von CAD-Systemen, VDI-Düsseldorf, erscheint 1990

[10] *Michael Gromm*, "Translate freely and damn it all", Gubin Publications, Dublin, 1990

Prof. Dr.-Ing. *Sándor Vajna*
Research project
CIM and computer-aided interactive Media
Mollstraße 40, D 6800 Mannheim

MODERN MANAGEMENT IN MANUFACTURING

Dipl.-Ing. Peter J. Vasak
Manufacturing Industry Consultant

Cincom Systems
Frankfurter Str. 27
D – 6236 Eschborn
West Germany

Today's World

In 1989, the world changed in many aspects. Political barriers such as the Berlin Wall and the Iron Curtain fell, East and West Europe are on the way towards a "Common European House". Within this political opening, new economic models allow a closer cooperation between East and West. Investments across the political boaders as well as joint ventures are becoming routine events.

For several years, the Western countries have been talking about globalization of the world's markets. In fact, there are today three key market areas:

- the American market dominated by United States of America,
- the Pacific market led by Japan and Corea, and
- the European market now comprising not only the member states of the European Community but also the EFTA and Comecon states. It is this market that is developing to the largest economic power of the whole world economy.

In the nineties, the presence and competitiveness of companies in the above markets is a vital prerequisite for their survival as companies in the foreseeable future of the rising century. The truth of this statement can already be seen by the tremendous investments of American and Japanese companies all over Europe.

Market position

The situation described above will force each company joining this new game to ask itself several questions on its own market position:

- Which specific market demands do we serve by our products / services ?
- Who are the other players ?
- What are our market advantages ?
  - = customer service / speed of reaction
  - = technology
  - = quality
  - = low cost
  - = other
- What are the challenges we have to face ?

The **first set of rules** in a market oriented economy is:

- The better the product/service suits the demand in terms of technology, quality and adaptiveness to the customer needs,
- the better the level of customer service – with regard to competitive lead time and timeliness of delivery,
- = the higher the price achievable on the market.

Therefore **market analysis and product selection** are very important tasks for each company producing and selling goods and/or services in order to maximize the revenue achievable by means of the resources available.

Efficiency Measurement

The efficiency measure is well known and fairly simple:

Profit = Revenue – Cost

Applied to each product and to the company as whole, we can recognize in which category the product and/or the company could be classified:

- survival
- stability
- competitiveness
- excellence

By the way, the "open market" cannot be restricted to product market only, it also includes the employment market. This means that the "low cost" of labor is only a short term advantage; the real measurement will be **real competitiveness and real productivity in manufacturing.**

Management Methods

The scope of factors influencing the efficency of a company includes – besides the market position and the immediate cost and profit situation – many other relevant components such as flexibility of the product lines, resources as well as organization and information services of the company.

To manage a manufacturing company means primarily to create long-term success potentials and to control the utilization and effectiveness of resources in the middle- and short-term range.

MRP II – Manufacturing Resource Planning
is a manufacturing management philosophy developed in the United States in the mid-seventies as a set of **Integrated and Generally Accepted Business Management Activities** for the management of an industrial production environment – regardless of size, process or product.
This method has been promoted in the USA by the American Production and Inventory Control Society (APICS) and by specialized industry consultants like Oliver Wight and George Plossl. Most of the successful American companies implemented this philosophy in their business practice.

In Europe, the most advanced use of MRP II could be found in the United Kingdom with the British Production and Inventory Control Society (BPICS) being the leading force regarding the implementation.

In Germany and France, a growing trend toward MRP II is obvious and chiefly promoted by several universities.

MRP II

A planning and scheduling approach to manage the resources to run a manufacturing business, given the manufacturing process - including parameters such as lead time, lot sizes scrap allowance and safety stock.

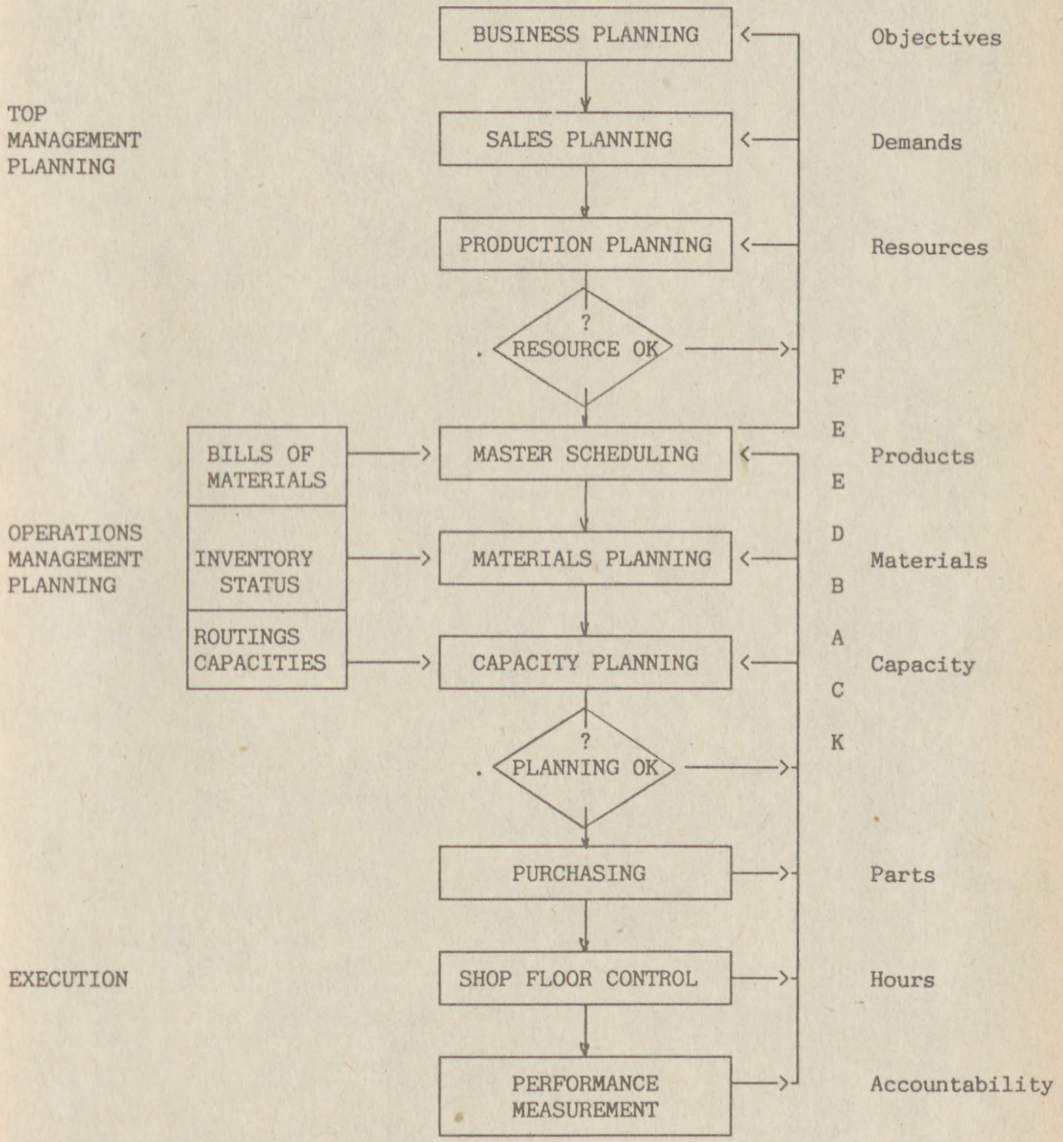
MRP II FOCUS

Accurate ...
- inventory records
- bills of material
- routings

Long range visibility
Valid and integrated plans
- sales
- master schedules
- capacity and material
- financial

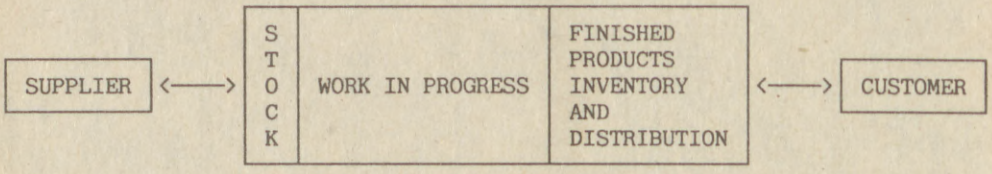
Stable master schedules
On-time deliveries

MRP II – MANUFACTURING RESOURCE PLANNING



Source: DEC

JIT - Just-in-time
is a new production and logistics strategy - one of the most interesting imports from Japan. The claim for having **the right materials in the right quantity and quality at the right place on the right point of time** requires a permanent attention to production flow, organization structure as well as quality and flow of information throughout the whole logistic chain.



JIT

An approach to simplify the manufacturing process and eliminate all nonvalue adding activities by overcoming all obstacles to reducing parameters such as lead times, lot sizes scrap allowance and safety stock.

JIT FOCUS

- product and component quality
- lot size reduction
- setup reduction
- lead time reduction
- work in progress reduction
- vendor reliability
- staff involvement
- paperwork / transaction reduction

OTHER MANAGEMENT METHODS

All management methods other than MRP II are focusing only on particular functional areas of the manufacturing business:

CONCEPT / FUNCTIONAL AREA	MRPII	JIT	BOA	OPT	FZ	KAN-BAN	TQC	
MASTER SCHEDULING	■			■				
QUANTITY PLANNING	■	■			■			
DETAILED SCHEDULING	■	■						
ORDER RELEASE	■	■	■	■	■			
SHOP FLOOR CONTROL	▌▐	▌▐	▌▐	■		■		
FACTORY DATA COLLECTION	■	■	■	■	■	▌▐	■	*)
PURCHASING	■	■		▌▐	■	▌▐	■	
QUALITY ASSURANCE	▌▐						■	
CONTROLLING	▌▐				■	■		

BOA => Load-oriented input/output control
OPT => Optimized production
FZ => Floating cumulative quantity control
KANBAN => Lot/Batch-controlled production flow
TQC => Total quality control

*) Add-on only

■ = completely covered

▌▐ = partially covered

Competitive Standards

"The financial statement does not testify that a company is well-run or has a rosy future ..." (R. D. Garwood – American industry consultant)

How to evaluate a company's performance level in managing their business ?
How to make it comparable to the performance of other companies ?
How to track the performance regardless of the permanent changes with respect to market demands, internal organization, and product and technology innovations ?

Help is available! A generally accepted set of standards has been established allowing to execute the above tasks. The performance assessment can be elaborated in each organization either by internal staff members or by external specialists – using a special questionnaire and comparing the results with a defined set of values. The questionnaire includes 70 questions relating to the functional areas as specified below:

- business strategy
- sales and operations planning
- demand management activities
- master scheduling
- material planning
- data quality
- supplier scheduling
- shop/plant floor scheduling
- education
- capacity planning and input/output control
- benefits
- performance measurements
- financial

The number of questions answered positively as well as their combination and the value of measure achieved define the classification of the company performance (into a specific class):

below 36 Points	= Class D
36 – 49 Points	= Class C
50 – 62 Points	= Class B
63 – 70 Points	= Class A

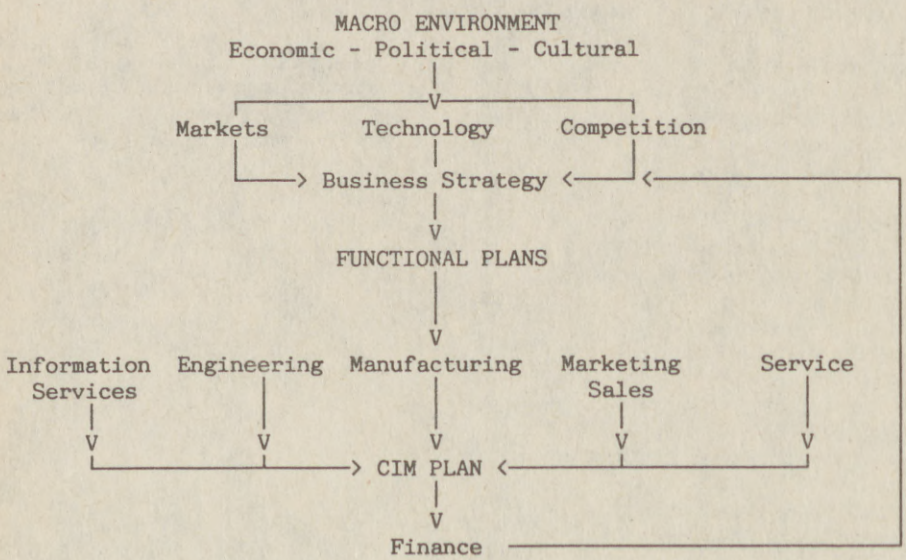
The highest bar is the "World Class". For those wanting to measure themselves against this highest set of standards, the following table shows a subset of relevant values:

Source: R. D. Garwood, Inc.

	Class "A"	World Class
Quality	95-98% Yield	99,9999%
Inventory turns	2-6 Turns	20-50 Spins
Service	+/- 1 Week	Just-in-Time
Lead times	Weeks	Days/Hours/Minutes
Productivity	3-6% Increase	30-50% Increase
Purchase cost	5% Reduction	30-50% Reduction

The role of CIM

CIM – Computer Integrated Manufacturing could simply be defined as the **"common and integrated part"** of all the above–mentioned management methods. The implementation of CIM presupposes the development of a company's fundamental understanding of the real business needs and the establishment of a plan based on the real priorities. Robots and automated systems are not the only solutions to achieve the most efficient manufacturing capabilities.
Following the MRP II methodology, the approach to define such a plan could only be as follows:



If the finance planning allows the realization of the CIM plan – let's go.

The critical point now consists in the selection of the proper tools.

Let's concentrate now on **Information Services** being one of the key areas of the CIM implementation process. CIM itself is the application and integration of computer–based technology and information in order to provide an optimized support for the strategic targets of the company, such as:

- Improving quality
- Reducing costs
- Minimizing product development life cycle time
- Increasing flexibility

The most sensitive area is the **selection of the appropriate software** tools and their **integration** and **customization** to the specific needs of a company.

Software Selection Criteria

The "Business Information System" of a company plays a major role in the CIM concept – in many aspects similar to the roles of functionality, architecture enabling the integration required, and management information capabilities allowing ad–hoc requests, analyses, etc.

Critical experienced users measure the quality of a business system package by two criteria – functionality on the one hand, the technology used and the software architecture itself on the other hand. Both are vital regarding the reliability of the system and the security of the investment planned.

Key Attributes

The **key attributes** of a modern business system are listed below:

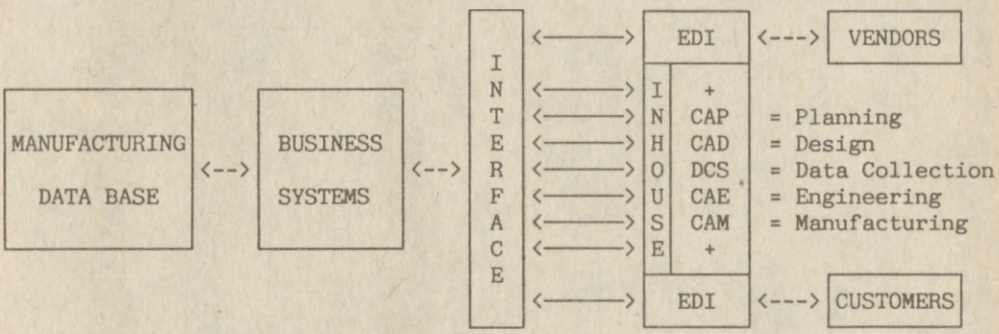
1. MRP II-based business transactions oriented logic.
2. Integrated planning, operational and financial capabilities.
3. Discrete, repetitive and project management techniques.
4. Support of Just-in-Time (JIT) principles.
5. Centralized and/or distributed implementation options.
6. Foundation of relational DBMS and 4GL technologies.
7. Consistent operation on multiple hardware platforms.
8. Open architecture for CIM supported by communication facilities.
9. Functional characteristics:
   - = closed loop,
   - = net-change,
   - = effectivity-driven, subject-oriented data base,
   - = fully integrated, interactive, borderless operation.
10. Availability of inquiry and report writing capabilities.
11. Customizing capabilities and releaseability of the package.

The Business System is the foundation of the company's information services.
Now let's focus on two of those attributes that may have a substantial impact on the cost of a CIM realization.

Open Architecture for CIM

The "Business System" (either developed in-house or a standard software package) should incorporate generic facilities allowing communications with other in-house systems as well as with suppliers and customers.

The following diagram shows the components and the attributes of the communication facilities:



The **Generic Interface** for the integration of external systems must provide:

- * Standardized input from external systems with:
  - real-time and batch modes,
  - little or no programming required,
  - implementation support maintained.
- * Standardized audit facilities.
- * Standardized output to external systems available.

EDI is a an acronym for **Electronic Data Interchange**. This facility allows the exchange of standardized documents via public networks.

Distributed Implementation

What if the company operates multiple plants or sites – maybe in different countries (with different languages) – with centralized functions such as sales and distribution, planning and purchasing as well as financial operation and local materials planning, shop floor control and intraplant relationships ?

What does the term **"distributed"** really mean ?

DISTRIBUTED = DECENTRALIZED + INTEGRATED

Decentralization is required to maximize the operational independence of all sites allowing separate, self-sufficient applications at each site.

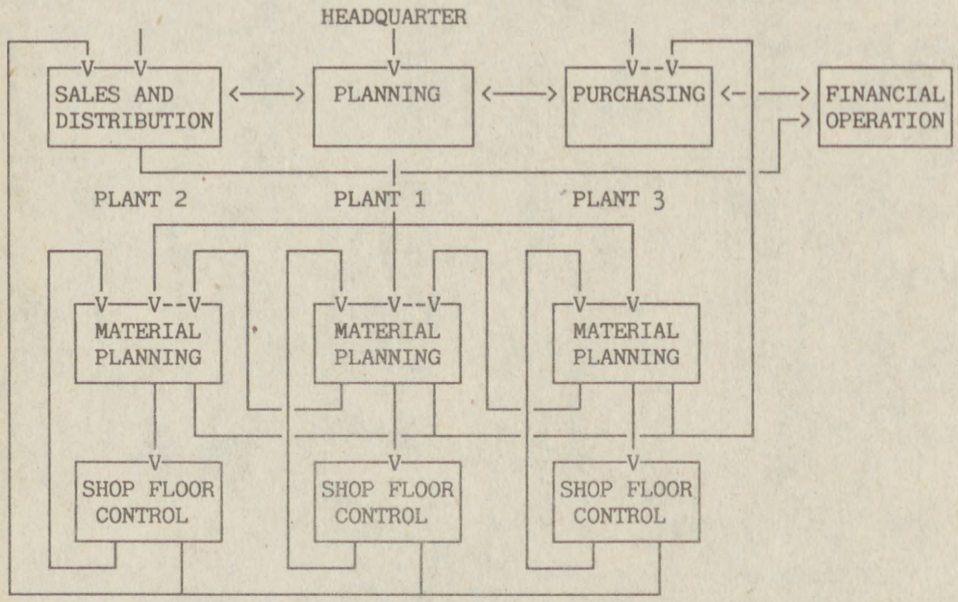
ntegration of all sites is required to manage consistent and controlled overall company information based on:

- dynamic information flow among sites via transactions,
- application-specific consolidated information,
- relational or later on distributed DBMS capabilities.

In this scenario, there are four major prerequisites assumed:

- the network is the system,
- multiple hardware platforms can be used,
- the transaction flow is maintained and controlled automatically,
- local policies, languages, currencies and other parameters are optional.

The following schema shows a model of such an implementation structure:



The standard interface and EDI facilities are used to communicate through local and public networks. All relevant transactions are automatedly passed to the headquarters or to the addressed site.

A substantial part of this scenario has already become a reality: the technical solution of communications through networks handling different hardware systems is developed and executable, the software necessary to handle these company structures is available, standard interfaces and EDI are existing, automated communications on the transaction level has been proved, and the distributed data base facility is under development.

And the languages, currencies and other multi-national facilities ? Modern standard software packages cover this market demand to a substantial extent – and the software industry is continuously improving its products – since the MRP II philosophy is also valid for companies "manufacturing" software.

Vendor Selection

When selecting CIM software, you should evaluate certain characteristics of the software vendor who will probably be your strategic partner for many years:

- The vendor should be commited to both information systems technologies and applications for manufacturers.
- All vendors supplying CIM components should have an open and cooperative attitude, and work together with other CIM vendors, system integrators and management consultants.
- Not only software, but also implementation services are required – for both end-users and DP staff.
- World-wide presence and support capabilities guarantee a short response time and availability of technical and applicational expertise in case of customer need.

CINCOM SYSTEMS

Cincom is the largest privately held software company in the world. The company has offices at more than 70 locations all over the world. All offices and agencies are connected by CINTERNET – the company's own network system.

Cincom supports more then 19,000 product installations and 8,000 customers.

Cincom's revenues in 1989 exceeded $ 168,000,000; all revendues were generated by selling software.
Cincom is investing more than $ 20,000,000 per year into software research and development activities.

Cincom's product line includes excellent application software as well as application development tools:

SUPRA		Relational DBMS
SUPRA/SQL		Relational and distributed DBMS
MANTIS		4th generation language
SPECTRA		Query/report facility (portable in IBM / VAX environments)
M/TEXT		Text management
CPCS	–	Project management tool

CONTROL:Manufacturing/Financial is a comprehensive business application system.

Cincom has more than 20 years experience in software technologies; its most successful product was the first manufacturing-oriented data base TOTAL with the number of installations exceeding 3,500.
In 1976, Cincom started the development of the first MRP-oriented modular application package MRPS. Based on Cincom's experiences gathered during the preceding 15 years in many different industries and businesses and its state-of-the-art information technology, CONTROL: Manufacturing and CONTROL: Financial have been developed as a full-scope MRP II **Business Control System** for large manufacturers. CONTROL has been installed at more than 350 sites and 250 customers. Many of them are multi-national, multi-site companies.

Cincom has cooperation agreements with a large number of international CIM partners.

CINCOM Europe

With more than 150 installations of C:M/F and a revenue share of approximately 66% in 1989, the European market has become the Cincom's most important market.

Cincom has three subsidiaries in Europe:

- The headquarters of the Europe North region is located in Maidenhead/Surrey, UK and is also responsible –besides UK and Ireland – for the Scandinavian countries Sweden, Norway and Denmark.
- The headquarters of the Europe West region is located in Paris, France and also supplies and supports clients in the Benelux countries and in Switzerland.
- The headquarters of the Europe Central region is located in Eschborn near Frankfurt/Main, West Germany. There are four additional offices in Germany (Hamburg, Düsseldorf, Stuttgart, Munich), and another subsidiary has been founded in Vienna, Austria.

