KOMUNIKÁCIE
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MODELOVANIE VÝROBKU PRE ÚČELY CAD/CAM INTEGRÁCIE

PRODUCT MODELLING FOR CAD/CAPP INTEGRATION

Základnou podmienkou dosiahnutia plnej automatizácie je integrácia CAD/CAPP/CAM systémov. Dôležitou časťou vo vývoji počítačom podporovaných systémov v predvýrobných etapách je modelovanie výrobku. Najrozšírenejšou modelovacou metódou je prvkové modelovanie. Spomenutá metóda je veľmi sľubná, pretože môže do značnej miery využiť geometrický model vytvorený v CA systéme. Zlepšenie výmeny informácií o výrobkoch medzi CA systémami pracujúcimi v prostredí CE, môže zvýšiť stupeň počítačovej podpory v automatizácií. V článku je prezentovaná architektúra navrhnutého CA systému, spĺňajúceho určené požiadavky.

The key condition for achieving the full automation is the integration of CAD/CAPP/CAM systems. The important element in the development of computer aided production preparation system is product modelling. The most widely known modelling method is feature based modelling. The mentioned method is very promising because it can extensively use the geometric model created in CA system. The enhancement of product information exchange between systems working in CE environment can increase the level of computer automation. The proposed system architecture fulfilling the requirements is presented in the article.

Introduction

The widely used tools for computer aided production preparation are CAD/CAPP/CAM systems (Computer Aided Design/ Computer Aided Process Planning/ Computer Aided Manufacturing). The key condition for achieving the full automation is the integration of these systems, they must exchange information between themselves. In other case, to perform operations automatically some information must be entered, and this process of information input is tedious and often a source of errors. For example, in non- integrated CAD/CAPP systems environment, all information about the product must be once again fed to CAPP system although they have been already modeled in a CAD system. Similarly, in a case of non- integrated CAPP and CAM systems, to program a machine tool the user must enter all geometric information about the product (Fig. 1).

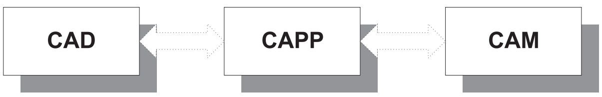

Fig. 1 Non- integrated CAD/CAPP/CAM systems: "Islands of automation"

The key element in the development of computer aided production preparation system is product modeling. It is of fundamental importance in Concurrent Engineering where teams of experts (designers, process planners, etc.) together develop a new product. In modern implementation of CE methodology teams are replaced by computer systems which must be capable of exchanging information, especially information about the product which is in the focus of realized activities (Fig. 2).

The most widely known modeling methods are syntactic pattern description, problem- oriented languages, declarative languages, GT coding, feature based modeling. The method mentioned last is very promising because it can extensively use the geometric model created in CAD system. In this method features can be interactively defined. The user designs the use of the already prepared set of features, or features can be extracted automatically. There are also several methods of feature recognition including pattern recognition, decomposition approach, logic approach and AAG graph methods [4].

However it should be noted that many solutions to the problem of product modeling does not fulfill the requirement of concurrent engineering environment because they are narrowly focused on some aspects, as for example on feature recognition. The system for product modeling working in CE environment should have the product model fulfilling the requirement of all systems using it, it should read the geometric model directly from CAD system and must be capable of bi-directional exchange of the information between particular systems.

The enhancement of product information exchange between systems working in CE environment can increase the level of computer automation. The proposed system architecture fulfills the requirements mentioned above.

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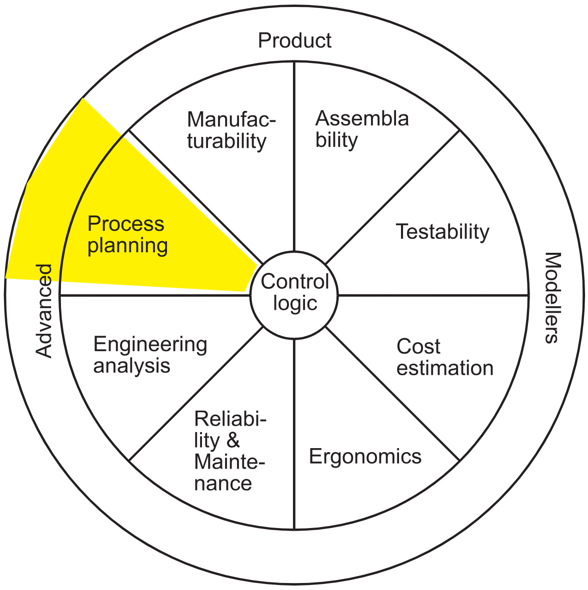

Fig. 2 The use of product model in Concurrent Engineering environment [Joshi94]

1. System architecture

The system for product modeling should feature:

- user- friendly interface and modeling approach
- access to the information on different level of abstraction,
- possibility for modeling all product- related information,
- bi-directional exchange of information between system working in CE environment,
- mechanisms for information exchange with other systems for product modeling.