  Europe Central will serve as the bridge to the Eastern Europe.

CONTROL:Manufacturing/Financial

C:M/F is a business control application package including the following modules:

OMS	–	Order Management System
BOM	–	Bill of Materials and Routings
ECC	–	Engineering Change Control
MAT	–	Material Control
LST	–	Lot/Serial Number Traceability
MPS	–	Master Production Scheduling
MRP	–	Material Requirement Planning
PMC	–	Project Manufacturing Control
SFC	–	Shop Floor Control
RMC	–	Repetitive Manufacturing Control
PUR	–	Purchasing
CMS	–	Cost Management System
PCC	–	Project Cost Control
A/P	–	Accounts Payable
A/R	–	Accounts Receivable
G/L	–	General Ledger and Financial Reporting System

Detailed product information sheets are available. On demand, product presentations can be arranged at your company's premises. Cincom's product specialists will support your implementation project.

References:

HOT LIST II, Vol 1, May 1987. Published by R. D. Garwood, INC., Atlanta GA.

Class "A" MRP II Performance Assessment by R.D.Garwood, INC., Atlanta GA.

MRP II Manufacturing Excellence Presentation, Digital Equipment Corporation.

Prof. Dr. Horst Wildemann: PPS als Erfolgsfaktor für eine kundennahe Produktion
Belastungsorientierte Fertigungssteuerung, Tagungsbericht 1989 gfmt
Lehrstuhl Betriebswirtschaft / Fertigungswirtschaft, Universität Passau.

MRP II Educational Materials, Advanced Systems GmbH, 1984

MAIN ASPECTS OF PHISICAL VAPOUR DEPOSITION FOR RESISTING COATINGS ON CUTTING TOOLS

Volin E.M. ALL-Union Light Alloy Research Institute, USSR

ABSTRACT

This paper deals with the influence of main phisical parameters of ion plasma techniques on coating performance. Rate of deposition and sputtering, homogeneity of coating and microhardness of coating are investigated in relation with the energy and density of ions, pressure and composition of reaction gas and other parameters of the process. Influence of these parameters on composition of multi-alloy coatings deposited from alloyed cathode is investigated. Influence of deposition process conditions on coating surface morphology and wear resistance of coated cemented carbide tools is demonstrated.

INTRODUCTION

Wear resisting coatings are effective means of improving performance of cutting tools, allowing to "design" the cutting surface of a tool by rendering various additional properties to it, and meet contradictionary specifications for tool material in this way.

At present, the most part of cemented carbide cutting tools are produced with either single- or multilayer coatings obtained by the chemical vapour deposition (CVD) method using mostly TiN, TiCN, TiC, Al_2O_3, HfN and other compounds.

Recently, however, more widely used for deposition of wear resisting coatings are physical vapour deposition (PVD), especially such ion plasma techniques as activated reactive evaporation, sputtering (including magnetron sputtering) [1], ion plating and ion plating with arc discharge [2]. As distinct from the chemical vapour deposition, these methods are realised at substrate temperatures within 200 to 500 deg.C, which prevents formation of η-phase embrittlement if a hard metal is used, and preserves properties of the tools made of HSS.

The use of plasma assisted plating methods in the presence of ionized particles in the flux of the material being deposited ensures a wide-range energy control of the particles by applying the corresponding negative (bias) voltage to the substrate. As distinct from the chemical vapor deposition, this method facilitates deposition of multilayer and multialloy coatings representing multicomponent structures consisting of both metal- and nonmetal component materials.

The present experiance in the use of ion plating processes shows that tool life be increased by ten and more times, de-

pending on kind of tools and the conditions of application [3].

The ion arc plating (one of its versions is known as the ION BOND) is of particular interest [2]. This method uses the plasma flux generated due to errosion of material in cathode spots burning on the cooled cathode made of the material corresponding to the one to be used for coating. The chamber is most frequently used as the anode. The vacuum discharge is maintained within approximately 10^{-2} to 10^{-4} Pa. The rate of errosion is proportional to the arc current, and the proportionality coefficient grows with the decrease of evaporation temperature and latent specific heat. For Ti, Cr, Zr and Mo, for example, this coefficient ($\mu.10^{-4}$) is 11, 10, 7 and 6.10^{-2} respectively [4]. The plasma of a stationary vacuum arc contains a large number of multicharged ions [5]. In the materials having low melting temperature, the majority is constituted by the ions having low positive charges, while in the high-melting materials, there are ions having five or six unit charges. Apart from that, the plasma also includes neutral particles and a microdroplets, whose characteristics are defined by thermal physics specifications of cathode.

This process differs from the other ion plasma techniques in highest ionisation fraction of vapour flux amounting to 80--95 percent. This allows the use of electrical and magnetic fields arranged crosswise for effective acceleration of plasma flux (provided its electrons are magnetized) and focusing it to a required degree [6]. It has been show [7] that the use of magnetic fields allows not only to focuse the plasma flux, but also considerably intensify the plasma chemical reactions and increase the ionisation fraction of flux.

This process occurs in the conditions established by two competing processes: condensation and self-sputtering. Mutual effect of these two processes on displacement of the boundary has been considered in [8] for determination of the inversion energy, i.e. the magnitude at which the transition from the formation of coating to sputtering of a substrate takes place. If this energy exceeds that of inversion, the ion etching of substrate occurs at a speed depending on the ion density and the bias voltage. If the energy is less than that of inversion, the deposition takes place in the conditions of its bombardment by the coating material ions. The density and energy of the ions define the intensity of sputtering, formation of defective areas in upper layer, destruction of cristalline structure, temperature of the part and structure of coating, morphology and composition of coating surface, internal stress.

So, the coating process depend on many condition. The main parameters which are to be controlled to provide the proper quality of coating are: arc current (I_a,A), substrate bias voltage ($-U_s$,V), pressure and composition of reaction gas (P_g,Pa), magnetic field strength (H,E) or solenoid current (I_s^g,A), distance from evaporizer to the part to be coated (l),

temperature of the part before and during deposition (t,deg.C), density of ion current (i, A/sq.cm), deposition rate (V,μm/h) and the route and speed of displacement of the part of a particular configuration. The parameters to be controlled constantly are as follows: coating thickness (δ), microhardness (HV.1oo), flank wear of coated cutting inserts (h).

EXPERIMENTAL TECHNIQUE

The experiments have been carried out using an installation furnished with three arc evaporators with electrostatic stabilization of cathode spots and including a coaxial focusing system consisting of a conic watercooled anode and a solenoid. The installation set-up is shown in Fig.1. During evaporation the vacuum system maintained the pressure below 5.10^{-3} Pa. The reactive gas was supplied through a needle-type leak and a automatic valve. For obtaining the mixture of nitrogen and acetylene, the use was made of an intermediate vessel. The ion density was measured with the use of a flat screened probe. For the measurement of coating thickness, a special technique was developed using optical microscope MИМ-3 and the molybdenum foil of 50-μm thickness. The microhardness of coating was measured using instrument ПМТ-3. The chemical analysis of was carried out with the use of Electrone probe X-ray Microanalyzer JXA-733 (Jeol LTD) provided with Energy dispersive X-ray Microanalysis System-860 (LINK Systems), morphology of coating surfaces was studied using electron scanning microscope MSM-5.

RESULTS AND DISCUSSION

The important parameters of process are: arc current, bias voltage and ion density. Fig.2 shows the influence of these parameters on equilibrium temperature of a steel substrate for the case of chromium coating. As seen from the chart, the most significant parameter is a bias voltage allowing to control the substrate temperature during deposition.

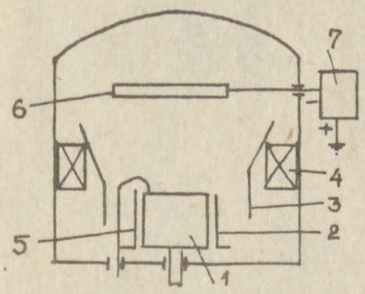


Fig.1. Installation for plasma arc plating: 1-cathode; 2-electrostatic screen; 3-anode; 4-solenoid, 5-firing electrode; 7-power supply source

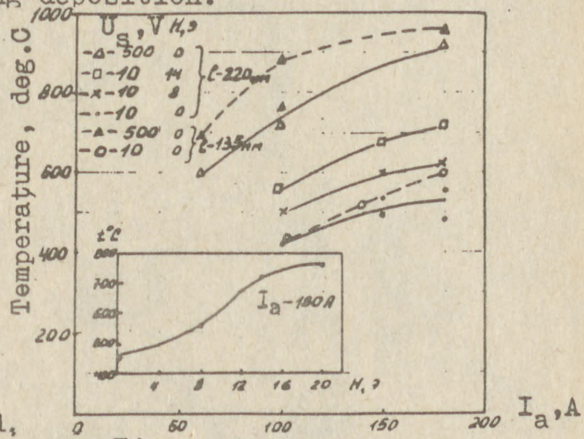


Fig.2. Influence of parameters (U_s,H,I_a,l) on equilibrium temperature of steel substrate

The relation between the deposition rates and the ion current densities is presented in Fig.3. The directly proportional dependence is an extra evidence of highest ionization fraction of the plasma vapour phase being deposited; the lower curves depicting more refractory metals indicate an increased content of multicharged ions in the plasma based on those metals.

Fig.4. presents the results of measuring the ion current density and coating thickness along the radius with respect to the strength of magnetic field. It can be seen that the magnetic field allows to effectively focuse the plasma flux and by this way considerably increase the deposition rates in the centre (by 5 and more times). With the pressure increase, the coating homogeneity along the radius also slightly grows (Ref. Fig.5).

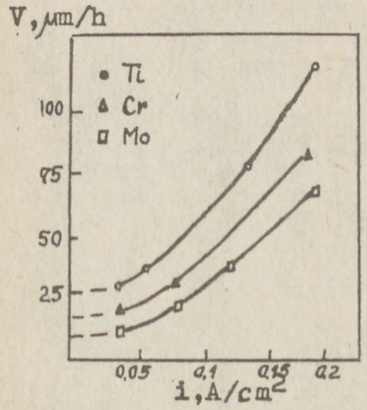


Fig.3. Deposition rate versus ion current density

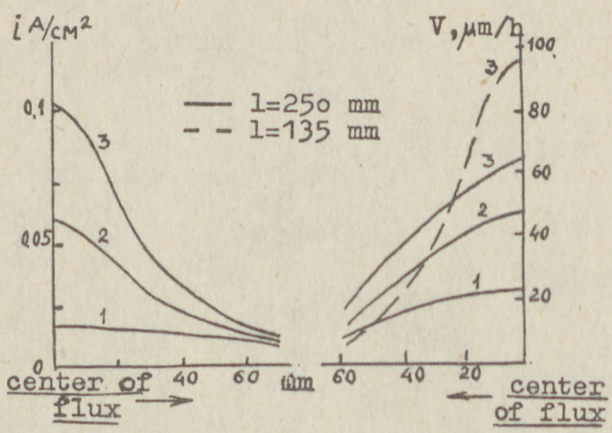


Fig.4. Influence of magnetic field on ion current density and deposition rate of chromium: 1-0 E; 2-25 E; 3-50 E

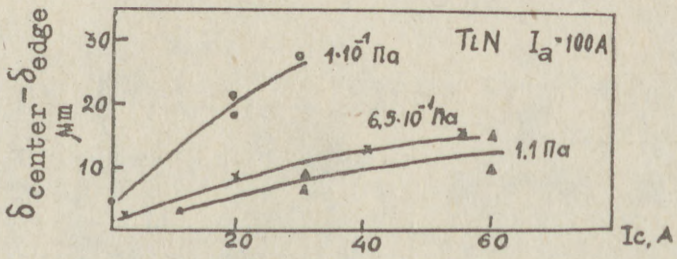


Fig.5. Influence of P_N on homogeneity of TiN thickness on substrate of dia.150 mm at various solenoid currents

The sputtering processes have been investigated without the magnetic field. As a result, a number of coating have been obtained at different bias voltage, and the inversion energy has been found out for various cathode materials. For instance, for Cr, Mo and Ti, it proved to be respectively 180, 200 and 350 V. The relation of these values correlates fairly well with the date obtained for self-sputtering coefficients of those materials [9]. However, due to the presence of a droplets in plasma, the quality of preliminary ion treatment depends not only on the density and energy of ions. Fig.6 presents the comparison of a steel surface after being treated with chromium and titanium plasma. It can be seen that in the case of titanium, the surface contains microdroplets adversely affecting the quality of treatment. In the case of Chromium, the ion etching gives better results. Depending on a grade of steel and its initial structure, the etching may go quite differently (ref. Fig.6 (b), (c)). When dealing with coating of a hardmetal, a preliminarily heating up to high temperature provides a good bond of the substrate with droplets (Ref. Fig.6 (d)). The same photo displays the selectivity ion etching of cemented carbide alloy: the cobalt matrix is sputtering more intensively than the particles of WC.

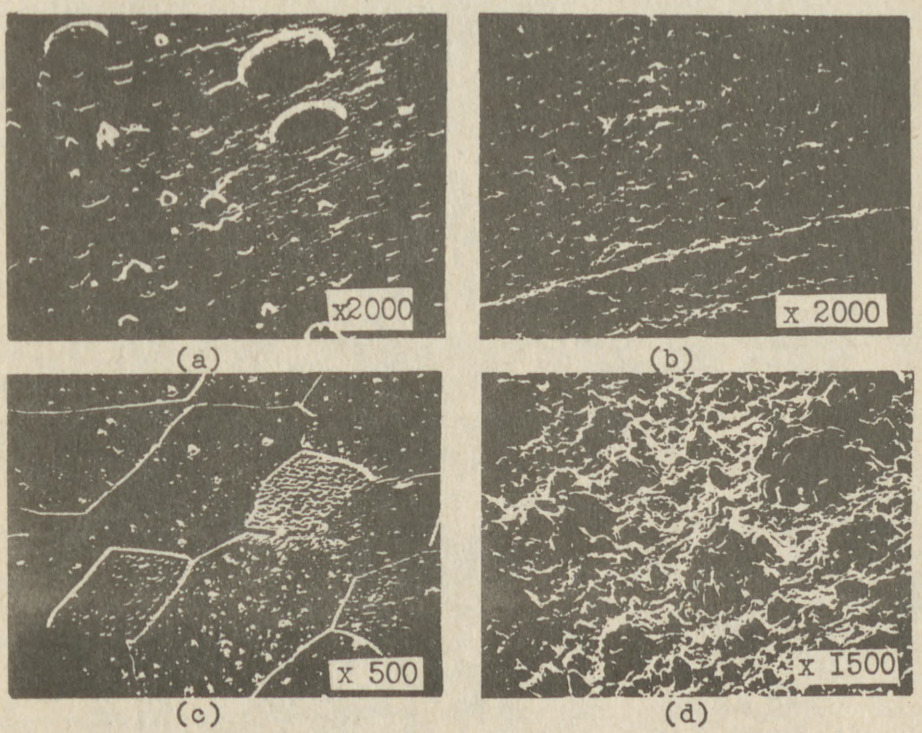


Fig.6. Substrate surface after being cleaned with plasma of Ti (a),(d) and Cr (b),(c): (a),(b)-steel У8, (d) - -cemented carbide insert (BK8); (c) - steel 3Х2В8

The results of measuring the sputtering rate versus ion current density (Ref. Fig.7) show that as the ion current density grows, the sputtering rate increment drops, approaching zero. Evidently, in the conditions of arc plating at comparetively low energy levels (500 eV, approx.), sufficiently high sputtering rate can be achieved, amounting to 2.5 μm/min.

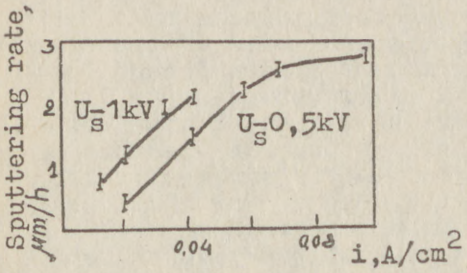


Fig.7. Rate of sputtering Mo with ions of Cr versus E and i

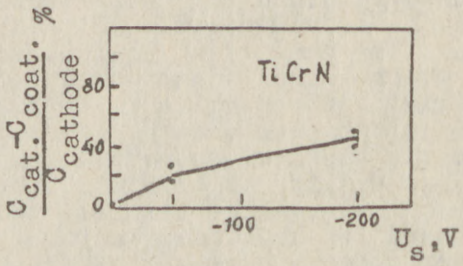


Fig8.Relative change of coating composition (Cr) in TiCrN versus U_s

The contribution of sputtering to the deposition process has been estimated on a number of materials. In particular, it has been established that an increas of the bias voltage results in increasing the coating homogeneity on the radius due to a sputtering acceleration in the centre of flux. Apart from that, studied has been the influence of sputtering using alloyed cathodes on the composition of coating. The study has been carried out on alloys of system Ti-Cr-N, whose components differ mainly in the value of sputtering coefficients and on a nickel-based alloy, whose components differ not only in sputtering coefficient, but in atomic mass also. The analysis results for the coatings obtained from those alloys are presented in Figs. 8 and 9. It follows from Fig.8 that as the bias voltage is increased, the coating composed of Ti-Cr-N becomes sufficiently impoverished (by 40 percent, rel.) by more intensively sputtered chromium.

Fig.9. shows the analysis results for nickel alloy coating as plot the coating composition deviation from cathode composition against alloying element-to-nickel sputtering coefficient ratio and alloying element-to-nickel atomic masses ratio. Evidently, although the correlation takes place for all elements (except W) in the first and second cases, the main influence consists of a difference in the component sputtering coefficients (the mass difference is not significant), while in the case of W, differing in mass considerably, the second factor is more important.

So, although the generation of plasma vapour phase from an alloyed cathode goes partically without loss of stoichometry due to a high temperature of cathode spot (over 30,000 deg.C) and extremely short duration of the process taking place in micro-

volumes (5–40 ns) [11], the coating composition may differ a lot from the composition of cathode material due to selective sputtering.

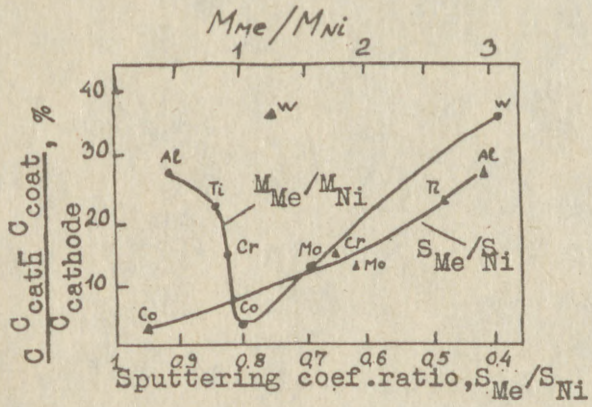
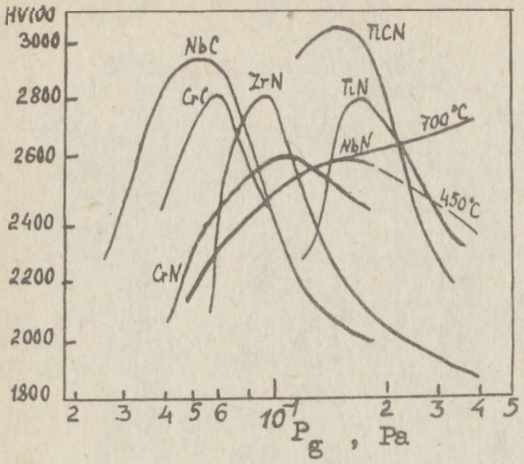


Fig.9. Deviation of coating composition from cathode composition versus relative sputtering coefficient of alloying element (S_{Me}/S_{Ni}) and ratio of element and nickel atomic masses (M_{Me}/M_{Ni})

The dependence of coating composition on the bias voltage has been used in [12] to control the composition by the thickness of TiAlN-coating in order to increas its properties.

The important characteristic of a coating significantly influencing on its wear-resistance is a microhardness. Formation of a composition and coating structure are determined by such process parameters as pressure and composition of the reactive gas, ratio of the density of non-metal atoms supplied to the surface to that of metal atoms, surface temperature of the part being coated, energy of the particles, degree of activation of the particles taking part in the reaction. Fig.10 shows the results of studying the influence of the pressure offered by reactive gas on microhardness of some coatings. The dependence of microhardness on the pressure is of significant nature and in the most cases it tends to feature evident maximum. The position and magnitude of this maximum depend on the type of composition. It is seen from the example of system NbN that this relation can be of a quite different nature depending on the temperature.

A likely different influence on the microhardness may be exerted by the bias voltage of an part being coated, which on reaching a certain minimum value results first of all in increasing the temperature. Fig.11 gives an example of this influence for Cr-base compositions: as the bias voltage rises, the hardness of nitride goes down, and that of carbonitride goes up.



Fif.1o. Influence of reactive gas pressure on HV hardness of hard coating

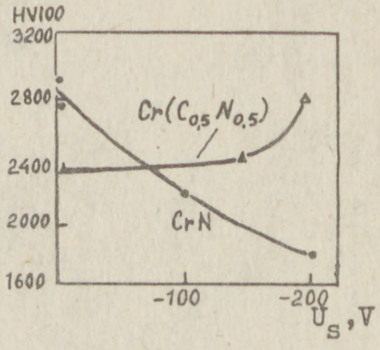


Fig.11. Hardness of Cr-base compositions versus bias voltage

An introduction of a second component, either metal or non-metal, sufficiently influences on microhardness of the composition. Fig.12(a) shows the influence of carbon in Nb-N and Ti-N (by introduction of a corresponding volumetric quantity of acetylene to nitrogen), Fig.12 (b) shows the some other metal elements. It should be noted that in both cases the nature of microhardness change with the second component concentration is similar, which indicates the identity of the hardening mechanism associated probably with the crystalline lattice distortion caused by introduction of the third component.

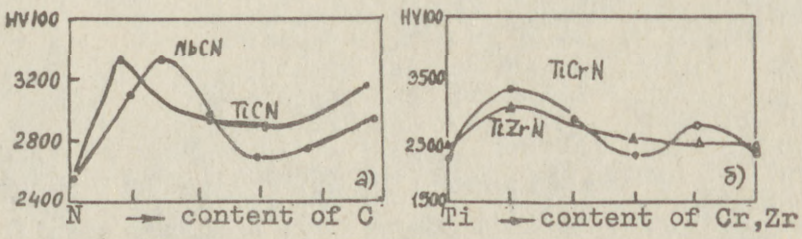


Fig.12. Influence of third component: carbon (a) and metal (b) on HV hardness of nitrides

The microhardness depends also on orientation of a surface being covered with respect to the flux, and the distance from the cathode, as those factors have an effect on the ratio of the gas atoms to those of the metal delivered to the substrate. Also important is the magnetic field strength, the effect of which is equivalent to an increase of gas pressure [7].

Thus, it can be seen, that for optimization of coating material properties it is necessary to take into account both the constitution of cathode and the parameters of process. Fig. 13 illustrates as an example the results of cutting test of cemented carbide inserts BK8, coated with TiCrN being optimum by the composition and deposition parameters and obtained by the turning of high temperature nickel alloy, compared with the identical cutting tools having either no coating of TiN-coating. It can be seen that the tool life has increased up to five times.

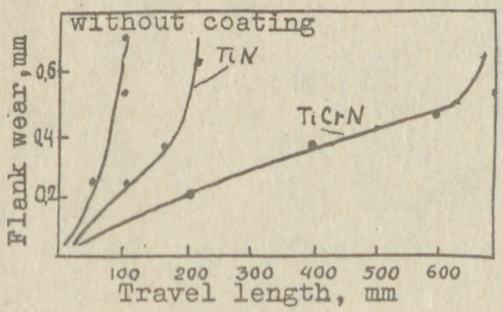


Fig.13. Wear resistance of cemented carbide inserts BK8 with optimum TiCrN coating upon turning of high-temperature nickel superalloy (speed 20 m/min, feet 0,2 mm/rev., depth 1 mm, coolant)

CONCLUSION

The ion arc plating process presents wide opportunities in creating wear resisting coatings of various categories. The maximum operational characteristics of those coatings on cutting tool can obtained on the condition of optimization of the main parameters of the process, i.e. arc current, bias voltage, magnetic field strenth, pressure and composition of reactive gas, etc.
The process parameters allow to control the coating composition within a wide range by changing the component contained in the cathode material.

REFERENCES

1.Schiller S., Heising U., et al. "Vacuum Techn.", 1981, 30, Heft 7, June
2. Rother Bernd, Wi de Bertran, Weißmantel Christian, "Neüe Hutte", 1987, 32,Heft 4, April, pp.121-126
3. "Product Engineering", 1983, 62, No.3, pp. 44-45
4. Rakovski V.I. Fundamental physics of electric current switching in vacuum, M, Nauka, 197o, p.536
5. Lunev V.M. Padalka V.G. Khoroshikh B.M., JTPh, 1977, 47, pp. 1491-1495
6. Dorodnov A.M., Petrosov V.A., JTPh, 51, pp. 514-516, 1981
7. Aksenov I.M., Antufiev Yu.P., et.al., JTPh, 1981, 51, pp. 303-308
8. Dorodnov A.M., Miroshkin S.I., Petrosov V.A., JTPh letters, 1975 , 5, No 7, pp.425-428
9. Pleshivsev N.V., Physical problems of cathode sputtering, Rewiev, M., IAE, 1979, pp. 61-66
1o. Ivanovski G.F., Petrov V.M., Ion plasma treatment of materials, M., "Radio i sviaz", 1986, pp. 43-48
11.Engin Erturk, "VDI-Z", 1987, Bd 129, No.1, pp.89-94
12. FreellerH., GüntherK.G., Annals of the CIRP, 1988, 37, No.1, pp. 165-169
13. Vereshaka A.S., Tretjakov I.P. Cutting tools with wear resisting coatings. M.,"Mashinostroenie",1986, pp.7o-76

The Electronic Design Interchange Format EDIF
— Capabilities and Evaluation —

by

Klaus Quibeldey-Cirkel, Dipl.-Ing.
Michael G. Wahl, Dr.

University of Siegen
Institute of Data Processing
Hölderlinstraße 3
D-5900 Siegen
West Germany

Abstract

This article gives an introduction to the de-facto industry standard for the exchange of electronic design information: EDIF. First, the incentives for a common interchange data format are analyzed and — contrasting the flaws of previous formats — the evolution of the EDIF standardization effort is outlined. Currently, EDIF is mainly used as a flexible vehicle for information exchange between electronic circuit designers on the one side and both CAD/CAE and semiconductor industries on the other. In the areas of mask artwork, netlists and schematics, the format is already well established as a standard in a multivendor design environment. Intensive on-going work is focused on the domains of printed circuit design, behavioral description and test. With the help of some illustrative examples, a digest of the EDIF framework — basic concepts and syntax — is presented. The paper closes with an evaluation of the status quo and an outlook on the long-term objectives of the EDIF community.

1 Introduction

1.1 Motivation for a Standard Interchange Format

The rapidly widening CAx scenario of today places the electronic circuit designer in a predicament: On the one hand, highly sophisticated design and verification tools are readily at his disposal supporting all stages of the design process — from the abstract view of behavioral description down to the geometric patterns of mask layout. In principle, he is free to choose equipment and services best suited for his particular task from a growing number of silicon foundries and CAD/CAE system and workstation companies. On the other hand, however, the variety of feasible choices is strongly narrowed by the incompatibility of the diverse data formats actually in use.

Looked at in the short term, the problem of data exchange between in-house design systems and out-of-house equipment and services from ASIC, PCB and tester industries can only be solved by format translators tailored to the internal data structures of the individual tools. It goes without saying that this solution brings about a large overhead of software development. In the long run, solely a common interchange format for all facets of electronic design data will drastically diminish investment in format converting. Fig. 1.1 is to illustrate this. Given the number of senders and recipients by n, $n(n-1)$ different formatters would be necessary for an unrestricted bidirectional information exchange. Compared with $2n$ conversions using a common information interface, the strongly felt need for an international cooperative standardization effort is self-evident.

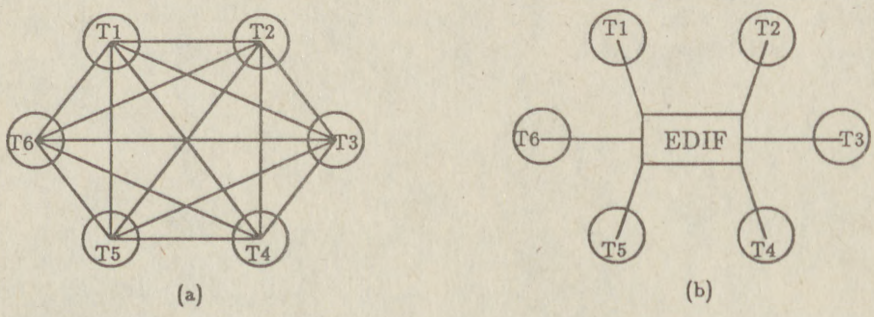


Fig. 1.1: Reducing the number of formatters from quadratic (a) to linear (b).

1.2 Shortcomings of Previous Data Formats

While a wide variety of interchange formats and hardware description languages have been developed over the past decade, none of them has turned out to be a suitable candidate for an industry standard because of one or more of the following drawbacks.

- *Narrow scope*

  Not all aspects of electronic design data (e.g. mask artwork, netlists, behavioral description) are adequately addressed by the same format.

- *Proprietary constraints*

  Many formats are owned or controlled by specific CAD/CAE companies and silicon foundries. Thus, access and proliferation are limited by licensing.

- *Difficult to implement and to extend*

  The development and maintenance of parser and generator software, especially if upward compatibility is an issue, are not always supported by a straightforwardly structured data format. As design and verification methods of integrated and printed circuits rapidly evolve, the spectrum of design data widens and requires easily manageable extensions to the actual version. A great deal of present formats misses the capability to meet future needs of the design process.

The public interchange format EDIF has successfully overcome most of these drawbacks. From the beginning, it has been designed to achieve compatibility in the multivendor CAD/CAE environments of today and tomorrow. Not by decree but by broad applicability, EDIF has become a de-facto industry standard.

1.3 The Evolution of the EDIF Effort

In late 1983, EDIF was launched as a cooperative initiative of major CAD system and semiconductor corporations: Daisy Systems, Mentor Graphics, Motorola, National Semiconductor, Tektronix and Texas Instruments. The initial approach was to extract the best features from previous formats to develop a powerful unified industry standard. A steering committee was formed to coordinate the development activities with recognized institutes of standardization. The first version of the Electronic Design Interchange Format (1985) already covered the necessary subsets of data to be exchanged between ASIC designers and silicon foundries. From the beginning, ASIC-oriented information, such as macro libraries, technology specifications, netlists, schematics, mask layout and stimulus/response vectors, could be expressed in EDIF. In order to investigate special problem areas of the design process, the steering committee impaneled several subcommittees of experts to address the issues of printed circuit design, test specification, device modelling, behavioral description, physical design rules, process and device, reliability and quality. With upward compatibility in mind, the solutions found are

proposed for inclusion within the evolving EDIF framework. Fig. 1.2 illustrates the scheme of the EDIF organization as a whole.

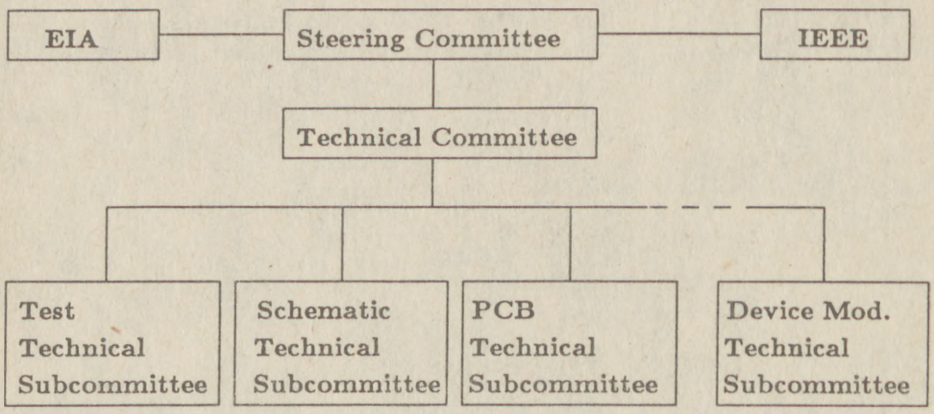


Fig. 1.2: EDIF organization scheme

2 EDIF Digest

2.1 Basic Concepts

Modern design methodology is mainly based on two powerful principles of structuring: *abstraction* and *instantiation*.

Different levels of abstraction, such as behavioral, logical and physical, help to structure the mass of data compiled during the entire design process of electronic circuits. The top-down approach involves the method of gradual refinement as it is well known in software engineering. The bottom-up approach facilitates the composition of complex structures from less complex ones.

The instantiation principle is essential for VLSI design. By referencing previously defined and verified design units — called cells —, an instantiation hierarchy avoids the time and storage space consuming efforts of replicating cell contents. At a given level of abstraction, it further supports structuring and, thus, clarity of information.

The basic concepts of EDIF strictly observe these fundamental principles of structuring mass data. The following is to demonstrate this.

2.2 The Structure of an EDIF Description

Fig. 2.1 illustrates the EDIF hierarchical approach of representing design data. At the highest level, the description contains all aspects of information in a single logical file. The file may contain several libraries defining cells and technologies. A library represents a grouping of cells with a set of technological features in common. Libraries may be defined either locally, i.e. within the current EDIF file, or externally. In the former case, design information should be complete. This is not to say that the design to be shipped has to be complete, too. The format allows shipment of partial information, such as macro libraries and technology specifications from ASIC manufacturers, the only condition being that the subset of information is self-contained.

As most design and verification tools only support a narrow scope of application — a design rule checker, for instance, will mainly work on mask layouts while a simulator, by contrast, will do so on netlists, device models and testvectors —, EDIF provides several perspectives of the information content of a cell. A cell definition can be partitioned into one or more different representations, called *views*. Currently, ten *view types* are provided. While eight views are directly concerned with design information, two are for general purposes.

- *netlist*

  This view is used to specify connectivity. It holds the details of instantiated cells and the connectivity between them.

- *schematic*

  Besides connectivity, associated diagrammatic information for schematic capture is described.

- *symbolic*

  The *symbolic* view is used to transfer high-level topological information of cells. It is placed at an intermediary stage between *schematic* and *maskLayout*.

- *maskLayout*

  This view describes geometric figures on mask layers and the information of how to interpret and represent them. The description is restricted to the corresponding cell boundaries. No information of connectivity is given.

- *pcbLayout*

  The *pcbLayout* view represents a class of information similar to the one of *maskLayout* except for the top level cell being a board.

- *behavior*

  (still incomplete in the present version)

- *logicModel*

  This view is used to describe the logic simulation model of a cell. It includes support of stimulus and response data.

- *graphic*

  Graphical information shared by several cells, like symbols, logos, pageborders, etc., can be expressed by this representation.

- *document*

  The *document* view holds textual information, diagrams and symbols in a printable form.

- *stranger*

  In all cases where the main EDIF views do not suffice, this one permits the use of any constructs to define special sets of data. However, no guarantee is given that the semantics of this view is transferable to or interpretable by another CAD system.

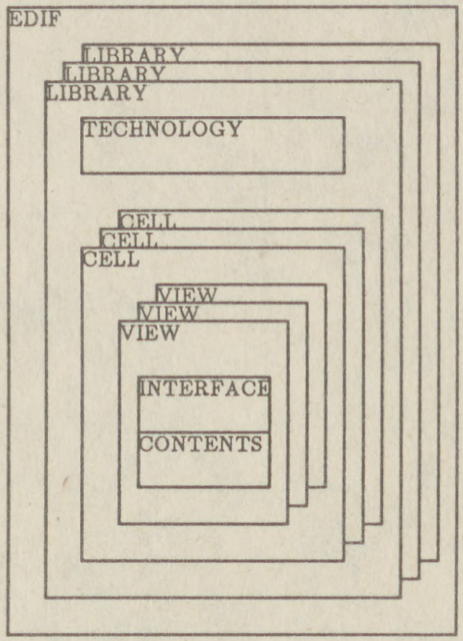


Fig. 2.1: Hierarchical structure of an EDIF file

At a given view, a cell is further structured into two blocks: *interface* and *contents*. The *interface* block can be regarded as the abstraction of the cell. It gives the set of information necessary for an instantiating cell to communicate with the instantiated one, e.g. via port references.

The detailed implementation of a cell at a particular *view* is described in the *contents* block. The description involves either the actual cell definition at the lowest level or

instantiations of simpler cells together with their connectivity. In the latter case, EDIF requires a *define-before-use* approach to make sure that the cell definitions are completed before the cells are instantiated, i.e. referenced. This concept facilitates the development of single-pass parsers and ensures design consistency.

2.3 Basic Syntax and Semantics

First and foremost, it should be stressed what EDIF does not stand for. It is neither a programming language nor a database system for electronic designs. In spite of its resemblance to the *Lisp* programming language, it is not executable. The intention solely lies on the transmission of design data from one database to another. Furthermore, the format does not specify any medium of transport, nor does it determine any physical compaction or encryption techniques. Issues of data access and storage efficiency are not addressed.

The syntax of EDIF shows a *Lisp*-like nested structure. The "atoms" are primitive data like identifiers and tokens. Complex structures are composed of parenthetical lists containing either primitive data or other lists as elements. Typically, the first element of a list is a reserved keyword which gives meaning to the following items.

Thus, the general form of an EDIF statement is as follows:

(keyword
    { *integerToken* | *stringToken* | *identifier* | *form* }
)

The curly braces {} indicate that an item may be repeated zero or more times. A vertical bar | symbolizes a choice. The *Lisp*-like syntax is obvious: A form is always put in parentheses (). It begins with a keyword followed by a list of items. As items may be other forms, an EDIF statement is typically given by a nested structure.

As the scope of the description may range from geometric primitives in the *maskLayout* view to procedural description of a microprocessor in the *behavioral* view, the language definition supports three different levels of complexity which are upward compatible. At *level 0* the user can exclusively describe non-parametric designs, i.e. only simple constants are permitted. *Level 1* allows the use of variables and expressions. This implies that parametric cells, e.g. a register with word length as parameter, can be expressed. If complex data types and procedural description are an issue, *level 2* provides the necessary constructs as they are known from higher programming languages.

The authoritative source of the language definition is given by the *"EDIF Reference Manual"*. Fig. 2.2 gives a simplified example of the syntax of an EDIF description. A flipflop is described from different views. Reserved keywords are set in bold type.

```
(edif SimpleExample
  (edifVersion 2 0 0)
  (edifLevel 0)
  (keywordmap (keywordlevel 0))
  (status
    (written
      (timeStamp 1990 09 13 12 45)
      (dataOrigin "University of Siegen") ...
    )
  )
  (library SimpleMacros
    (edifLevel 0)
    (technology ... )

    (cell NAND ... )

    (cell RSflipflop (cellType generic)

      (view LogicalNetlist (viewType netlist)
        (interface
          (port R (direction input))
          (port S (direction input))
          (port Q (direction output))
          (port NQ (direction output))
        )
        (contents
          (instance G1 (viewRef NANDNetlist (cellRef NAND)))
          (instance G2 (viewRef NANDNetlist (cellRef NAND)))
          (net FlipFlopNetlist
            (joined (portRef IN1 (instanceRef G1)) (portRef R))
            (joined (portRef IN2 (instanceRef G2)) (portRef S))
            (joined (portRef IN2 (instanceRef G1))(portRef OUT (instance G2))(portRef NQ))
            (joined (portRef IN1 (instanceRef G2))(portRef OUT (instance G1))(portRef Q))
          )
        )
      )

      (view SchematicDiagram (viewType schematic)
        (interface ... )
        (contents ... )
      )

      (view MaskArtwork (viewType maskLayout)
        (interface ... )
        (contents ... )
      )

      ...

    )
  )

  (design (cellRef RSflipflop))

)
```

Fig. 2.2: File extract to demonstrate the syntax of EDIF

3 Evaluation and Outlook

3.1 Status Quo

EDIF has become *"Recommended Standard ANSI/EIA—548"* which contains the official definition of the format. The present EDIF version 2 0 0 dating from April 1987 enjoys broad acceptance among both industry and science.

In the last few years, a great deal of CAD/CAE system and workstation companies in the U.S.A., Europe and Japan has developed EDIF-oriented design interfaces. Numerous software implementations based on the open standard are available on the market. It is widely used as an industry standard for the exchange of design data in the process of designing, testing and manufacturing electronic circuits with different CAx tools and on different sites.

The format has been subject of several international scientific conferences on VLSI design, testing and manufacturing. The EDIF standardization effort is a permanent focus of interest within international projects like ECIP *(European CAD Integration Project)*, JESSI *(Joint European Submicron Silicon)*, EIS (*Engineering Information System, U.S.A.)*, to name but a few. Many universities and research centers are deeply involved in EDIF development activities.

In addition to the initial organization scheme abroad, a similar one was formed in Europe (*European EDIF Technical Subcommittee* and subordinate bodies). Several EDIF User Groups emerged as a national forum for users who want to participate in the evolving standardization process. All EDIF bodies pursue an open policy of information and are open to any user from both industry and research.

3.2 Future Directions

Future releases of EDIF are planned to be incremental, meaning that extensions to the present standard will be targeted at particular domains. Later versions will include extensions to schematics, PCB and test. Currently, a great deal of research work is concentrated on data modelling aspects. The general objective is to build a consistent universal data model that will help to ensure semantic conformity. The authors of this paper are involved in the definition of such a data model for the area of testing. At the University of Siegen, intensive research activities are dedicated to the information link between CAE and ATE, that is to say between simulation and test of electronic circuits.

In case of further questions on EDIF organization and standard, feel free to contact the authors at their address.

References

- EDIF Electronic Design Interchange Format Version 2 0 0. EDIF Steering Committee, Electronic Industries Association (EIA), Washington D.C., April 1987
- Introduction to EDIF. EDIF Monograph Series, Vol. 1, EIA, Sept. 1988
- EDIF Connectivity. EDIF Monograph Series, Vol. 2, EIA, June 1989
- Using EDIF 2 0 0 for Schematic Transfer. EDIF Schematic Technical Subcommittee, EIA, July 1989
- Proceedings of the First European EDIF Forum. Brussels Airport, Belgium, Sept. 1987
- Proceedings of the Second European EDIF Forum. Amsterdam, The Netherlands, Oct. 1988
- Proceedings of the Third European EDIF Forum. Bonn, Germany, Oct. 1989

Abbreviations

CAD: Computer Aided Design

CAE: Computer Aided Engineering

ATE: Automatic Test Equipment

PCB: Printed Circuit Board

ASIC: Application Specific Integrated Circuit

VLSI: Very Large Scale Integration

LISP: List Processing Language

ANSI: American National Standards Institute

EIA: Electronic Industries Association

IEEE: Institute of Electrical and Electronic Engineers

INTERTECHNO '90 Budapest/ Hungary

Production Planning and Control (PPC) with Pull-Prinziple and Integated Bottle-neck-Management

1. No Jit without Synchronization
2. Synchronization with Availability Checks
3. Jit needs PPC with PULL-Principle
4. Diagnosis and Integrated Bottle-neck-Management
5. GRIPPS: Just-in-Time with Simultaneous MRP/CP

Prof. Dr.-Ing. Dr.-Ing. h. c. Dr. E. h. H.-J. Warnecke
Dr.-Ing. Dipl.-Math. H. Kühnle
Dipl.-Wirtsch.-Ing. R.-M. Fuchs

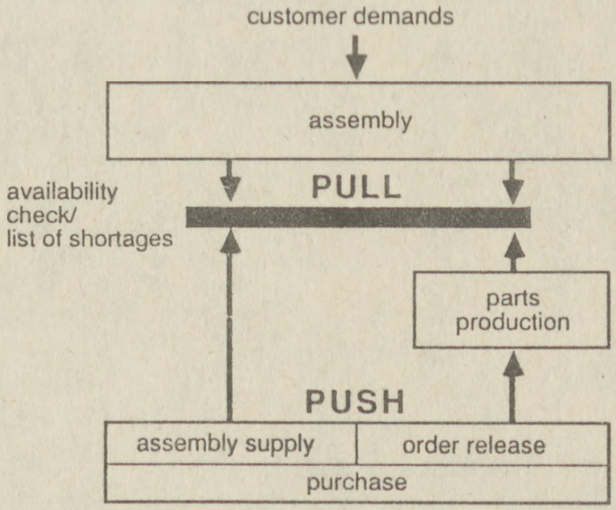
Fraunhofer-Institut for Manufacturing Engineering and Automation (IPA), Stuttgart / FRG

1 No JIT without Synchronization

The improvements in production technology (mechanization/ automation) and increasing customer demands (variety of products, short delivery times, high tech-low price) are the actual problems in the field of production planning and control (PPC). Especially in companies with large-scale-production a possible answer seems to be a just-in-time-production (JIT). A closer look at the situation in assembly shows some effects:

- mechanized and automated assembly lines lead to capacity constraints. For assembly scheduling the availability of material and capacity has to be considered.
- while customer demands may change daily, a short-term lot-sizing and scheduling is necessary to adapt the planning objekts. According to the Pull-principle the assembly schedule must be directly linked to the actual customer demands.