Fig. 3 presents the architecture of system fulfilling the requirements mentioned above. The presentation of its most important modules and methods of implementation follows.

2a. Feature oriented product model

The product is described by the graph:

$$G = < F, R >$$

where F - The set of features
R - The set of relations between features

Feature is any entity used in reasoning of design, engineering, and manufacturing [3]. Features have different abstraction levels. They can represent assemblies, subassemblies, workpieces, surface sets, and even low-level geometric entities. Assemblies are composed of subassemblies, subassemblies are composed of workpieces, the components of workpieces are simple and complex manufacturing features. Simple manufacturing feature consists of surfaces, edges, etc.

The example of simple manufacturing features are thorough slots, countersink holes, steps, etc. The simple feature can be grouped into complex features. The example of complex features are multi-staged holes or combination of pocket and slot. The features reflect the hierarchy of product structure (Fig. 4). Features are represented using the object-oriented approach. The object is a set of data, procedures for these data processing and mechanism for message (information) exchange. The use of object-oriented methodology enables to reflect the hierarchy among features and relations occurring between them.

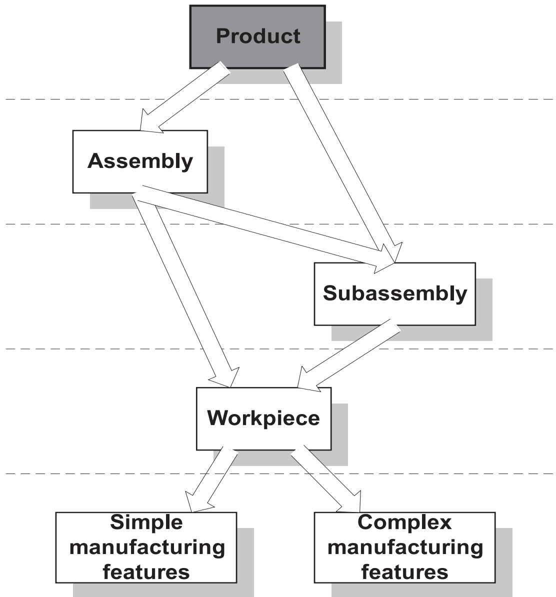

Fig. 4 The hierarchy of product structure

The Relation is a constraint imposed on a single feature (object), or constraint imposed on two or more features. Several types of relations can be distinguished, the most important from the process planning view are:

- tolerance relations (for example: parallelism, perpendicularity)
- assembly relations used to model assemblies (for example relations 'based_on' and 'fits' describing the relative positions of parts)
- relations between features describing the relative positions of features (for example 'perpendicular_to' and 'parallel_to')
- parametric relations in the form of algebraic equations (for example: 'maximum diameter < 60, 'dimension A + dimension B < dimension C)
- Functional relations of movement, force and localization.

The partial taxonomy of relations is presented in Fig. 5.

2b. Communication bus

The systems working in CE environment must exchange information, particularly information about the product being developed. The product model is an intermediate element between design and manufacturing, and it is also used to create different variants

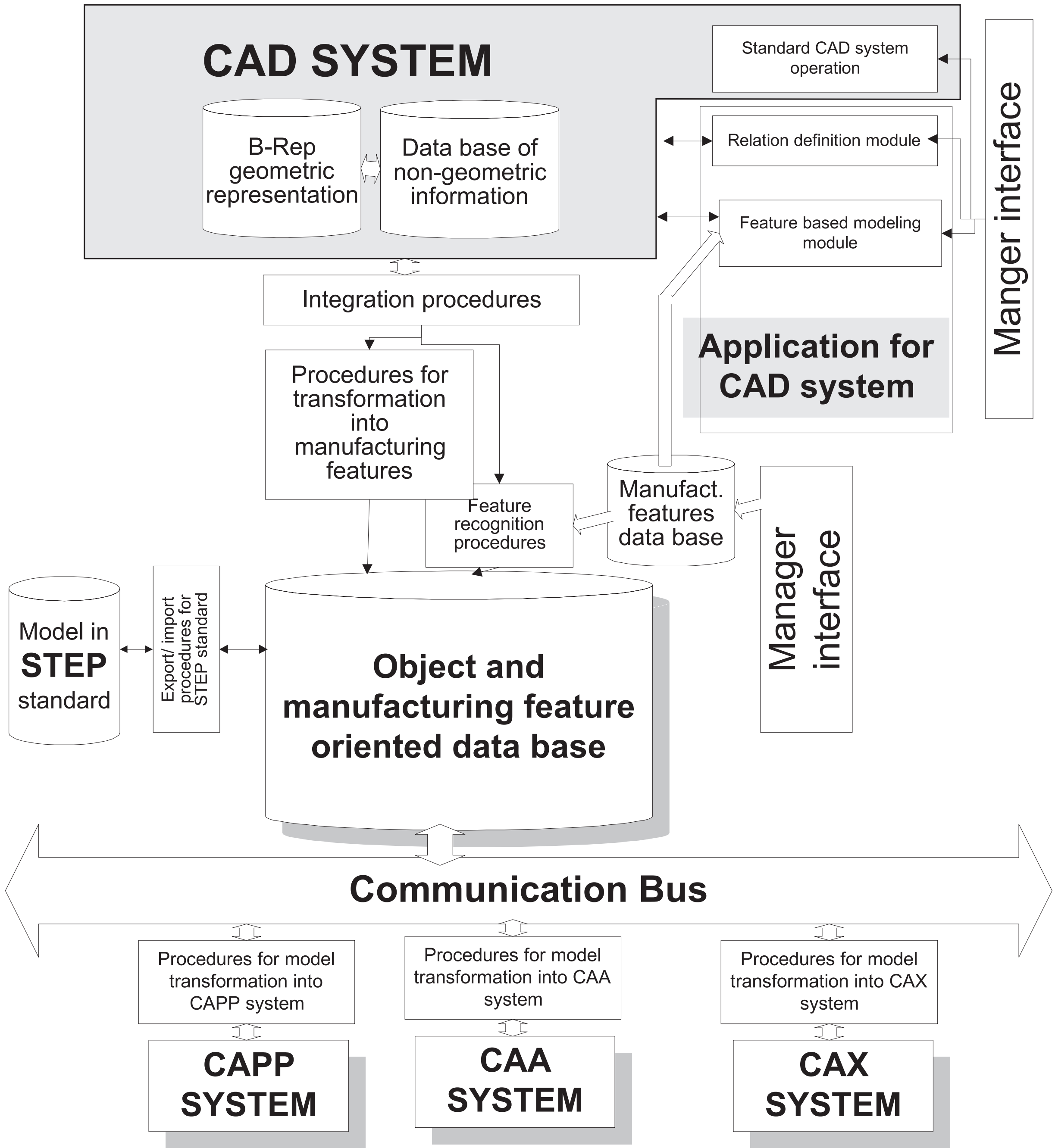

Fig. 3 The architecture of system for product modeling in CE environment

during its whole life-cycle. The example application using this model are Computer Aided Design (CAD), Computer Aided Process Planning (CAPP), Computer Aided Assembly (CAA) and Computer Aided Fixture Design (CAFD) systems. This is the reason why proper modeling and representation of product related information is a key element in CE environment development.

According to the recent research and experience gathered in industry, the product information is sent not only from CAD system to CAPP system, but the information must be also sent in a reverse direction, from CAPP system to CAD system [5]. Such feed-back information from the CAPP system will enable the designer to take adequate decisions related to material, machining accuracy, hole diameters, etc. Also the information about the