Therefore many companies are confronted with problems which arise from an organizational gap between parts production and assembly: while assembly is loaded with customer orders 'just-in-time', the parts production still runs under the Push-principle with adjusted production orders (picture 1).



Picture 1: Organizational gap between parts production and assembly

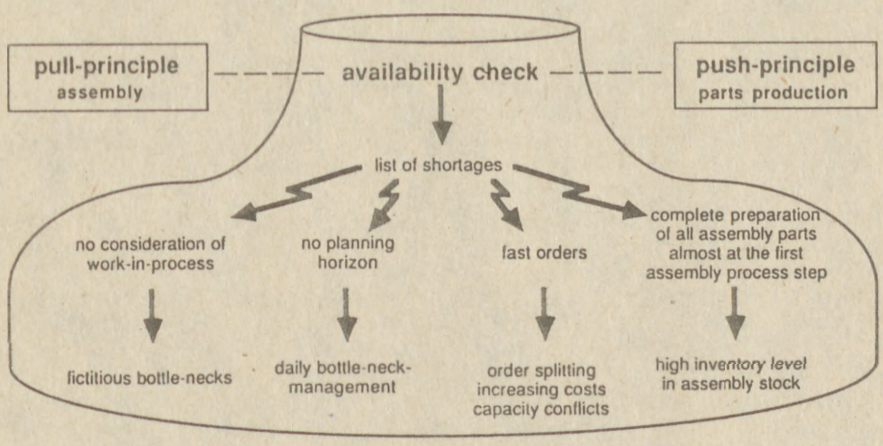
These orders are the result of a two-phase-planning procedure with material requirement planning (MRP) and capacity planning (CP). The planning procedure is usually done cyclically (e.g. MRP monthly and CP once a week). Each modification of assembly order sequences and quantities makes the planning data for the parts production become obsolete. Therefore MRP uses generously dimensioned lead times and defines high inventory levels in order not to run out of material. This security leads to inventories in the assembly stock, which

- disconnect the parts production from customer demands,
- compensate for diverging processing times and job sizes,

but also show the lack of synchronization between production segments, planning systems and principles.

2 Synchronization with Availability Checks

A detailed look at inventory levels in the assembly stock is necessary to link both production segments. In order to discover inventory shortages the availability is checked daily before assembly order release. The result is a list of shortages which leads to fast orders in the parts production and to 'special actions' in the purchase department. Some consequences of this procedure are (picture 2):



Picture 2: Availability checks - link between separated produvction units ?

o the inventory level doesn't include work-in-process. Therefore sometimes the list of shortages announces fictitious bottle-necks although inventory will soon increase.

o the list of shortages demonstrates that common MRP/CP-systems - although very complex and expensive - do not always secure the supply of material for the assembly. This task belongs further to the shop floor staff through short-term operative bottle-neck-management. Due to the missing planing horizon

it is impossible for them to consider all causes and consequences of their actions which may occur. Although shortages will be removed quite often, this actions lead to new bottle-necks in the future or on different production level.
o fast orders enforce a short-term reordering/ sequencing in the part production. In order to cover the demand for two or more parts at the same time, capacity conflicts might arise. Then part-deliveries and additional set-up operations will be necessary, resulting in an increase of both existing capacity bottle-necks and manufacturing costs.
o necessarily the parts for all assembly levels have to be supplied almost at the beginning of the first assembly step. For multi-stage and time-intensive assembly this is much to early for those parts beeing used in the last assembly level.

Daily bottle-neck-management for solving availability problems shows that orders are not practicable even if time buffers or inventory buffers have been planned. But large inventories are neither sufficient nor economical to protect from shortages, since they don't guarantee the availability of every required part, any variety of part or assembly component all the time.

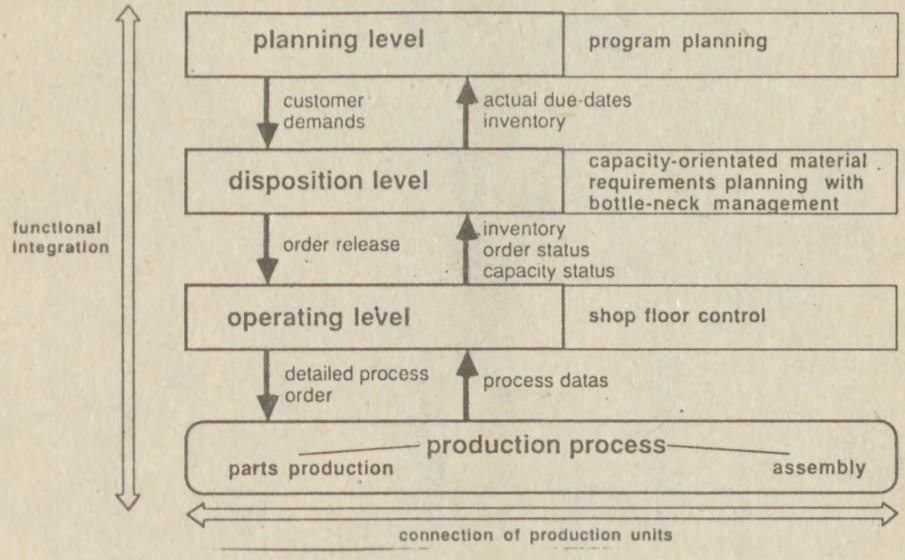
Shortages call for a modification of the assembly schedule taking the insufficient availability of resources into account. But conventional PPC-systems do not support this feedback of material and capacity constraints into assembly scheduling. So availability checks just show the inadequate integration of those systems - they are neither useful as a link between the planning principles nor able to close the organizational gap between assembly and parts production. Furthermore it's evident that the insufficient integration causes productivity losses, high inventory levels and customer order delays.

3 Just-in-time needs PPC with PULL-Principle

Just-in-time (JIT) means high delivery performance with low inventories. Although conventional PPC-systems promise to support these targets, daily experience tells it's own tale. Therefore a JIT-PPC needs new planning methods and procedures. As shown in picture 3 the characteristics of a JIT-PPC-System with PULL-principle are functional integration of planning and control levels and overlapping connection of separated production segments.
An essential deficiency of applied PPC-systems is the inaccurate representation of production process steps and material flow connections in the planning structures. This prevents e.g. from

- scheduling the assembly during capacity planning (CP),
- inventory planning and control for single process steps in the parts production

and thus contributes to an insufficient co-ordination of the resources. Therefore a main element of JIT-planning is a process-orientated planning structure which enables to go much more into details (ordering and scheduling for single process



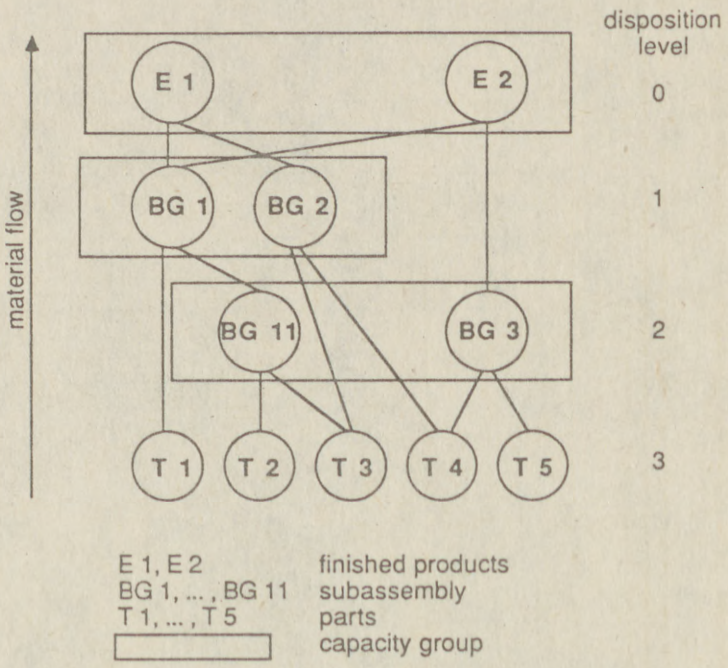
Picture 3: Just-in-time-planning

steps/ units with consideration of capacity constraints and material connections such as assembly or multi-using). To outline the capacity aspects of a process level all objects which compete for capacity of this process level have to be combined to a so-called capacity group (picture 4).

Short processing times are typical in large-scale-productions. Therefore daily adjustments of schedules and inventories are necessary. On the other hand the single time unit for a JIT-planning should be one shift. To illustrate medium-term developments the planning horizon should be more than two months.

Some companies have been very successful in short-term-ordering their suppliers urging them to deliver straight to the assembly line. The next logical step is to transfer this procedure to the own parts production ("Inhouse-JIT"). In order to plan both - assembly and parts production - completely with the PULL-principle the planning process must start with the demand of final products. Then the material planning (order, inventory) has to be adjusted to the material demands (requirements) in a step-by-step backward calculation against the material flow direction. This presumes that ordering and scheduling is determined by simultanous consideration of

- discrete capacity availability
- competition among the elements of the capacity group and
- resulting order delays and inventory levels.



Picture 4: Process-orientated planning structure

JIT-planning means that requirements for each process step are directly calculated from already scheduled orders of all next preceding process steps in the material flow direction. For this calculation the shortest possible lead time can be used which lead to optimal work-in-process levels (picture 5).

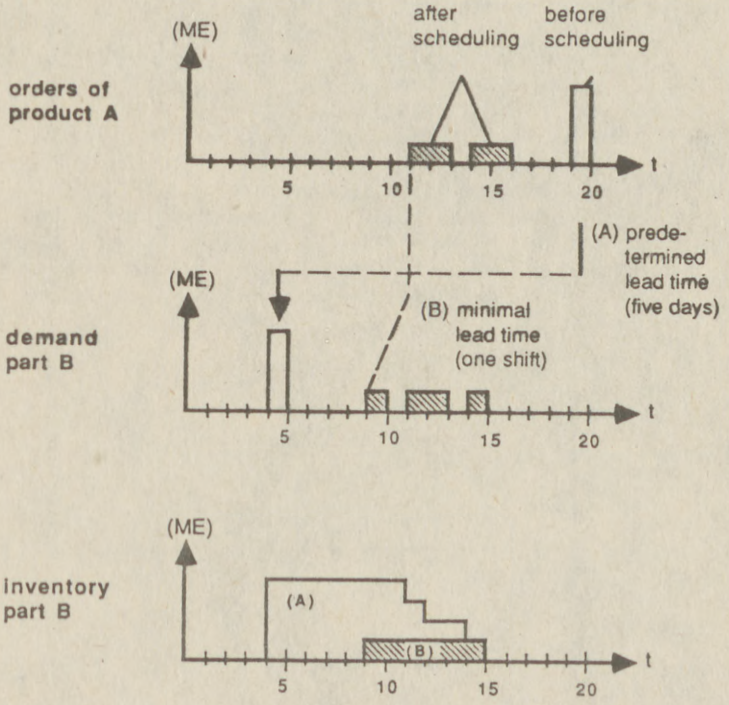
4 Diagnosis and Integrated Bottle-neck-Management

Results of a JIT-planning-procedure are

- scheduled orders consecutively calculated for all assembly and parts production levels and
- planned order quantities, requirements and inventories for all process steps that have to be planned.

The main requirement of a just-in-time-production is that the planning results and scheduled orders

- support the targets of a JIT-production and
- are praticable with regard to capacity and inventory constraints.



Picture 5: Inventory-optimized step-by-step determination of demand

If a JIT-planning-procedure with

- detailed order schedules (shift as planning time unit)
- process-orientated planning structure
- daily planning and
- an exact step-by-step calculation of scheduled orders and resulting material requirements

is used there will be only a small margin for a short-term operative bottle-neck-management. Therefore diagnosis is an important element of the planning procedure. Diagnosis during the planning procedure deals with

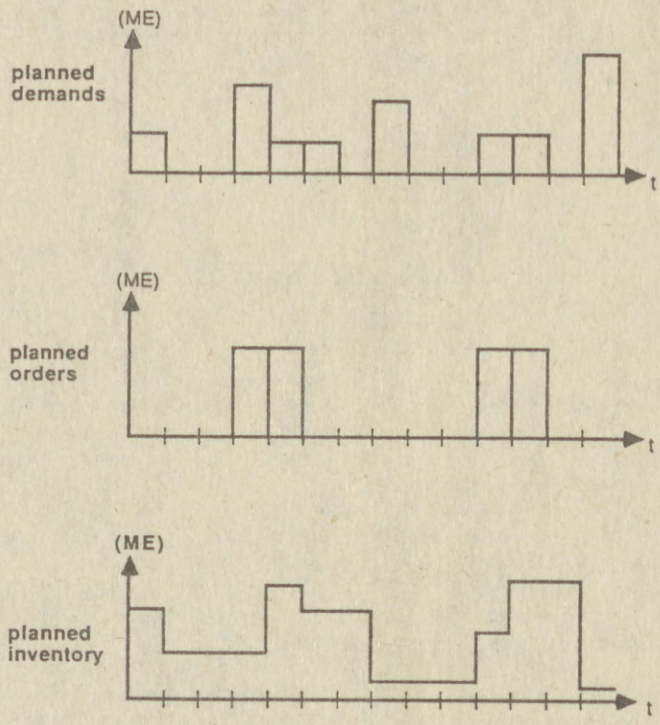
- analysis of planning results with regard to the availability of capacity and material resources as well as
- deduction of convenient actions and strategies in order to manage material/ capacity bottle-necks.

JIT-planning with integrated diagnosis is the key to discover bottle-necks and to start adequate actions in time. Therefore it's necessary to compare planning results with the targets on each production level:

o Covering the demand

- for all planning objects (products, components, parts, process steps and purchased materials)
- on each production level and
- in each time unit (shift) of the planning period.

With short lead times between the production levels, every breakdown or resulting shortage on a production level will call for availability problems on the following levels. In order to discover shortages resulting from planned orders and requirements the inventory level has to be analysed (picture 6).

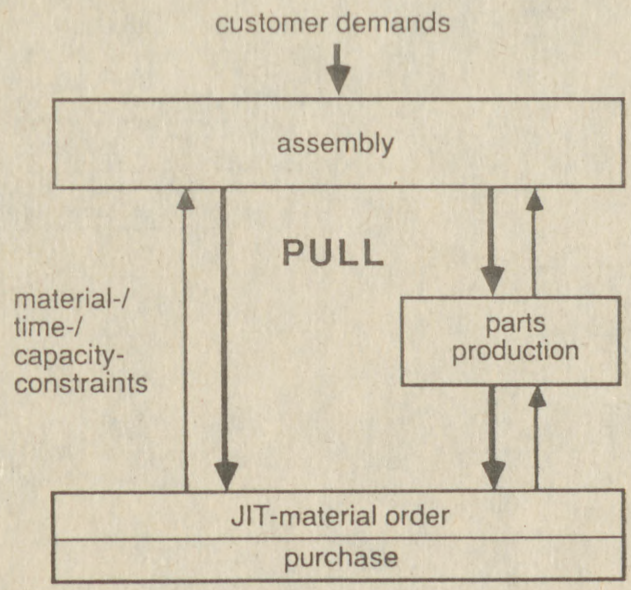


Picture 6: Analysis of time-discrete planned inventory

JIT-planning reduces work-in-process with a step-by-step calculation according to the PULL-principle. That means: "Production when there is a demand". Therefore other planning targets are

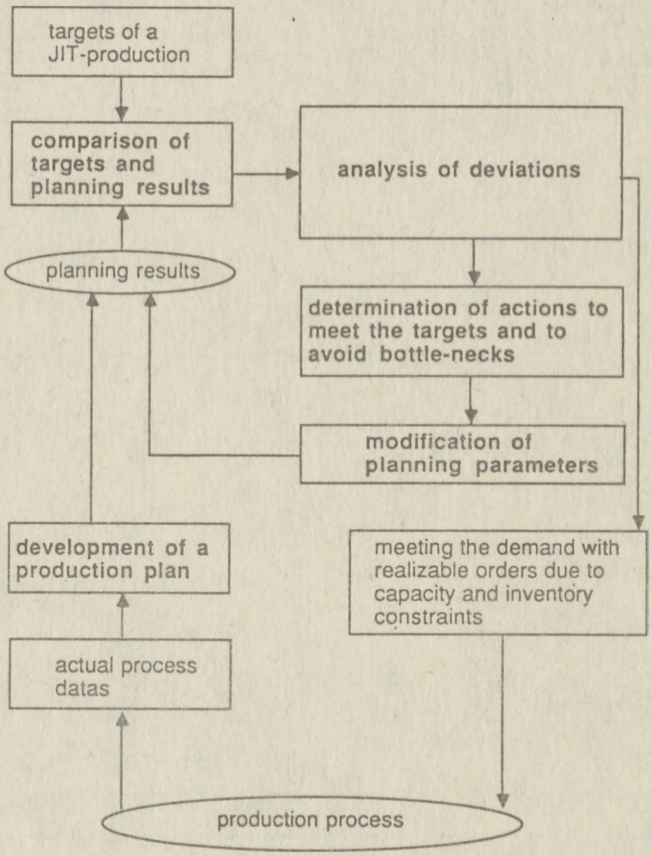
o minimal inventory when starting a production process step and keeping a presumed 'economical' lot-frequence (medium range of inventory) and
o full capacity loading - but only where it is necessary. In a JIT-planning system orders have already been scheduled with regard to capacity constraints. Then capacity bottle-necks will always lead to shortages and can be located by analysing the planned inventory. It is not a JIT-target just to fill-up the given capacity on each production level as much as possible. For order scheduling this has to be taken into account only for certain process levels (e.g. heat-treating shop). On the other hand free capacity should be identified in time.

The analysis of shortages during the planning procedure will show that targets have been missed by the planned orders. But deviations on different production levels have specific effects on the primary target of a JIT-production "covering customer demands". Another aspect is that - if an impending bottle-neck on one of the first production levels is recognized - it may be possible to release additional capacity or security stocks on the following production levels. Therefore analysing expected bottle-neck-effects includes considering their relevance - always according to the "tolerance conception": the relevance of



Picture 7: JIT-planning with integrated feed-back

an impending bottle-neck increases if it's close to the actual planning date and with the amount of the resulting shortages. This new target-plan-diagnosis offers the possibility of defining certain actions in time to avoid bottle-necks by modifying orders and schedules. Actions are e.g. buffer release (security stocks, capacity) and adaptation of the planning results by a specific bottle-neck-orientated modification of order quantities and sequences. These may not necessarily lead to an avoidance of a realized bottle-neck. In this case the planning direction must change: the constraints now have to be taken into consideration while reordering the following production levels in the material flow direction. So a step-by-step feedback procedure is integrated within a JIT-PPC (picture 7). Impending bottle-necks in assembly, parts production or purchase will already be discovered during the planning procedure and avoided by modifying order quantities and schedules.



Picture 8: JIT-planning with integrated diagnosis

5 GRIPPS - Just-In-Time with Simultaneous MRP/CP

Picture 8 shows the conception of a PPC-procedure with integrated diagnosis, which has been created especially for a multi-stage flow-shop-production with a large variety of products. This conception has been implemented in a JIT-PPC-prototype "GRIPPS" at the IPA-Fraunhofer Institut in Stuttgart. Important characteristics of GRIPPS are

- a preview resource planning by analysing planning (and not former production) results with regard to target deviations and
- the use of a simultaneous MRP/CP planning procedure.

Experiences e.g. in a moulding part of an automotive plant have proved that establishing a JIT-production needs more than using a suitable PPC-system. First of all several projects have to be started to remove organizational handicaps in the field of

- Process planning
  Not only technical but also capacity constraints have to be considered while adjusting process steps o their preferred capacity units
- Data registration
  On-line or at least daily registration of all actual process data (inventory, capacity,..)
- Inventory management
  Dealing with both stocks and work-in-process
- Quality management
  Quality checks during production process so that only approved parts will pass to the next process level

The installation of GRIPPS offers the following advantages:

- Production planning and control with PULL-principle
- Flexibility to cover changing demands by daily planning
- JIT-planning-procedure abolishes the organizational gap between production segments
- Integrated diagnosis to succeed in covering the demand by realization of bottle-necks and specific modification of the planning results
- Improvements in lead times and inventories
  First implementations show that today's inventories and work-in-process-levels can be reduced by more than 50 % together with a higher performance in covering customer demands.

LOCAL MODIFICATION OF A FREE-FORMED SURFACE PRESERVING SHAPE DATA

WATANABE, Michiko
Computing Room, Asahikawa National College of Technology, JAPAN
FURUKAWA, Masashi
Dept. of Technology Information Integration, Asahikawa National College of Technology, JAPAN
KAKAZU, Yukinori
Dept. of Precision Engg., Faculty of Engg, Hokkaido University, Sapporo, JAPAN

This paper represents a local modification technique to model a free-formed surface. Our approach to the local modification to the free-formed surface uses the control parameter technique. Two kinks of parameters control the 1st order derivatives which guarantee the 1st order derivative (C^1) continuity and make connection between two patches in the free-formed surface. These parameters are called "Tension and Bias" parameters. Two other kinds of parameters control the 1st order derivatives which make C^1 discontinuity and generates non-smooth connection such as a sharp edge. These parameters are called "Tension-continuity and Bias-continuity" parameters. Furtheremore, the same techniques are expanded by dealing with the 1st order derivatives approxmated by 2nd order derivatives to make the local modification of the free-formed surface. It makes possible to interpolate arcs and give the surface boundary rapid rising. The uses of these parameters enables us to reconstruct the real form of the object preserving the shape data as the computer model.

INTRODUCTION

Designing interpolatory surface and modifying it has been an important problem in a field of computer aided geometric design. In most of cases, the interpolatory surface methods need lattice points as input for defining the surface. After this first definition, it usually needs to modify the initial surface locally. There are roughly two ways to make the local modification to the surface. The first is to move some

lattice points (or control points) to satisfy the designers image. The second is to control partial tangent vectors. To move the input lattice points often causes the variational diminishing and keep the result surface at a distance from the designers image. In resetting the partial tangent vectors, it becomes defficult to intutively understand the suitable tangent vectors. When using the Bezier method, it is not so difficult to locally modify the surface as other methods. But, it requests the inversion transformation procedure from the control points to the initial points for interpolation. Althogh Coons method is widely used, it has the lack to estimate twist vectors, which sometimes makes it difficult for the designers to use the Coons method.

This paper describes the local modification method satisfying (1) preserving the input lattice points for modification, (2) modifying the surface by controlling the partial tangent vectors with use of shape parameters, and (3) neccesary not to treat the twist vectors. The interpolation method adopted here is Brown method [1] for the above condition. The Brown method does not need to use the twist vectors. The partial tangent vectors across boundary curves arround surface patches on the lattices are estimated by adding chord vectors of the adjucent patch to the chord vectors of the current patch. In this operation, the shape parameters are introduced to control the partial tangent vectors. The shape parameters can control not only C^1 continuity but also C^0 continuity (C^1 discontinuity) of the surface. Experiments using the shape parameters show us validity of locally modifying the surface preserving the input shape data.

BROWN SURFACE

We use the notation and expression defined by Forrest,A.R. [2]. Curve definition takes the form :

$$Q(t) = F(P), \tag{1}$$

where F denotes the vector-valued function applied to a set of data points P. Nolationaly we can regard Q as an approximation to some curve P which we may know its discrete points. We can rewrite the equation (1) as

$$Q(t) = \phi P, \tag{2}$$

where ϕ is an approximation operator. When we turn to surfaces, which are bivariate functions, let ϕ be an operator associated with the parametric variable u, and ϕ be the operator associated with the parametric v. I.e. ϕ and ϕ are univariate operators. Surface definition reduces determining which operators ϕ and ϕ to use, and how to combine them. The surfaces are generally built up as arrays of the patches over the given lattice points. As we define a curve by interpolation to the points, a surface is interpolated to an array of the lattice points. Several surfaces are defined as follows.

a) Cartesian product surfaces

$$Q(u,v) = \phi\ (\phi\ P(u,v)),$$
$$= (\phi \cdot \phi)P(u,v), \tag{3}$$

where $Q(u_i,v_j) = P_{i,j}$.

b) Lofted surface

Suppose we know a family of curves of constant v, $P(u,v_j)$, we can interpolate between these curves using interpolation to generate the surface ;

$$Q(u,v) = \phi P(u,v). \tag{4}$$

In term of constant u, we have the surface ;

$$Q(u,v) = \phi P(u,v), \tag{5}$$

c) Coons surface

Coons surface is known as the boolian sum surface. By using the notations (3) ~ (5), it is denoted by

$$Q(u,v) = \phi P(u,v) + \phi P(u,v) - (\phi \cdot \phi)P(u,v). \tag{6}$$

When the cubic Helmite interpolation is used as the operators for the Coons surface, twist vectors appear. It is difficult to estimate the twist vectors in general. Brown,J.H. proposed the interpolation method which does not need the twist vectors [1]. Brown surface is expressed as follows.

d) Brown surface

$$Q(u,v) = g_1(u,v)\,\phi P(u,v) + g_2(u,v)\,\phi P(u,v), \tag{7}$$

where $g_1(u,v) + g_2(u,v) = 1$.

When applying the cubic Helmite interpolation to the operator, the Brown surface is given by

$$Q(u,v) = g_1(u,v)H(u)^T P(v) + g_2(u,v)H(v)^T P(u), \tag{8}$$

where $H(t) = [\ 2t^3-3t^2+1 \quad -2t^3+3t^2 \quad t^3-2t^2+t \quad t^3-t^2\ ]$,

$P(u) = [\ P(u,0) \quad P(u,1) \quad P^v(u,0) \quad P^v(u,1)\ ]$,

$P(v) = [\ P(0,v) \quad P(1,v) \quad P^u(0,v) \quad P^u(1,v)\ ]$,

$g_1(u,v) = v^2(1-v)^2/f(u,v)$, $\quad g_2(u,v) = u^2(1-u)^2/f(u,v)$,

and $f(u,v) = u^2(1-u)^2 + v^2(1-v)^2$.

The Brown surface in the equation (8) may be defined by four boundary curves and their partial tangent across the boundary curves called cross boundary derivatives. C^0 and C^1 continuities (compatibility) are guaranteed by them. We now introduce the shape parameters for locally modefying the Brown surface preserving the C^0 continuity and controlling C^1 continuity. The Brown surface is shown in Figure 1.

LOCAL MODEFICATION OF BROWN SURFACE

Lofting allows us to specify input data along one or other of the set of lattice lines. It includes all the data at the lattice points. The Coons surface is defined by data along both sets of lattice lines, and includes lofting in either direction as

spesial case. The Brown surface has the same properties. Each lattice is called a patch. we call a patch, which is enclosed between the i-th and (i+1)-th lattice lines along v direction and between j-th and the (j+1)-th lattice lines along the u direction, (i,j) patch. The compatibility of the Brown surface between (i-1,j) patch and (i,j) patch along the v direction is given by $P(u_i,v)$ and $P^v(u_i,v)$. In order to locally modify surface geometry, we only deal with the cross boundary derivatives(the partial tangent) $P^v(u_i,v)$. Let $P^v(u_i,v)$, $P^v(u_{i-1},v)$, $P^v(u_{i+1},v)$ set as

$$P^v(u_i,v) = c, \quad P^v(u_{i-1},v) = a, \quad \text{and} \quad P^v(u_{i+1},v) = b \tag{9}$$

Let us consider how to estimate c if a and b are given.

C^1 CONTINUITY CONTROL

The surface geometries on the (i-1,j) and (i,j) patches along the v direction is controlled by a, b, and c. Under the C^1 continuity, we estimate c by

$$c = \lambda a + \mu b, \quad \text{where} \quad 0 \leq \lambda, \ \mu \leq 1. \tag{10}$$

If we set

$$u = (1-\lambda), \tag{11}$$

We have

$$c = \lambda a + (1-\lambda)b. \tag{12}$$

When λ is approaching to 1, c is approaching to a. This means that a slope of(i-1,j) patch along the v direction is close to a. On the other hand , λ is approaching to 0, c is approaching b. This occurs that a slope of (i,j) patch along that v direction is close to b. This allows us to locally control the slope of (i-1,j) or (i,j) patch.

If we set $\mu = \lambda$, then we have

$$c = \lambda(a+b). \tag{13}$$

When λ is approaching to 1, c is close to (a+b) and |c| is being the maximum value. In this case, the surface geometry on the (i-1,j) and (i,j) patches is close to be flat along the v directions passing through the common boundary $p(u_i,v)$. When λ is approaching to 0, c is close to 0 and the surface geometry on the (i-1,j) and (i,j) patches is being singular at $P(u_i,v)$.

C^1 DISCONTINUITY CONTROL

In the case that the surface has the C^0 continuity and C^1 discontinuity, let us define c^+ and c^- as follows,

$$c^- = \lim_{\Delta v \to -0} \frac{P(u_i,v+\Delta v)-P(u_i,v)}{\Delta v}, \quad \text{and} \tag{14}$$

$$c^+ = \lim_{\Delta v \to +0} \frac{P(u_i,v+\Delta v)-P(u_i,v)}{\Delta v}. \tag{15}$$

The surface geometry on the (i-1,j) and (i,j) patches is defined by a and c^- and b and c^+, respectively. In order to estimate c^- and c^+, we use the same manner as in the equation (10) as follows,

$$c^- = \lambda^- a + \mu^- b, \quad \text{where } 0 \leq \lambda^-, \mu^- \leq 1, \tag{16}$$

and

$$c^+ = \lambda^+ a + \mu^+ b, \quad \text{where } 0 \leq \lambda^+, \mu^+ \leq 1, \tag{17}$$

We set that

$$\lambda^- = \lambda, \ \mu^- = (1-\lambda), \ \mu^+ = (1-\lambda), \text{ and } \mu^+ = \lambda. \tag{18}$$

If λ is approaching to 0, c^- is approaching to a and c^+ is approaching to b. This means that the slope of the (i-1,j) patch is close to a and the slope of the (i,j) patch is close to b. The surface geometry on the (i-1) and (i,j) patches becomes a bud like shape. If λ is approaching to 0, c^- is approaching to b and c^+ is approaching to a. The surface geometry on the (i-1,j) and (i,j) patches becomes a heart like shape.

We set that

$$\lambda^- = \mu^- = \lambda, \text{ and } \lambda^+ = \mu^+ = (1-\lambda). \tag{19}$$

If λ is approaching to 1, c^- is approaching to a and c^+ is approaching to 0. In this case, the surface geometry on the (i-1,j) patch along the v direction becomes flat and the slope of the (i,j) patch is close to b. If λ is approaching to 0, the reflected geometry occurs when λ is approaching to 1.

We may set that

$$\lambda^- = \lambda, \ \mu^- = (1-\lambda), \ \lambda^+ = \mu^- = \lambda, \tag{20}$$

or

$$\lambda^- = \mu^- = \lambda, \ \lambda^+ = \lambda, \ \lambda^- = (1-\lambda). \tag{21}$$

There are the combination of the equations (18) and (19).

ESTIMATION OF CROSS BOUNDARY DELIVATIVES

In the equations (13),(16) and (7), a and b have not yet been estimated. One estimation is to give their value by chords spanned to the (i-1,j) and (i,j) patches, respectively. Namely, a and b are defined by

$$a = P^v(u_i,v) - P^v(u_{i-1},v), \tag{22}$$

and

$$b = P^v(u_{i+1},v) - P^v(u_i,v). \tag{23}$$

We call λ a shape parameter. In the case described by the equation (11) and (13) in the C^1 continuity, the shape parameters are called bias and tension, respectively. These are illustated in Figure 2 and Figure 3. In the case described by the equation (18)and (19), the shape parameters are called bias-continuity and tention continuity.

We have another setting for a and b and they are define by

$$\begin{aligned} a &= [P^v(u_i,v) - P^v(u_{i-1},v)]/2 + [P^v(u_{i-1},v) - P^v(u_{i-2},v)]/2, \\ &= [P^v(u_i,v) - P^v(u_{i-2},v)]/2, \end{aligned} \tag{24}$$

and

$$\begin{aligned} b &= [P^v(u_{i+2},v) - P^v(u_{i+1},v)]/2 + [P^v(u_{i+1},v) - P^v(u_i,v)]/2, \\ &= [P^v(u_{i+2},v) - P^v(u_i,v)]/2. \end{aligned} \tag{25}$$

Estimation by the equations (24) and (25) is often valid when applied to the surface boundaries as the bias-continuity parameter. By using this, we may make the rapid rising of the surface when generating sphere or cylindrical geometry arround the surface boundary. In fact, we can prove that it can approximate semi-circle equivalent to Bezier curve approximation.

Across the u direction, we can estimate the same manner for $P^u(u,v_j)$ and the Brown patch is locally controlled.

EXAMPLES

To veryfy validity of the shape parameters for locally controlling the surface geometry, examples are shown in Figures 4 ~ 16. Figure 4 shows the initial surface given by four patches where cross boundary derivatives are defined by bias parameter $\lambda = 0.5$. It is always used as defaults when shape parameters are not specified. Figure 5 and 6 show the bias parameter examples. Figure 7 and 8 show the tension parameter examples. Figure 9 and 10 show the bias-continuity parameter examples. Figure 11 and 12 show the tention-continuity parameter examples. Figure 13 shows the initial modelling of the telephone receiver. Figure 14 shows result of the local modification of Figure 13 using the bias, tension and bias-tension parameters. Figure 15 shows the initial face modelling and Figure 16 shows its local modification. In Figure 16, a nose and lips are emphsized by using bias-tension parameters and a face boundary are defined by bias-continuity parameter using the equations (25) and (16).

CONCLUDING REMARKS

Shape parameters introduced to the Brown surface have intuitive properties. The designers can locally modify the surface with ease. It also becomes possible to generate the sophistcated geometry by the combination of the shape parameters. This mothod is suitable for reconstructing the surface preserving the shape data in a computer. Using shape parameters, it is easy to make feature geometry such as grooves, ghost lines, shape edges and so on. In this case, the lattice are input along the feature geometry.

ACKNOWLEGMENT

We thank Dr. Aomura,k. of the president of Asahikawa National College of Technology for his generous support. The research for this paper was in part suppor ted by the special research fund of Japanese educational department.

REFERENCES

[1] RARNHILL,R.E.,Brown,J.H. and KLUCEWICZ,I.M., A New Twist in Computer Aided Geometric Design ,Computer Graphics and Image Processing, Vol.8(1978) pp.78.-99

[2] FORREST,A.R., Computational Geometry, CGP report, University of East Anglia (1981)

[3] FAUX,I.D., Computational Geometry for Design and Manufacturing, Jhon Wiley & SONS(1982)

[4] BARSKY,B.A and BEATTY,J.C., Local Control of Bias and Tension in Beta-splines, ACM Transactions on Graphics, Vol.2, No.2, April(1983)pp.109-134

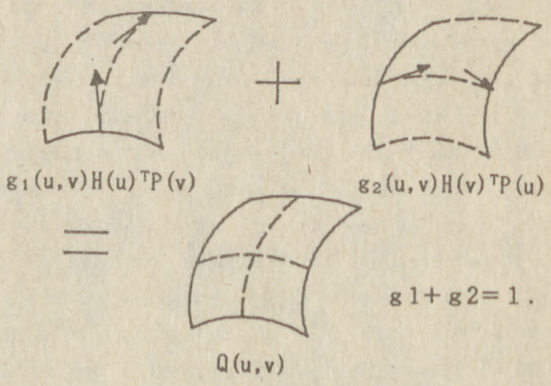


Fig.1 The Brown surface.

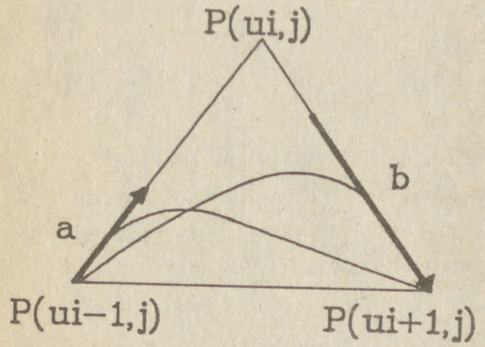


Fig.2 Bias parameter derivation.

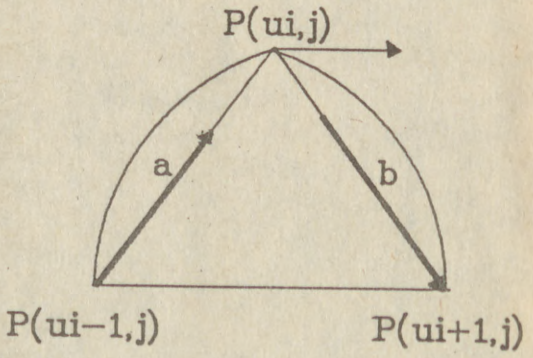


Fig.3 Tension parameter derivation.

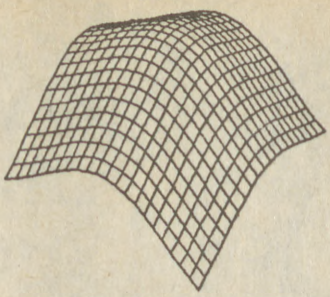


Fig.4 An initial surface defined by four patches.

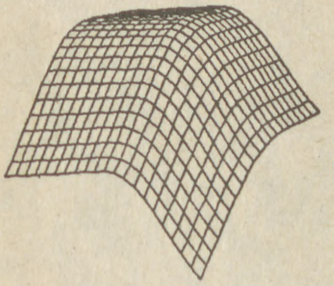


Fig.5 The surface set by Bias parameter 1.

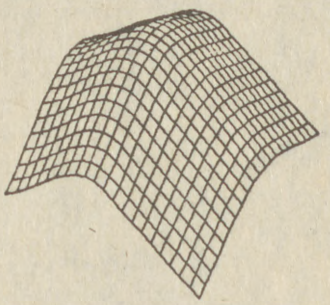


Fig.6 The surface set by Bias parameter 0.

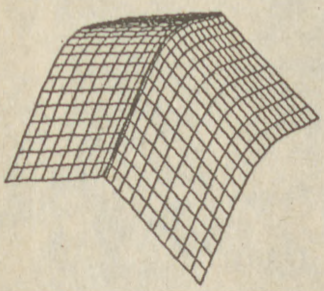


Fig.7 The surface set by Tension parameter 1.

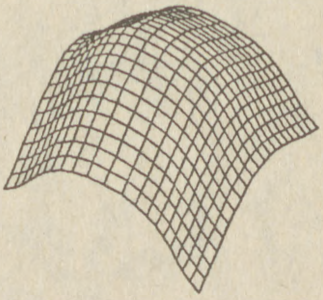


Fig.8 The surface set by Tension parameter 0.

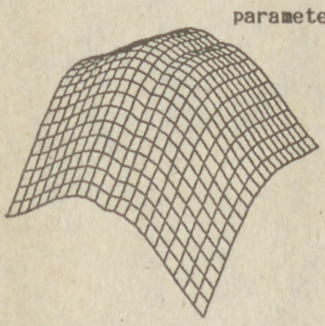


Fig.9 The surface set by Bias-continuity parameter 1.

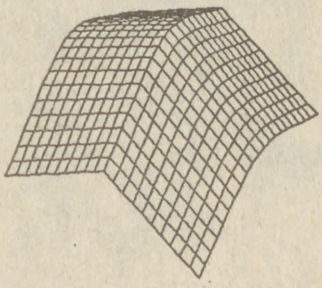


Fig.10 The surface set by Bias-continuity parameter 0.

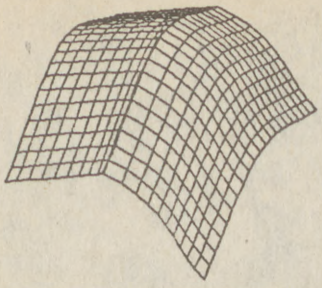


Fig.11 The surface set by Tension-continuity parameter 1.

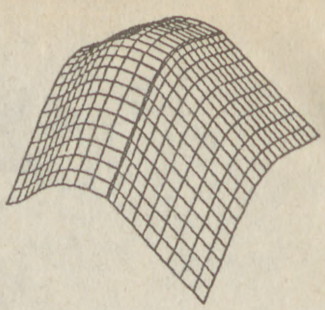


Fig.12 The surface set by Tension-continuity parameter 0.

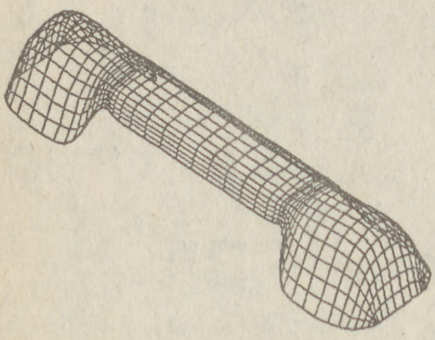


Fig.13 An initial model of a telephone receiver.

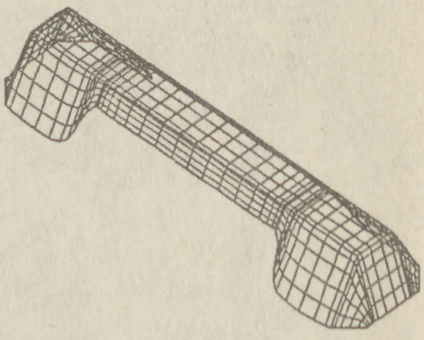


Fig.14 A modified model using shape parameters.

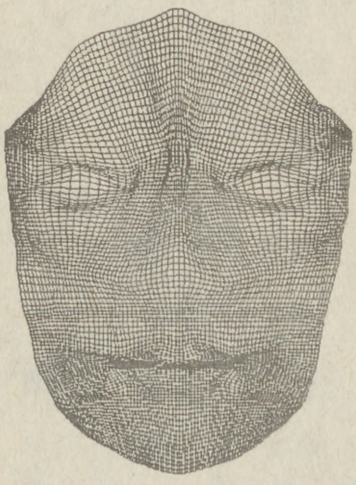


Fig.15 An initial model of a humam face.

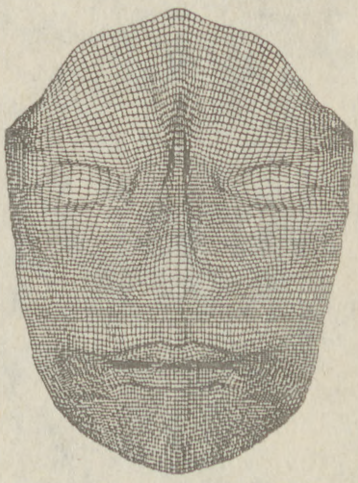


Fig.16 A modefied model using shape parameters.

A CAM APPLICATION ARCHITECTURE AND NEW METHODS FOR CAM-APPLICATION DEVELOPMENT

Hermann G. Weissenseel, Dipl.-Ing., Dipl.-Wirtsch.-Ing.
IBM Germany, Poccistraße 11, 8000 München 2

Contents

1. CAM REQUIREMENTS AND APPLICATION FUNCTIONS

2. A CAM APPLICATION ARCHITECTURE AS THE BASE FOR AN INTEGRATED SYSTEM

3. AN INFRASTRUCTURE FOR SYSTEMS HARD- AND SYSTEMS SOFTWARE

4. APPLICATION DEVELOPMENT IN CAM

1. CAM REQUIREMENTS AND APPLICATION FUNCTIONS

New manufacturing methods and technologies is the foundation to increase the competiveness of manufacturing enterprises. This is especially true for the plant floor operations in controlling processes, improving yields, managing changes to products, reducing scrap and rework, optimizing inventory, reducing lead-times and product costs.

Information processing is a key factor in using new technologies. The mission of information processing is threefold, that is the integration of

- the communication flow,
- the application functions and
- the data

with the objective to control the manufacturing processes in real-time and to keep in step in monitoring and managing exceptional situations. Information processing can include digital and analog data, text, graphics, geometry, application programs - even image and voice.

Today's applications to manage the production processes are to a great extent island solutions, covering only sections of the CAM (Computer aided manufacturing) application area. They are also limited in expandability and flexibility. The real challenge of the future is to integrate

the technological and logistical processes into one whole system. Such a system will not only manage the shop floor orders and collect feedback data (see figure 1) but also support:

- the control of flexible automated machining and assembly systems
- the control of the material and workpiece flow
- the management and provision of the plant wide facilities like tools, numeric control programs, geometry-data for robots, testplans and testtools, etc.
- the monitoring and analysis of the manufacturing processes
- the real-time response to alarms
- the management of the basic data for production processes and quality assurance

Integrating all these functions into one whole system the information volume to be processed in CAM will increase considerably (see figure 2).

2. A CAM APPLICATION ARCHITECTURE AS THE BASE FOR AN INTEGRATED SYSTEM

The integration of the various functions at the shop floor level requires an application architecture that contains a comprehensive structure of its various functions, defined program modules from which by appropriate selection a real manufacturing/process control system can be created.

Such an architecture is certainly part of a CIM Concept (Computer Integrated Manufacturing) that means it has interfaces to other functions within the CIM-environment like PPS (Production Planing Systems, CAD/CAE (Computer aided Design/Engineering) and BS (Business Systems) (s. figure 3). CAM expects from the PPS a realistic volume of released shop floor orders and from CAD/CAE the basic production data like numeric control programs, testplans, geometry-data etc. CAM responds to these systems with feedback data about the manufacturing process.

The machine/device controllers like PLC (programmable logic controller), RC (robot controller), CNC (computer numeric controller) with their various interfaces can be considered as being given from an application point-of-view.

So the CAM application area lies between PPS and CAD/CAE on one side and the device controllers on the other side. In this area a whole variety of functions are to be structured within an integrated system.

Figure 4 shows a rough model of a structure, a first step towards an architecture. Future modifications are to be expected.

The "steering element" in the CAM system are the shop floor orders or requirements data for JIT (just-in-time), the same as the customer orders or the sales plan are the "steering element" in the PPS.

The area control system manages the shop floor orders with their various operations. It schedules the orders, allocates the operations to the work centers, creates operation queues, balances capacity load variations and handles break downs and faults. The area control system also coordinates the operations to and between the manufacturing cells like

- the distribution of NC-programs, testplans, geometry-data, etc.

- the material/workpiece transfer from cell to cell, from cell to store etc. These activities may be manual, semi-automated (using control panels, fork lifts and conveyers) or fully automated (relying on programmable logic controllers, distributed control systems, stacker cranes, automated guided vehicles).

- management of the plant facilities like tools, gripping and holding devices and their technological data.

At the area level is also the management of the basic production and quality data for the shop floor orders to be worked on: like the bill of materials, routings, NC-programs, testplans etc. At this level are also evaluated the feedback data collected at the shop floor and prepared for the user in the form of status and trend reports and/or statistical analysis.

The cell level - subordinate to the area level - controls the flexible automated machining or assembly stations and also the manual workstations. Functions to be supported are:

- the management of working queues per work- or teststation

- the optimization of the operation sequence within a cell

- the transfer of the production data to the device controllers (CNC, PLC, RC)

- the collection of feedback data

- the online response to exceptional situations

- offline programming to develop NC-programms at shop floor level

The allocation of the application functions within the plant hierarchy is in accordance with the configuration principle: "delegate the functions as much as possible to the front end to increase the total systems security".

The CAM application architecture serves as the base to develop application packages of standard modules from which by appropriate selection a real system can be built. It allows the flexible implementation at area

and cell level and also vertical and horizontal communication at the shop floor.

Three basic packages are to be distinguished (see figure 5), these are:

- the area controller
- the stationary cell controller
- the material floor controller

The "area controller" package takes charge of the central management of the manufacturing process.

At the cell level five basic manufacturing cells are defined:

- production cells for machining and assembly
- tooling preparation cells
- measure and test cells
- warehouse cells
- material flow cells

An analysis of the functions within these basic cells showed that their application structure only differs non-essentially from each other, with the exception of the material flow cell. Therefore four of the defined manufacturing cells - the first four of above - are considered within the "stationary cell controller" package and the last is considered within the "material flow controller" package. It is justified to allocate this package to the cell level, since the material flow control functions interact directly with the device controllers at the device level.

Figure 6 shows the functional structure of the area controller as an example of one of the basic packages defined. According to this structure program modules can be developed, from which by appropriate selection a real system for a specific company can be built. For example the system would cover:

- the scheduling and dispatching of shop orders and their operations
- the management of parts manufacturing and assembly processes
- the control of material and parts movement, transport and storage
- the management of tools assembly, calibration and commissioning
- the communication with device controllers like CNC, PLC, RC
- the monitoring and diagnoses of the production processes

3. AN INFRASTRUCTURE FOR SYSTEMS HARDWARE AND SOFTWARE

The typical structure to combine area, cell and device controllers is shown in figure 7. LAN's (local area networks) are effectively used for the horicontal and vertical communication, for example from the planning host to the device controllers or from one area controller to another one. The IEEE (Institut of Electrical and Electronic Engineers) has three different LAN-types standardised, LAN-Typ 802.3, 4, 5. Examples of existing LAN's are IBM Token-Ring and MAP 3.0 (Manufacturing Automation Protocol).

There are various hardware systems avaiblable for the different level in the CAM-hierarchy. IBM for example offers two platforms such as IBM's SAA (Systems Application Architecture) and AIX (Advanced Interactive Executive).

SAA is IBM's comprehensive blueprint for consistency and compatibility establishing the definitions for four key application aspects - Common User Access, Common Programming Interface, Common Communications Support and Common Applications.

AIX is IBM's offering of the UNIX operating system. AIX combines consistent user and application interfaces to aid in the development of integrated applications across UNIX operating system environments.

Within SAA IBM offers optimized operating systems for different hardware product lines. With AIX IBM offers a uniform operating system with negligible hardware dependency (see figure 8).

The various computers in the area level correspond to the different product lines of IBM and to the customers required performance. For the cell level the IBM Industrial Computers (IC) and Personal Systems (PS/2) with A Real-Time-Interface-Coprocessor (ARTIC) are available. The ARTIC serves for

- realtime processing and the
- adaption of the various interfaces to the device controllers

In this context the interface to the device controllers is a given by the manufacturers of the device controllers.

4. APPLICATION DEVELOPMENT IN CAM

The cost effective and fast development, implementation and plant wide integration of applications for the plant floor operations at area and at cell level are key factors in order to stay competitive. Two concepts are outlined to cope with that requirement. These concepts correspond to two groups of people with different tasks. The first group is system-oriented for example program developers and system integrators. The se-

cond group is application oriented for example manufacturing manufacturing-engineers, process-engineers, quality-engineers and end-user-operators. For both groups a platform is provided with

- system components (SYSTEM ENABLER) and

- application components (APPLICATION ENABLER)

in order to reduce effort and time for application development and implementation (see figure 9).

The architectural view of the enabling software concept is a layered approach where the System Enabler provides a foundation common to the area and cell level for

- Data Management,

- Systems Network Communications,

- Device Management,

- Presentation Services.

The systems Enabler is a set of application program services intended to mask the implementation complexities and ease the overall integration effort. The Application Enabler then extends the System Enabling platform services to the end user, for non-programmers using a fourth generation application definition language. The resultant application software developed on either platform represents the third software layer.

In its simplest form, the System Enabler is a rich set of program function calls or tools for systems integrators and software developers to perform the complex task of plant wide application system development and implementation. A key requirement is to provide the ability to separate and distribute application software function from its physical data, and to permit full function and data distribution across a factory-wide network. This means the System Enabler should provide the programmer with a fully distributed system capability, but with a "single system view".

The System Enabler provides distributed resource independence from the application software. This means that any application in any network node has transparent access to the resources and services of any other node through a common application program interface (API). Using this API, the application programmer need not be aware or concerned about the physical location of resources he needs to access. This gives total independence of area or cell resources from the application software logic. This means also that the applicataion program is not bound to a particular LAN technology, application data can be distributed and accessed from any application on any node in the plant floor network. In addition, data management techniques range from memory resident real-time data to relational data base management.

The Application Enabler provides tools that enable the manufacturing and process engineer to develop his solutions without the assistance of a programmer. These tools allow an engineer to build, test and execute applications for monitoring, coordinating, controlling, tracking and reporting on plant operations, beginning with one product line on a single workstation or node and eventually extending to the entire factory. Designed for use in a network environment the Application Enabler provides the capabilities to run applications distributed across multiple computers, allowing multiple applications and equipment to share information. It can also integrate a host computer with factory computers that provide localized application and device support to programmable controllers, terminals, bar code scanners and so forth.

The Application Enabler has two environments: build-time and run-time. The build-time functions enable an engineer to design and develop applications more reliably and efficiently. Included are functions to define application data structures, Input/Output variables and points, the topology of the plant floor network, the application logic and a wide range of techniques for the display and presentation of the applications data to plant floor operational personnel.

The build-time environment consists of a fourth generation application facility for use by technical end-users. The application generation process itself consists of a comprehensive set of definition exercises performed at the users graphics display terminal. During this process software links are established between pre-programmed application functions stored in a function library. These pre-canned functions are then chained together for later excution in the run-time environment.

The run-time functions execute applications, collecting the data used to control and manage events as they occur and maintaining historical records for the application and the plant-wide computing environment. These functions also include a powerfull facility for plant floor monitoring that permits enduser alterations to the system without manufacturing process interruptions.

The run-time services utilize the distributed System Enabler platform for the management and presentation of real-time and relational data. Concurrent operation of the build-time and run-time environment provides the end user with his built time tools to modify his application once it is running in production mode.

Using the enabler concept allows a considerable reduction of effort and time to develop, implement, modify and maintain applications, compared to applications only based on the operating system.

IBM offers two products within the IBM Plant Floor Series: The Distributed Automation Edition program product (DAE) as the system enabler and the Application Automation Edition (AAE) as the application enabler (see figure 10). They are a key part of the IBM CAM-strategy, providing a complete development environment, containing tools that enable a non-programmer, who understands the requirements of the plant, to customize all aspects of operational management and control.

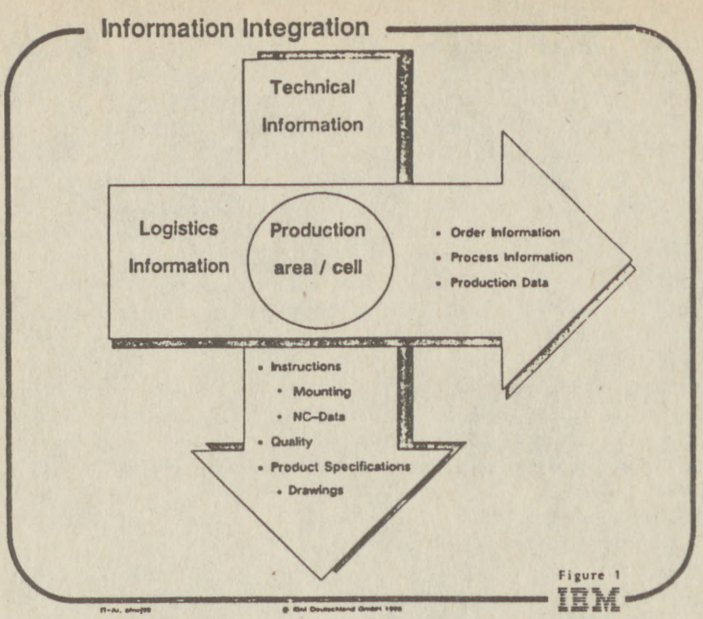
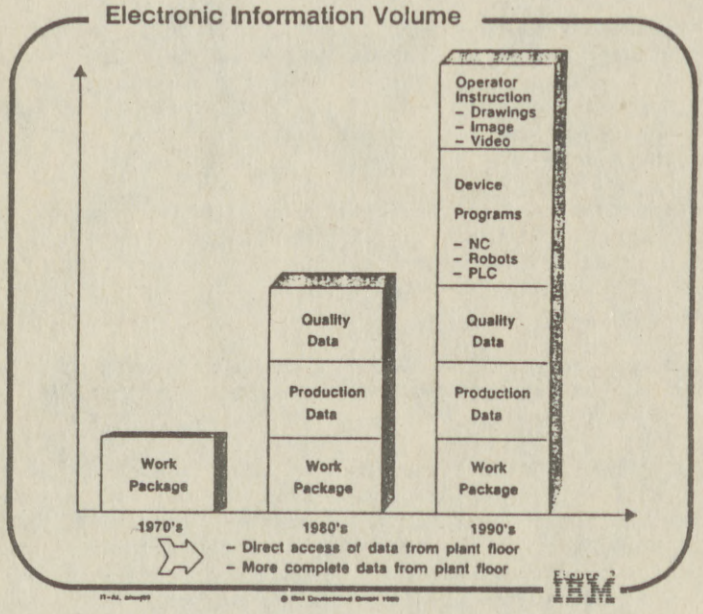
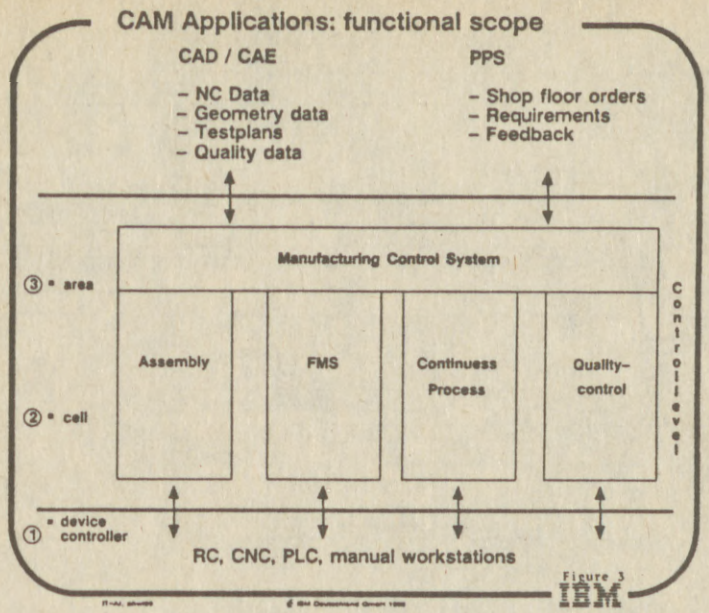
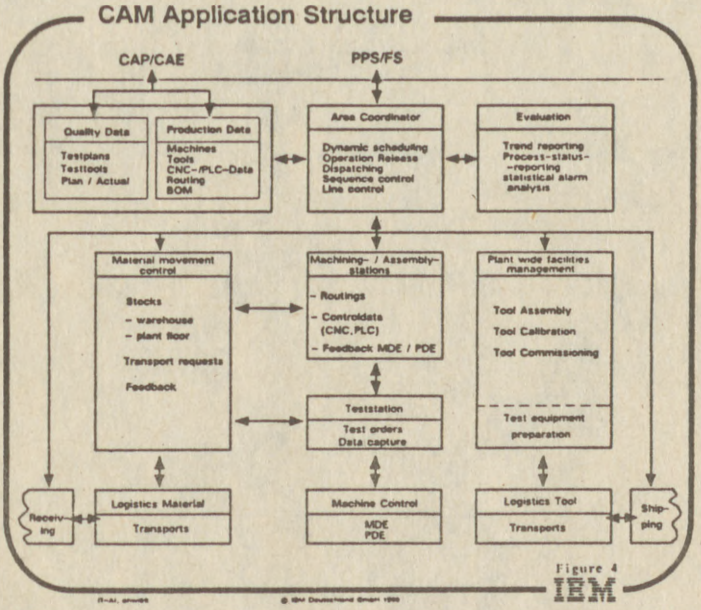

Information Integration
Technical
Information
Logistics
Information
Production
area / cell
• Order Information
• Process Information
• Production Data
• Instructions
• Mounting
• NC-Data
• Quality
• Product Specifications
• Drawings
IBM

Figure 1


Electronic Information Volume
Operator
Instruction
– Drawings
– Image
– Video
Device
Programs
– NC
– Robots
– PLC
Quality
Data
Production
Data
Work
Package
Quality
Data
Production
Data
Work
Package
Work
Package
1970's
1980's
1990's
– Direct access of data from plant floor
– More complete data from plant floor
IBM


CAM Applications: functional scope
CAD / CAE
- NC Data
- Geometry data
- Testplans
- Quality data
PPS
- Shop floor orders
- Requirements
- Feedback
Manufacturing Control System
③ = area
Assembly
FMS
Continuess Process
Quality-control
② = cell
Control level
① = device controller
RC, CNC, PLC, manual workstations
Figure 3
IBM


CAM Application Structure
CAP/CAE
PPS/FS
Quality Data
Testplans
Testtools
Plan / Actual
Production Data
Machines
Tools
CNC-/PLC-Data
Routing
BOM
Area Coordinator
Dynamic scheduling
Operation Release
Dispatching
Sequence control
Line control
Evaluation
Trend reporting
Process-status--reporting
statistical alarm analysis
Material movement control
Stocks
- warehouse
- plant floor
Transport requests
Feedback
Machining- / Assembly-stations
- Routings
- Controldata (CNC,PLC)
- Feedback MDE / PDE
Teststation
Test orders
Data capture
Plant wide facilities management
Tool Assembly
Tool Calibration
Tool Commissioning
Test equipment preparation
Receiv-ing
Logistics Material
Transports
Machine Control
MDE
PDE
Logistics Tool
Transports
Ship-ping
Figure 4
IBM

CAM Control software packages

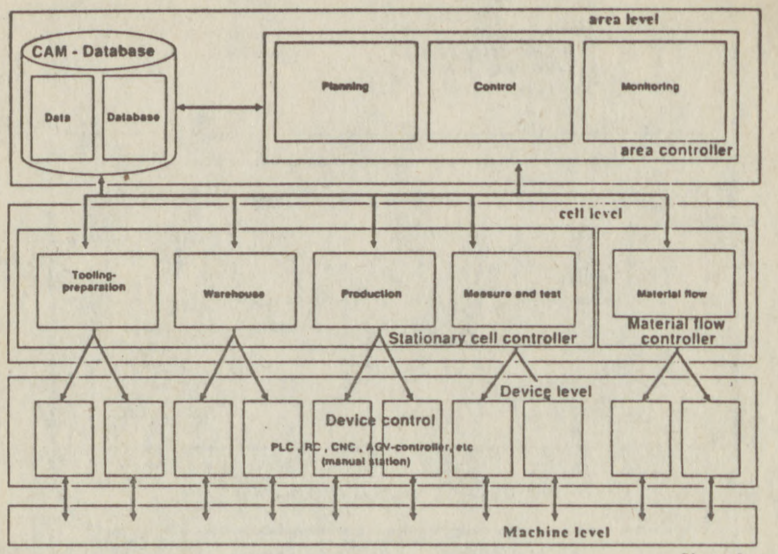


Figure 5

Funktional structure of the area controller

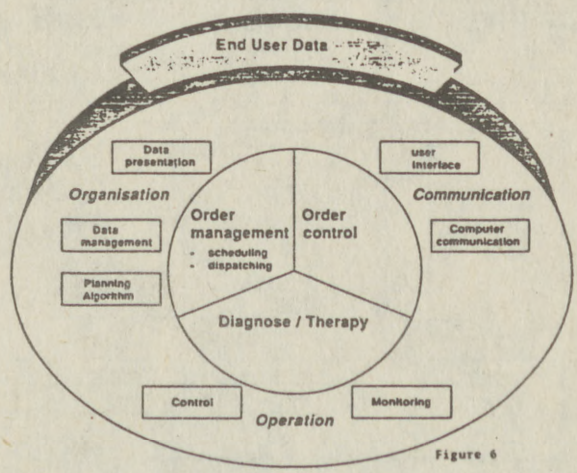
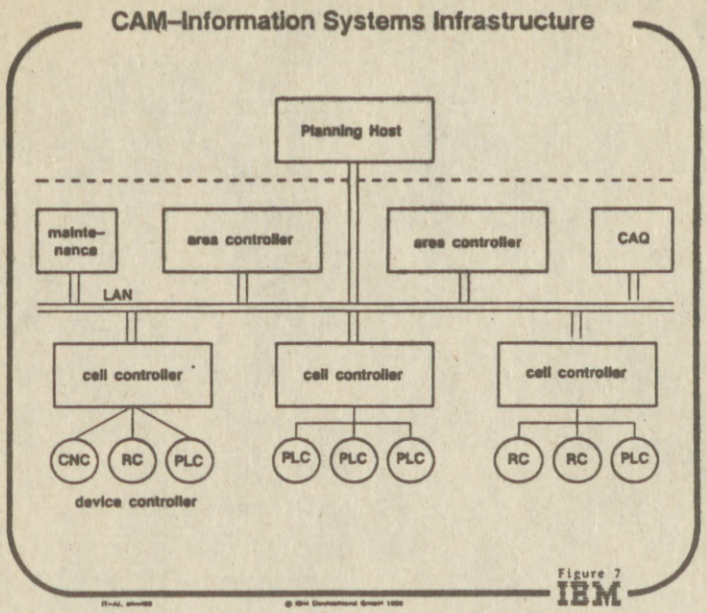
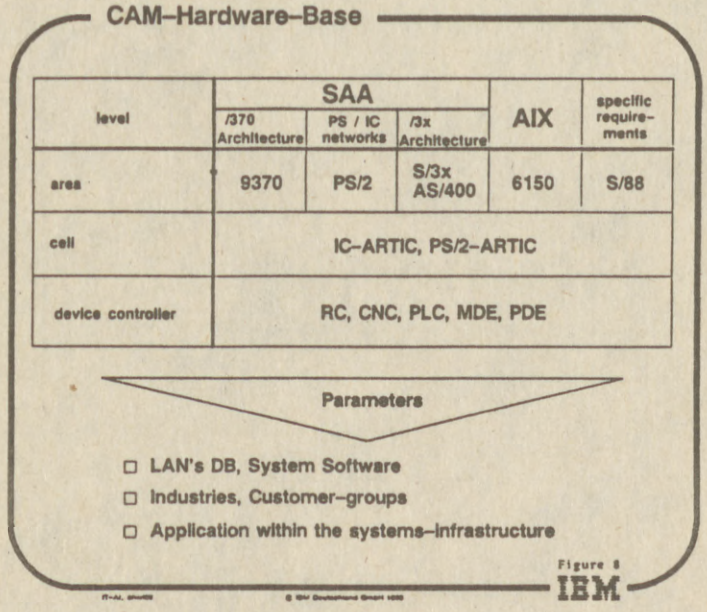
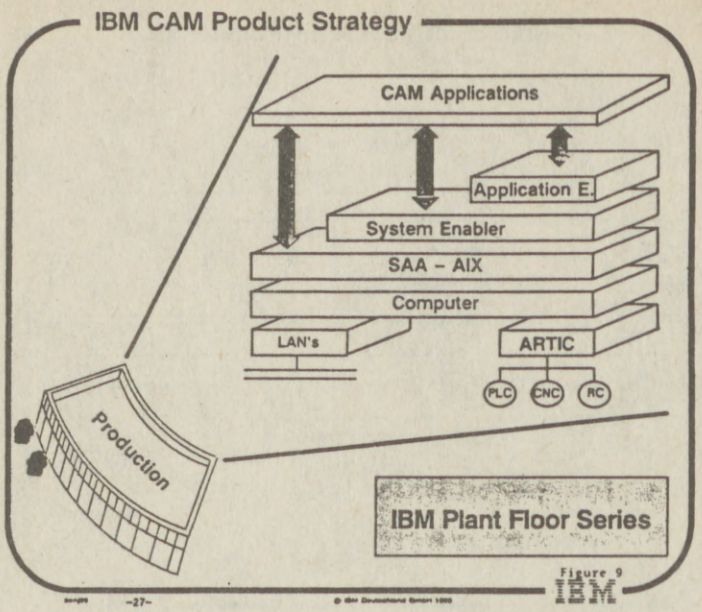
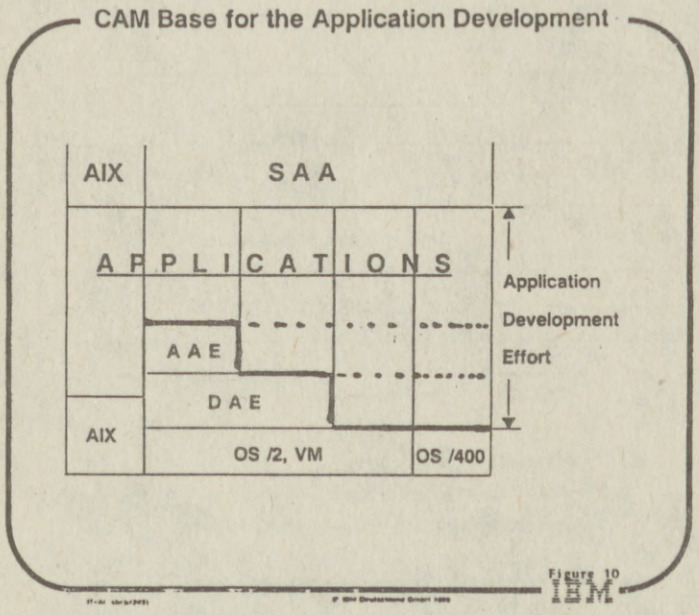


Figure 6


CAM–Information Systems Infrastructure
Planning Host
maintenance
area controller
area controller
CAQ
LAN
cell controller
cell controller
cell controller
CNC
RC
PLC
PLC
PLC
PLC
RC
RC
PLC
device controller
Figure 7
IBM


CAM–Hardware–Base
level
SAA
/370 Architecture
PS / IC networks
/3x Architecture
AIX
specific requirements
area
9370
PS/2
S/3x AS/400
6150
S/88
cell
IC–ARTIC, PS/2–ARTIC
device controller
RC, CNC, PLC, MDE, PDE
Parameters
LAN's DB, System Software
Industries, Customer–groups
Application within the systems–infrastructure
Figure 8
IBM


IBM CAM Product Strategy
CAM Applications
Application E.
System Enabler
SAA – AIX
Computer
LAN's
ARTIC
PLC
CNC
RC
Production
IBM Plant Floor Series
Figure 9
IBM


CAM Base for the Application Development
AIX
SAA
APPLICATIONS
Application
Development
Effort
AAE
DAE
AIX
OS /2, VM
OS /400
Figure 10
IBM

THE EXPERT SYSTEM WITH FUZZY REASONING
— An application in job shop scheduling

Zeng Qinghong

Senior engineer of Beijing Research Institute of Automation for Machine-Building Industry, People's Republic of China

ABSTRACT

This paper deals with an expert system using fuzzy logic reasoning for processing the uncertain informations. Knowledges in the system are represented by attribute-tables and production rules acquired from experts' heuristics under the guidance of concepts of fuzzy set theory. The system was developed for the job scheduling in a machine tool plant.

1 INTRODUCTION

The background of developing this expert system is the XJMS management information system practised in a medium-sized machine tool plant in southeast China. The XJMS, implemented on a NCR's TOWER 32/800 super-microcomputer system, has twelve subsystems such as Master Production Schedule Planing, Material Requirement Planing(known as MRP), Plant Monitoring, Inventory Management, Quality Control, and so on.

The Job Scheduling, as one of those subsystems of XJMS, has two main functions shown in fig.1. The first main function is making monthly production plans for every workcenter following the material requirement plan and the capacity requirement plan. The second one is to schedule and sequence the jobs to be worked on every workcenter.

An expert system has been designed to complete these functions. The advantage of the Artificial Intelligence method is that it can be used in pruning the decision tree, simplifying the problem solution and easing the maintenance.

2 PROBLEM AND SOLUTION OF THE JOB SCHEDULING

In a management information system, material requirement plans are planned by the MRP subsystem. The approach used by the MRP is generally as follows:

* to divide the whole product into its component parts in terms of the BOM (Bills of Material),
* to determine the desired quantities of every part to be made, considering the inventory and other factors,
* to determine the input date (planned order release date) for every part to be made, deriving backward from the required output date according to its machining leading time.

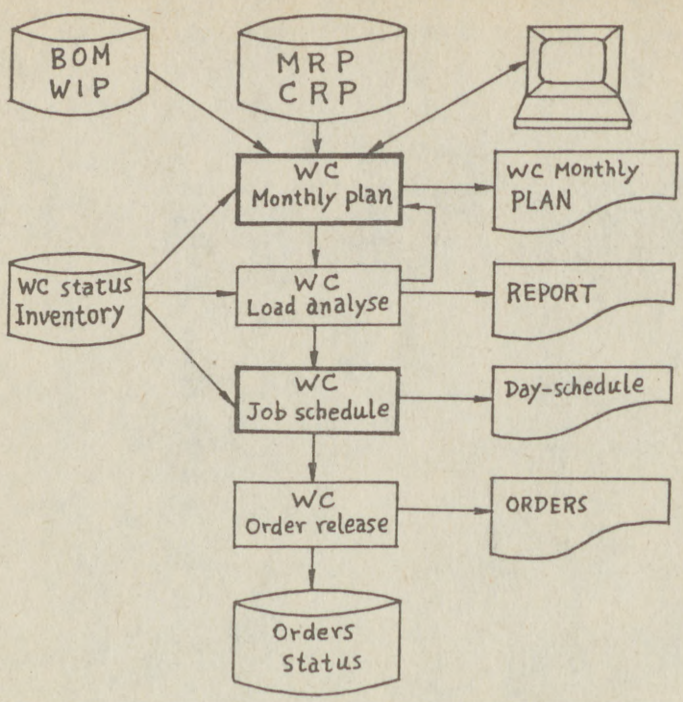


fig.1 Functions of job scheduling in XJMS

The quantity and the input-output date of a part can be graphically represented by a small bar, may be called task bar, and its length stands for the required time and its height for the required quantity. The task bar can be regarded as the unit in production planing, so a material requirement plan can thus be shown as in fig.2, using these taskbars drawn along the time axis.

We notice that when the MRP is executed, some tasks must be input in advance for balancing the capacities in the shop floor. The actual input date, therefore, is different from the planned one. As shown in fig.2, the task bars with different output date are overlapped on the time axis. Which task will be selected to be input in advance, that is a difficult problem. In fact, the experts have their own experiences to solve the problem. In the experts' view, when the production is in a dynamical but stable situation, from a given point at the time axis, we will observe a flow of task bars which consecutively flows in the counter time axis direction. In fig.3, which shows the flow of taskbars, we see that in our planing period the only thing we concern with is selecting some tasks originally planned to be input after the period and now puting them in this period in order to fill out the remaining capacity. How do we select them? If every task's priority might be evaluated, the selecting would become easy. Therefore, the problem is reduced to evaluating of priority.

The remaining problem is very the job scheduling.

When we plan to allocate a workcenter for a part to be machined we further divide the task bar into some smaller "job bars", because every part has several routing processes and each will be machined on a certain workcenter. Job-bar is the least unit of scheduling.

If we consider the problem that there are m workcenters allocated for n jobs, noticing that one workcenter can process only one job at a time and the leading job must be finished beforehand, we will find the number of possible solutions will become enormous. This has been already proven to be a NP-complete problem. If we attempt to find the optimum solution by trying all possible solutions, we will be knocked down by the combinatorial explosion. What can we do? The experts' approach is seting up a queue for every workcenter and puting every job in the queue by the sequence of its priority. However, priorities are changeable in time and jobs are consecutively moving in a job-bar flow so that the queue becomes dynamical. If we can dynamically adjust the queue, we may find a approximate optimum solution. This approach, therefore, is called "dynamical scheduling". Here the problem is also reduced to evaluating priority.

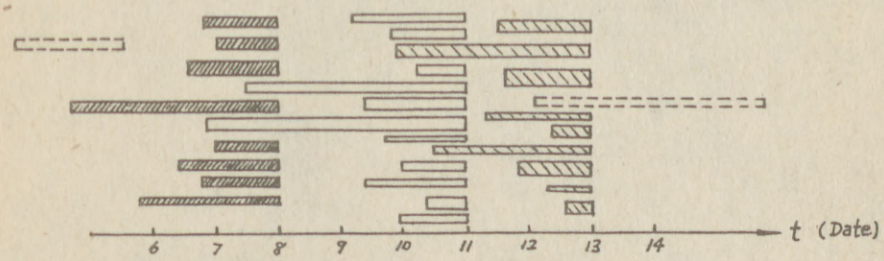


fig.2 Task bars

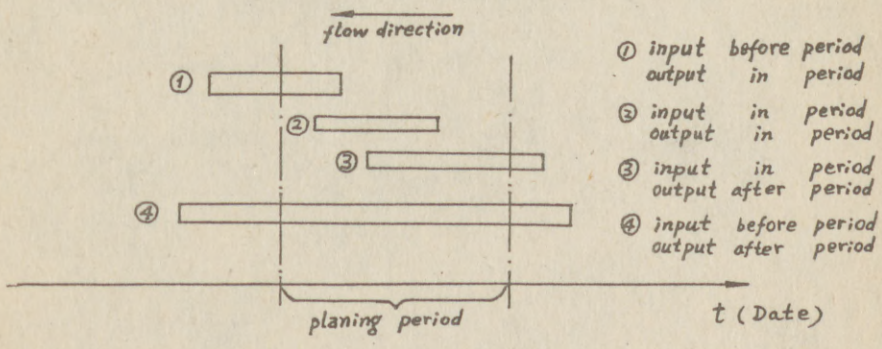


fig.3 Flow of task bars

3 ARCHITECTURE OF THE EXPERT SYSTEM

The goal of an expert system is to mimic an expert's thought processes in solving complex problems in a given field. An expert system takes the place of a human expert in a problem-solving environment by interpreting knowledge, making inferences, and reasoning in ways similar to those of the human expert.

In general, an expert system consists of four basic components: (1) the knowledge base, (2) the working database, (3) the inference engine, and (4) the user interface.

Our expert system is aimed, as above mentioned, to determine the priority of a task or a job and thereby to solve the job scheduling problem in terms of the dynamical scheduling. The architecture of the expert system is shown in fig.4.

The knowledges of experts are stored in the knowledge base. It contains attribute tables and production rules. The working database is used in puting in and taking out of the intermediate results and required data. The inference engine is the "thinker" of the expert system. It combines facts with the knowledge base, considers the relationships in the knowledge base, and proceeds to solve the problem in the working database, using its established reasoning and strategies.

The particular feature of the system described here is its using the concepts of fuzzy set theory to represent knowledges and to proceed reasoning, so it is more close to the thinking of human experts.

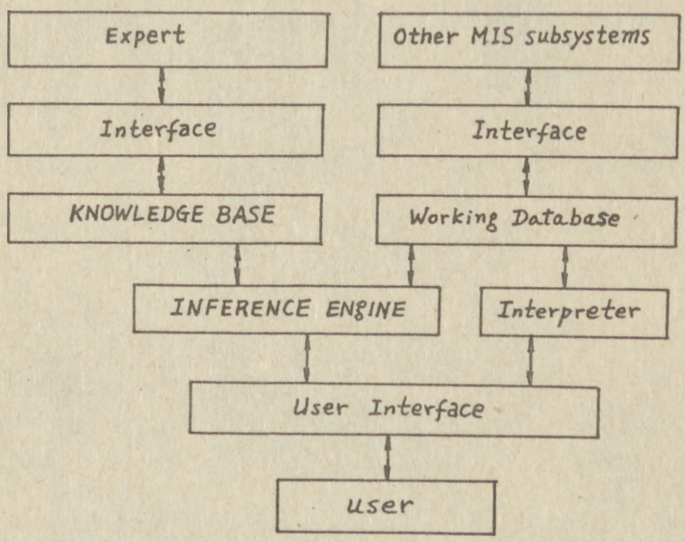


fig.4 The ES architecture

4 FUZZY LOGIC AND KNOWLEDGE REPRESENTATION

The first thing we have to do in the process of developing the expert system is to acquire knowledges from experts and to represent them in suitable forms. We remembered that our problem is evaluating the priority of a task or a job. What we are interested in is the part attributes and their relations with the priority. These are the very knowledges we want to represent and store in the knowledge base.

Undoubtedly, our experts have much enough experiences and knowledges in the job scheduling field. However, they generally describe their knowledge, especially about the relationship between priority of a part and its attributes, by some "fuzzy" expressions such as, for example, "If a part has more routing processes and its machining time period is longer and its size is bigger and its structure is more complicated, then it may have a higher priority". It is the very fact leading us to go on the way of fuzzy set theory.

In the Zadeh fuzzy set theory, a fuzzy logic is a many-valued logic where the truth space is the real interval [0,1]. By definition, when we have a fuzzy proposition P≙"X∈Ã", the truth value of the fuzzy proposition P, for the element X in the universe U, is equal to the membership of the element belonging to the fuzzy subset Ã on the universe U, i.e.

$$v(P) = \mu_{\tilde{A}}(X).$$

We also noticed there is a principle, known as max-membership principle, in the fuzzy set theory. It tells:

> Let $\tilde{A}_1, \tilde{A}_2, \cdots, \tilde{A}_n$ are n fuzzy subsets on a given universe U, and X∈U is an element,
> If $\mu_{\tilde{A}_i}(X) = \max(\mu_{\tilde{A}_j}(X))$,
> Then X has priority to belong to $\tilde{A}_i$.

These concepts allow us to translate the multivalued fuzzy propositions into a series of fuzzy subsets. The part attributes can be regarded as these fuzzy subsets. when we get the knowledge about the membership function of parts belonging to a fuzzy attribute we are able to evaluate the membership of every part and to determine whether it has priority to belong to that attribute. Thus we will get a attribute table in which every attribute is a fuzzy proposition and for each attribute a part may have values 1 or 0, where "1" stands for "belong to it", and "0" for "not belong to it".

The attribute table has been generated automatically by the inference engine and stored in the knowledge base for further use in reasoning.

5 FUZZY REASONING AND INFERENCE ENGINE

As we have repeated, the goal of our reasoning is to determine the priority for every task or job.

First, a priority coefficient is defined as a weighted average of a static priority level and a dynamic priority level:

$$p = \tfrac{1}{2} (w1*s + w2*d)$$

where p is priority coefficient,
s is static priority level,
d is dynamic priority level,
w1 and w2 are weights for s and d.

Then, in accordance with this formula, we can evaluate s and d respectively.

The static priority level s can be determined by the fuzzy reasoning--approximate reasoning from the attribute table and a series of fuzzy rules. These rules are gotten from experts and represented in the production form as following:

$$\text{If} \quad P_1 \wedge P_2 \cdots \wedge P_n, \quad \text{then} \quad Q.$$

where P_1, P_2, $\cdots$, P_n and Q are fuzzy predicates and $\wedge$ is the disjunction operator for predicate calculus.

In the developing of the inference engine we used the backward reasoning and the blind search as its control strategy. When the attribute of a part does not match with any condition of the rules, we have to select the most approximate one. Here we used the max-membership principle once again, but in another form, i.e.:

Let $\tilde{A}_1, \tilde{A}_2, \cdots, \tilde{A}_n \in (U)$ are n fuzzy subsets,
$\tilde{B} \in (U)$ is another fuzzy subset,
If $N(\tilde{A}_i, \tilde{B}) = \max (N(\tilde{A}_j, \tilde{B}))$,
Then $\tilde{B}$ is most near to $\tilde{A}_i$.

N is called nearability. It can be evaluated by a existing algorithm.

To determine the dynamic priority level, we first evaluate the dynamic factor defined as follows:

$$k = \frac{r}{o-n-r}$$

where r is remaining work time, o is planned output date, n is today's date, and $0 \leq k \leq 1$ is hold, when $k>1$, let $k=1$, here it means the priority is highest.

After evaluating the dynamic factor, the dynamic priority level can be derived from the membership function given by the experts.

As for the job scheduling, we set up a queue for every work-center and put jobs in the queue according to the order of their priority coefficient. In addition of the capacity considerings, we can finally give the day-schedule plan.

6 SUMMARY

The expert system presented here is designed for solving the job scheduling problem in a machine tool plant. There the expert system approach is used for helping the experts to collect their many years experiences in the given field. The concepts of fuzzy logic, fuzzy proposition, fuzzy predicate and fuzzy reasoning have been proven useful in the building of the expert system. The trying of using fuzzy logic in the knowledge representation seems successful. The practice told us that it is a passable way to arrive the solution by the means of fuzzy reasoning,

although there is still a shortage expecting for the future improvement.

7 REFERENCES

1. Zhang ba, Expert System Principle and Practice, Tsinghua Univ. press, 1988
2. King Sun Fu, Artificial Intelligence and its Applications, Tsinghua Univ. press, 1987
3. Wang Peizhuang, The Fuzzy Sets and the Falling Random Subsets, U.N. press, 1985
4. Robert A., An Expert System for Mission Scheduling and Conflict Resolution, "ROBOTICS and EXPERT SYSTEM-- 1986", Proceedings of ROBEXS'86, 179-188
5. Janet Hennard, ESRA:An Expert System for Resource Allocation, "ROBOTICS and EXPERT SYSTEMS--1986", Proceedings of ROBEXS'86, 189-199
6. Didier Dubois, Fuzzy Sets and System -- Theory and Application Academic press, 1980
7. Deborah D. Wolfgram, Expert System for the Technical Professional, John Wiley & Sons, 1987
8. Yang Chengen, A Class of Scheduling Problems and their solution, ACTA Mathematicae Applicatae Sinica, Vol. 10, No. 2, Apr., 1987
9. Newton S. Lee, Fuzzy Inference Engines in Prolog/P-Shell, "Expert Systems in Government Symposium 1986", 243-247
10. Chen Yongyi, Optimum Fuzzy Implication and Direct Method of Approximate reasoning, BUSEFAL, No. 16 (1983), 107-113
11. Gordon B. Davis, Management Information Systems -- Conceptual Foudations, Structure, and Development, McGraw-Hill, 1982
12. E.H.Mamdani, Fuzzy Reasoning and its Applications, Academic press, 1981
13. Communications Oriented Production Information and Control System, IBM, 1972

CNC PROFILE GRINDING OF NON-CIRCULAR SHAPES

by
TAKAO YONEDA, IKUO SUZUKI and KUNIHIKO UNNO
Toyoda Machine works, LTD.
1-1, Asahimachi, Kariya, Aichi-Pref., 448 Japan

ABSTRACT

When performing heavy grinding of non-circular workpieces at high speeds, high rigidity of the wheel and its supporting system are very important. Previous studies concerning the drive method for this type of mechanism have concentrated on hydraulic systems, such as the hydraulic copy-profiling mechanism and the hydraulic servo mechanism, in which high torque can be easily obtained.

The electrical servo mechanism used with today's numerical controllers is capable of high-speed, high-accuracy machining with high torque. The study discussed in this paper includes the control technology for high-speed, high-accuracy NC contouring operations. All problems involved are highlighted and possible solution are offered.

1. INTRODUCTION

The cross-sections of workpieces such as cams used for intake and exhaust control of engines are not truly circular. Copy milling using a master cam was formerly the general method employed for profile finishing work [1]. Such copy milling methods possess the advantages of high speed and permitting repetitive finishing operations.

However, concomitantly with the pursuit of improved engine performance, cam shapes are becoming increasingly more diversified, and consequently the time required for fabrication and interchange of master cams when altering the work process has become a non-negligible problem.

On the other hand, if master cams are not used, and the relative motion of the tool and the workpiece is adjusted by direct numerical control (NC), as in the case of NC mold contouring processes, then an alteration in the shape of the contour merely entails a change of data, thus permitting rapid changes in the production program [2].

The purpose of the present study was the development of a rapid, high-precision numerically controlled method for profile grinding of non-circular shapes combining the high productivity of the copy milling method and the wide applicability of the NC mold contouring method. To achieve this, the authors present a theoretical analysis of the relative motion of the workpiece and grinding wheel as a basis for using of numerical control, using intake and exhaust control cams of internal combustion engines as concrete examples. In addition, the profile errors arising from variable factors such as wear of the grinding wheel are investigated, practical methods of reducing profile error are proposed, and the effectiveness of these methods is demonstrated.

2. BASIC CONCEPTS IN NC DATA GENERATION FOR CAM SHAPE GRINDING

A grinding mechanism for NC cam contouring first requires an axis configuration permitting simultaneous execution of two types of motion, i. e., the motion which generates the required shape and the feeding motion which advances the grinding wheel into the workpiece. In addition, in connection with pre-finishing, a wheel head feeding mechanism for high-speed work with a diameter of 6-8 mm stock removal as well as the mechanism supporting the workpiece must possess sufficient rigidity to withstand heavy grinding operations.

For these reasons, the grinding mechanism illustrated in Figure 1 was adopted, facilitating the provision of the necessary mechanical rigidity and requiring a comparatively simple control structure.

Figure 2 illustrates the basic concepts involved in the generation of NC data for the cam profile grinding system designed and implemented by the construction of a prototype in the present study.

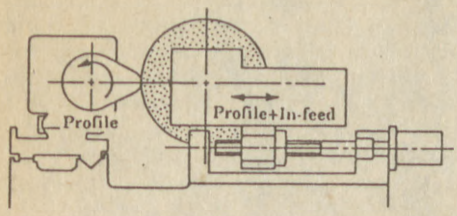


Fig.1 Cam grinding mechanism

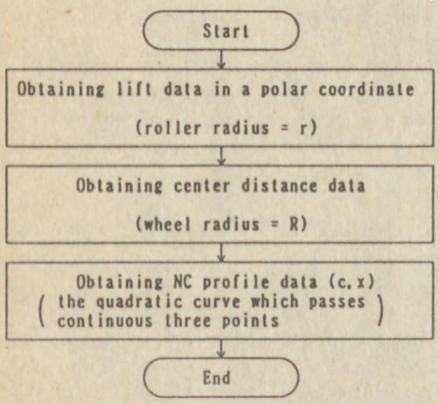


Fig.2 Basic concept for NC profiling data generation

As regards data input/output, the group of points representing the lift of the tappet with respect to the angle of rotation of the cam close to the actual program sheet information is provided as input data, while the axial translation distances per unit angle appropriate for high speed NC profiling are sought as output data.

The present procedure is basically composed of three processes.

In the first process, the input tappet lift data (Θ, ℓ), including attributes such "roller tappet", etc., are converted to polar coordinate lift data (Θ', ℓ'), regarding the tappet as a knife-edge and ignoring the effects of the specific type of tappet, thereby simplifying the subsequent processing.

In the second process, the polar coordinate lift data (Θ', ℓ') are transformed to intercentric distance data (Θ'', ℓ'') indicating the distance between the centers of rotation of the cam and grinding wheel when the grinding wheel and the machined surface of the cam are in contact.

In the third process, the intercentric distance data (Θ'', ℓ'') are transformed into NC profile command data (c, x) per unit angle with respect to the rotational axis of the work spindle head (C axis) and the feeding axis of the wheel head (X axis).

3. THEORETICAL ANALYSIS

Here, a theoretical analysis of the three processes indicated in Figure 2 will be presented with reference to the case of a roller tappet as an example.

3.1 Polar coordinate lift data transformation

Let ℓ denote the distance from the center of the base circle of the cam to the center of the roller tappet, Θ the rotational angle of the cam in that configuration and (Θ', ℓ') the polar coordinate data at the contact point P. Then, from Figure 3,

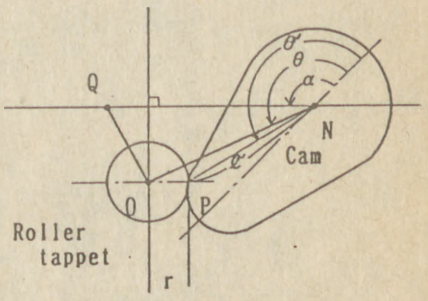


Fig.3 Obtaining lift data in polar coordinate

$$\Theta' = \Theta - \tan^{-1}\left\{\frac{\partial\ell/\partial\Theta}{\ell}\right\} + \tan^{-1}\left\{\frac{\ell\,(\partial\ell/\partial\Theta)}{\ell^2 - r\sqrt{\ell^2 + (\partial\ell/\partial\Theta)^2}}\right\} \quad (1)$$

$$\ell' = \sqrt{\ell^2 + r^2 - \frac{2\ell^2 r}{\sqrt{\ell^2 + (\partial\ell/\partial\Theta)^2}}} \qquad (2)$$

where

$$\cos(\Theta - \alpha) = \ell/\overline{QN} \qquad (3)$$

$$\overline{QN}^2 = \ell^2 + (\partial\ell/\partial\Theta)^2 \qquad (4)$$

3.2 Intercentric distance data transformation

In the case of grinding of the cam denoted in the polar coordinate lift data (Θ', ℓ') using the grinding wheel of radius R, the intercentric distance data (Θ'', ℓ'') indicating the distance between the centers of rotation of the cam and grinding wheel will be, then, from Figure 4,

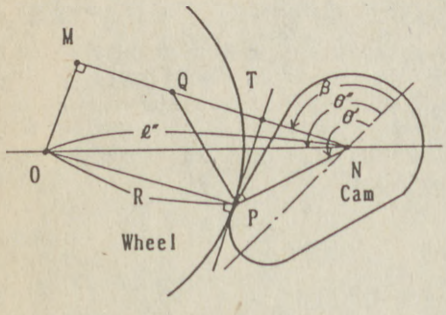


Fig.4 Obtaining intercentric distance data

$$\Theta'' = \Theta' - \tan^{-1}\{\frac{\partial\ell'/\partial\Theta'}{\ell'}\} + \tan^{-1}\{\frac{\ell'(\partial\ell'/\partial\Theta')}{\ell'^2 - R\sqrt{\ell'^2 + (\partial\ell'/\partial\Theta')^2}}\} \qquad (5)$$

$$\ell'' = \sqrt{\ell'^2 + R^2 + \frac{2\ell'^2 r}{\sqrt{\ell'^2 + (\partial\ell'/\partial\Theta')^2}}} \qquad (6)$$

3.3 NC profile command data transformation

The intercentric distance data (Θ'', ℓ'') determined from formulae (5) and (6) is equivalent to the relation between the movement of the feeding axis of the wheel head (X axis) and the movement of the rotational axis of the work spindle head (C axis)

On the other hand, in the case of high-speed NC profiling, piecewise linear NC data is preferably calculated in terms of axial translation per unit angle (or per unit time) in order to diminish, as far as possible, the position control processing load on the NC devices.

Therefore, the computational procedure adopted here consisted in approximating the NC profile command data (c_j, x_j) at one point c_j on the pitch angle of the spindle head axis, etc., by the quadratic curve passing through the three points (Θ''_{i-1}, ℓ''_{i-1}), (Θ''_i, ℓ''_i) and (Θ''_{i+1}, ℓ''_{i+1}), where c_j is the closest neighboring point.

4. METHODS OF IMPROVEMENT OF PROFILE ERRORS

The NC profile command data determined by the procedure of Section 3.3 above represents a theoretical analysis in an ideal model. In a realistic grinding model, many sources of profile error exist.

Therefore, several problems regarded as giving rise to profile error in realistic grinding models will be analyzed and methods for error improvement in connection with each of these problems will be proposed.

4.1. Avoiding grinding wheel interference

When interference between the grinding wheel and the workpiece occurs, then merely as regards the grinding of the workpiece into the required shape, use of the smallest possible grinding wheel would be most desirable. However, in consideration of various restrictions on the grinding process such as the rigidity and life of the grinding wheel, etc., grinding should be performed with as large a grinding wheel as possible while avoiding interference, and therefore checking interference is a necessary aspect of design and operation.

When the intercentric distance data (Θ'', ℓ'') is determined from the polar coordinate lift data (Θ', ℓ') and the radius R of the grinding wheel, if the i-th cam rotation angle ($\Theta''i$) found in the intercentric distance data represents a reverse rotation, then one may conclude that the grinding wheel and the workpiece are interfering.

That is, if the relation

$$\Theta''_{i-1} - \Theta''_i < -\varepsilon \qquad (7)$$

holds, where ε represents the permissible error, then this may be regarded as indicating interference.

4.2 Changes in grinding wheel radius

As indicated in formulae (5) and (6) above, the intercentric distance data (Θ'', ℓ'') is calculated upon the assumption that the grinding wheel radius R is constant. Therefore, the grinding wheel radius used in computation must agree with the radius in the actual grinding operation.

However, in actual grinding work, the grinding wheel radius is constantly diminished by dressing, etc., and as shown by Figure 5, the effects of variations in grinding wheel radius upon profile error are non-negligible.

Possible methods for coping with this problem include a sequential computation procedure whereby the second and third processes in Figure 2 are performed when the change in the

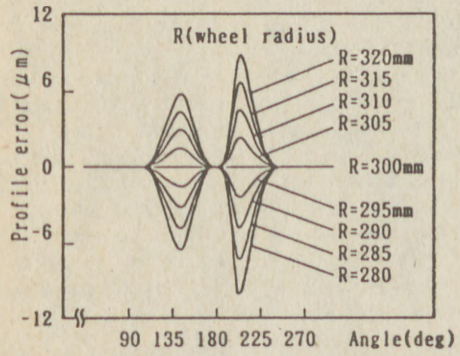


Fig.5 Relationship between wheel diameter and profile error

grinding wheel radius reaches the point where profile error cannot be neglected, or the comprehensive procedure of stratifying the maximum expected range of variation of the grinding wheel radius into increments such that the corresponding profile error is non-negligible, and then, before commencing the grinding operations, computing and storing in memory the NC profile command data for each stratified value of the grinding wheel radius. However, the former procedure is subject to temporal restrictions such as the possible stoppage of operation while numerical processing or data transmission are being executed, while the latter procedure is difficult to implement because of restrictions on the available memory capacity.

Therefore, in the present study, the above-mentioned problems of time and memory capacity were solved by adopting a parallel computation procedure. That is, the program structure permits the parallel processing for the operation control unit and the numerical processor by transmitting the information on grinding wheel diameter which is handled in the operation control unit to the numerical processor in real time, substituting previously computed NC profile command data as required, and simultaneously commences the computation of the NC profile command data in accordance with the grinding wheel diameter for the next grinding operation.

4.3. Acceleration variations in input tappet lift data

As shown by Figure 6, the acceleration and further higher order variations in cam shape are ordinarily large. Increasing the degree of the control system is generally sufficient as a means of improving the positional deviation in the NC control unit with respect to input tappet data with this sort of higher order variations. However, this may cause instability in the control system and thus adversely affect the characteristics of the ground surface.

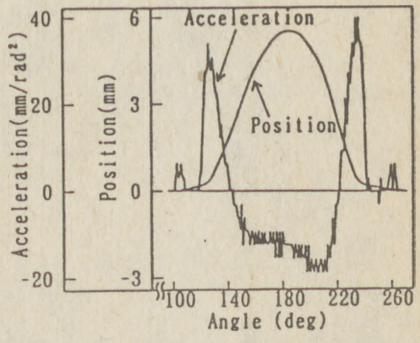


Fig.6 Characteristics of input cam profile

Therefore, as a simple means of coping with this problem, regression polynomials can be used to minimize as far as possible the higher degree components of the variation in input tappet data and smooth the variations to a level within the range of shape tolerance. With respect to the tappet lift data (Θ, ℓ), let m denote the number of sampling points and n the degree of the regression polynomial. Then

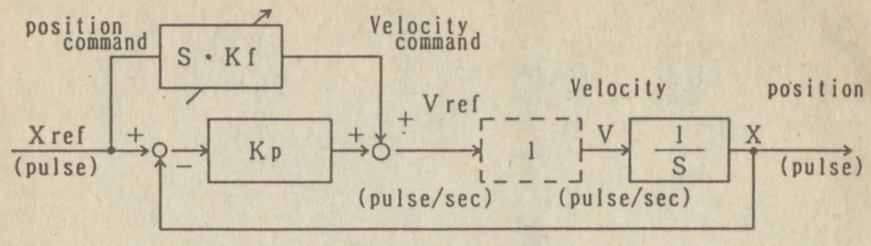


Fig.7 Positioning loop with feed-foward control

$$L = \Theta^T \cdot \Theta \cdot A \tag{8}$$

where

$$L = \begin{pmatrix} \ell_1 \\ \vdots \\ \ell_i \\ \vdots \\ \ell m \end{pmatrix} \quad A = \begin{pmatrix} a_0 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{pmatrix} \quad \Theta = \begin{pmatrix} 1, \Theta_1 \cdots, \Theta_1{}^n \\ \vdots \\ 1, \Theta_i \cdots, \Theta_i{}^n \\ \vdots \\ 1, \Theta_m \cdots, \Theta_m{}^n \end{pmatrix}$$

From formula (8),

$$A = L \cdot (\Theta^T \cdot \Theta)^{-1} \tag{9}$$

The result $(\Theta_i, \hat{\ell}_i)$ of smoothing with respect to the tappet lift data (Θ_i, ℓ_i) is expressed by the relation

$$\hat{\ell}i = a_0 + a_1\Theta_i \cdots + a_n\Theta_i{}^n \tag{10}$$

4.4 Response characteristics of servo system

Increases in the peripheral velocity of workpieces and the correspondingly synchronized feed velocity of the wheel head stock require servo systems with rapid response characteristics.

However, in conventional types of NC positioning mechanisms employing feedback control, if the loop gain is increased in order to improve rapid response characteristics, the stability of the system may be adversely affected.

To cope with this problem, the authors considered a feed-forward mechanism which provides both rapid response characteristics and stability by directly issuing compensation commands, corresponding to the velocity components of positional instructions, to the velocity control loop and thereby increasing the virtual positional loop gain.

Figure 7 is a schematic illustration of the servo system with a feed-forward control mechanism. Here, the positional control system is composed of a proportional control mechanism which in turn is approximated by a first-order lag system, while the velocity control system is assumed to provide sufficiently large feedback gain as compared with the proportional gain Kp of the position control unit, so that the relation V = Vref is assumed.

Considering a ramp function input with constant velocity F (pulse/sec) as the positioning command,

$$Xref(t) = F \cdot t \tag{11}$$

$$X(t) = F \cdot t - \frac{F}{Kp}(1 - Kf)(1 - e^{-Kp \cdot t}) \tag{12}$$

When $t \to \infty$, the steady state deviation ε is given by

$$\varepsilon = Xref(t) - X(t) = \frac{F}{Kp}(1 - Kf) \tag{13}$$

Thus, when the input is a ramp function, the steady state deviation can be greatly improved if the feed-forward gain is adjusted to a value near 1.

Furthermore, since the positioning control system was approximated by a first-order lag system and since the position includes higher

order variation components, the configuration of the system was designed so that the feed-forward control can be regulated by the command unit in accordance with the characteristics of the profile data.

5. RESULTS AND DISCUSSION

Figure 8 shows the system configuration of the prototype apparatus constructed for evaluation testing of the present system. This apparatus comprises a basic structure formed by an NC apparatus for triaxial cylindrical grinding linked by a common RAM with a first unit incorporating cam movement control functions and a second unit with cam numerical processing functions, the configuration being governed by a multiple MPU which performs multiple processing for both units. This system permits evaluation of system performance, including actual grinding operation.

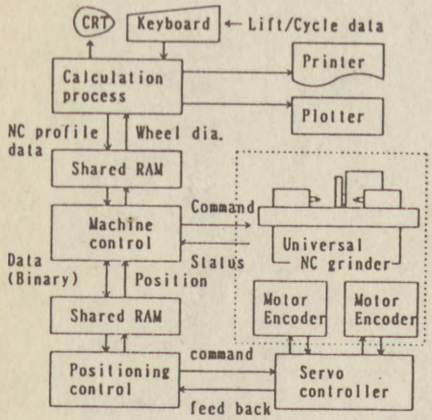


Fig.8 System configuration diagram of evaluation test

5.1. Variation in grinding wheel diameter

Figure 9 shows a processing flow chart for generation of NC profile command data in accordance with the follow-up of grinding wheel diameter changes incorporated in the prototype evaluation testing apparatus.

Since the profile tolerance (ΔD) affects the input tappet lift data (Θ, ℓ) and the grinding wheel diameter (Dg), the relation shown in Figure 5 was used for the approximate determination of ΔD. At the instant when the input tappet lift data is given, the profile error for the maximum, intermediate and minimum diameters of the grinding wheel are determined, the relation between the variation in wheel diameter and the profile error is approximated by a quadratic curve, and the computation is performed using the relation between previously calculated wheel diameter and profile error.

The average time required for prior computation of the intercentric distance data and the NC command data is generally about 10 minutes, but this is negligible as compared with the rate of decrease of the grinding workpiece diameter, hence, the numerical processing time has no adverse effect upon the operation control unit.

Also, although a multi-MPU configuration was adopted in the present study, if adequate MPU processing capacity is available, then the functions of the numerical processing unit and NC operation control unit can be implemented by multitasking[3].

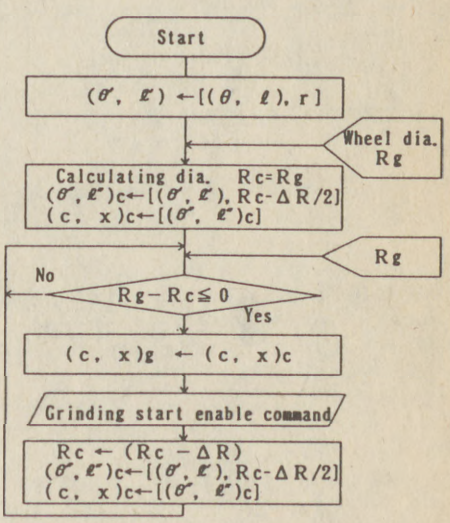


Fig.9 Flowchart of wheel diameter variation follow processing

5.2. Acceleration variations in input tappet lift data

If the number of sample points m and the degree n of the regression polynomial in formula (10) is varied, then the smoothing effect with respect to the acceleration variations of the input tappet lift data does not change greatly for values of n greater than n = 3, hence, from considerations of computational processing time, the value n = 3 was selected.

Figure 10 shows the smoothing effect upon acceleration variations when n = 3 and m = 15, while Figure 11 shows the relation between the number of sample points m and the deviation $\Delta\ell$ with respect to the theoretical tappet lift data. According to these results, increasing the value of m progressively improves the smoothing effect, but on the other hand, the deviation with respect to the input tappet lift data also increases, hence, the deviation may exceed the profile tolerance, and therefore the maximum value of m consistent with the profile tolerance must be chosen.

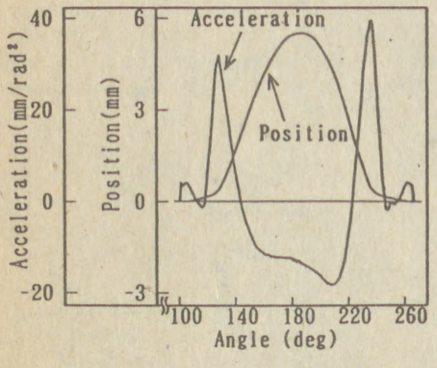


Fig.10 Smoothing result of input cam profile (n = 3, m = 15)

In order to assess the effect of smoothing upon realistic grinding operations, an accelerometer was mounted on the wheel head of a general purpose NC cylindrical grinder, and the input tappet lift data (Θ, ℓ) were compared with the smoothed tappet lift data for operation with n = 3 and m = 15, with the results shown in Figure 12.

Smoothing reduced the acceleration variation of the wheel head in the initial and final segments of the tappet lift data, indicating that adverse effects upon the finished surface characteristics would be greatly improved by this procedure.

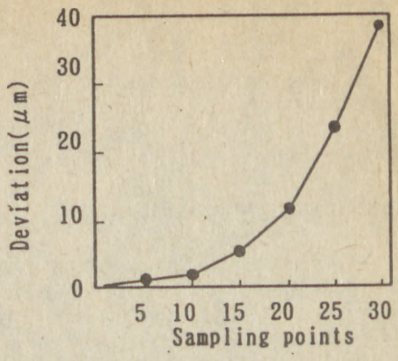


Fig.11 Relationship between sampling points and deviation value

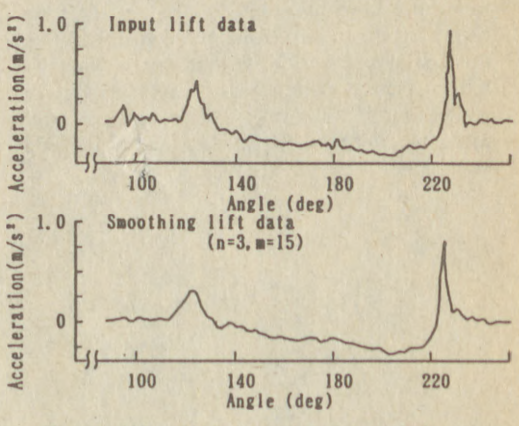


Fig.12 Wheel head acceleration variation effect

5.3. Feed-forward control

Figure 13 shows the results obtained by setting the positioning loop gain of the X and C axes of the evaluation testing apparatus to the value K_P = 30 rad/sec, i. e., the largest value such that no overshoot occurred in the step response, and varying the feed-forward gain in the range $0.6 \leq K_f \leq 1.0$.

As the value of K_f is increased, the apparent positioning loop gain increases, and the profile error is improved up to a factor of $1/10$, however, as Kp approaches 1, overshoot occurs and accordingly the profile error again increases. Also, the optimal value affects the profile characteristics of the input tappet data.

Consequently, a mechanism for self-regulation of feed-forward gain combining capabilities for varying K_P as well as numerical processing of the profile error from the sampled values of the motor

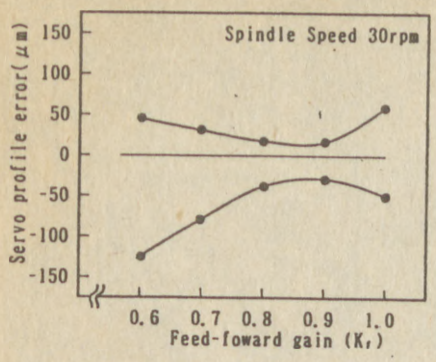


Fig.13 Relationship of Servo profile error and Feed-foward gain

follow-up error were incorporated in the NC devices.

Figure 14 shows the results obtained by cam profile measurements during actual grinding operations using this mechanism for self-regulation of feed-forward gain; an improvement of profile error up to a factor of about 1/8 was achieved.

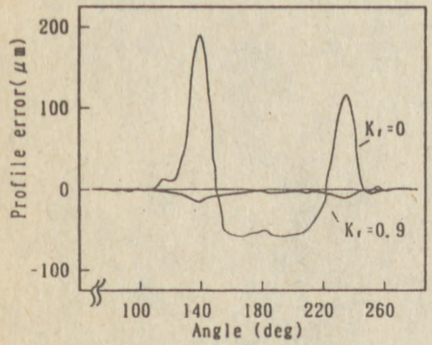


Fig.14 Relationship between sampling points and deviation value

6 CONCLUSION

(1) With the objective of realizing high-speed, high-precision NC grinding of non-circular contours, using intake and exhaust cams for internal combustion engines as representative examples, the relation between the relative movement of the wheel head (X axis) and the spindle head of the workpiece (C axis) was formulated, and the basic processing sequence was elucidated.

(2) The factors manifestingadverse effects upon contour precision were investigated by numerical analysis, and simple measures for the improvement of contour precision were proposed.

(3) A prototype processing system for numerical analysis was constructed, and the analytical results demonstrated that the proposed measures for improvement of contour precision are effective with respect to the ordinary type of cam shape.

REFERENCES

(1) Urata, "A Study on the Hydraulic Copying System", Transaction of the Japan Society of Mechanical Engineers, VOL46, No.409, (1980), P. 1713

(2) Ohara, "CAD/CAM in the Automotive Industry", Journal of the Japan Society of Mechanical Engineers, VOL86, No.776, (1983), P.759

(3) Ishikawa, Tokoro, "Object-Oriented Concurrent Programming Languages", Journal of the Information Processing Society of Japan, VOL29, No.4, (1988), P.325

Készült: ERFATERV Ny. ● Budapest VII., Csengery u. 11.
Felelős vezető: Tóth Béla igazgató ● Táskaszám: 90.114
Példányszám: 600 ● Terjedelem: 35,9 /A/5 iv/

4618/a-2