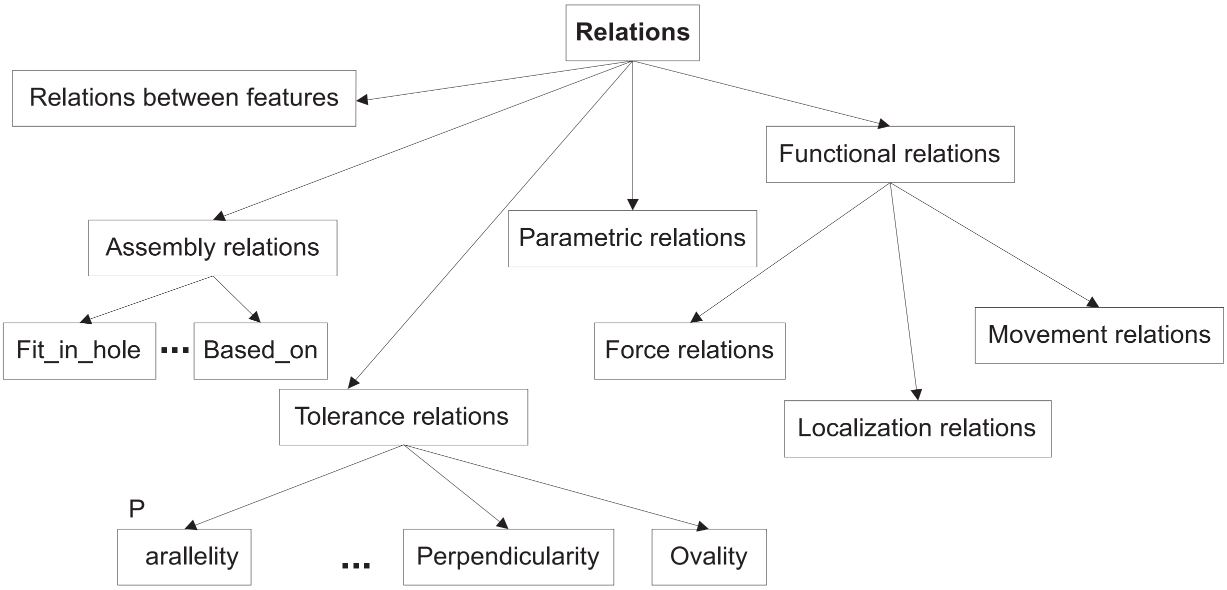

Fig. 5 The partial taxonomy of relations

costs of special features, special tools, and complex machining methods will help the designer to select most suitable design variant.

The exchange of information between a product modeling module and systems working in CE environment is done by means of messages which are sent thorough a communication bus.

The message has the following format:

```
MESSAGE(recipient, message_name, result,
(list of parameters))
```

where: `recipient` - the feature (object) to which the message is sent
`message_name` - the message identification
`result` - the result of message processing.

The messages are distributed in the feature tree (object tree) using the general message distributions techniques available in the object- oriented methodology.

One of the key development aspect are the means to implement the communication bus. The simplest solution, independent from the operating system is data exchange by text files. Such mechanism is used in the expert system Exsys Proffesional for the data exchange between Exsys and external programs. Beyond any doubt, the main advantages of this solution is the simplicity and the independence from the operating system. It is also possible to employ other more effective methods available in very popular nowadays windowed environments such as Windows 3.11, Windows 95 and Windows NT. For example OLE, DDE, or exchange through the Clipboard can be used. Despite the fact that these solutions are more difficult to implement, they secure greater throughput and allow for the use of more complex data-structure. In case of the distributed CE environment the messages are sent through the computer network.

2c. Commercial CAD system with application for non-geometric information modeling

A very important aspect influencing the modeling system functionality is the method of model creation. Two modeling methods can be distinguished [7]:
- process planning oriented methods
- methods using commercial CAD systems

Despite difficult implementation, methods using commercial CAD systems are gaining increasing popularity because they offer a full and unique geometric model, flexibility in the model creation, and CAD systems are widely used in industry.

Commercial CAD systems to be used must be customized. The reason is that non-geometric information such as tolerances, surface roughness, material treatment are stored in the form not suitable for processing by the computer software, especially by the expert systems. The non-geometric information is represented in drawing format (such as DWG, DXF, or IGS) in the same way as geometric information, using standard entities such as lines and texts. In the proposed solution the commercial CAD system is customized by the application running in its environment. This application attaches non-geometric information to the drawing entities, and it is also used to represent the relations used in the product model. The non-geometric information should be

interactively entered in a CAD system in a way not limiting the use of other system functionality. In the developed system, the

SolidEdge“ from Intergraph is used, it employs the B-Rep (Boundary Representation) method.

2d. Procedures for manufacturing feature oriented product model creation

The task realized by the procedures for feature recognition, feature transformation and data integration is to convert the geometric model from CAD system, non-geometric data entered with the use of application for CAD system into the fully manufacturing feature oriented product model. The feature are recognized from the B-Rep representation using the logic approach [4].

2e. Manager interface

The possibility to use the user-defined feature is a very important factor influencing the design and process planning functionality and effectiveness [4, 21]. It is not possible to create the finite feature set meeting the needs of all products, or manufacturing systems. Even in the boundary of one company, modernization of production facilities or introduction of new products requires the feature set to be changed. It is obvious that not all features are known at the time of system implementation. Because of this, the product modeling system must be equipped with mechanism for feature set modification.

The users should not be allowed to modify features individually, the formal procedure should be followed. The changes should be implemented by the manager of the product modeling system on requests from the users. The modifications are done through the interface of the system manager.

2f. Export/ import procedures for STEP standard

The standardization is a key aspect influencing the cost and the time of product development. The product information must be exchanged between companies participating in the project. Very often the companies are using systems from different vendors. On the market are also available the catalogues of standard parts on the electronic means of storage.

There are several data exchange format available for drawing data exchange including IGES, DWG, DXF, WMF and ACIS. The main disadvantage of these formats is the fact the information is exchanged on the level of geometric entities such as lines, circles, surfaces, basis 3D solids and texts.

The most promising now is the new generation format called STEP (Standard for the Exchange Product model data, or PDES - Product Data Exchange Standard) developed by the International Organization for Standardization (ISO) as the means for product data exchange. The information is exchanged without any losses.

Because of these facts the product modeling system will be equipped with the import/export procedures for STEP standard.

3. RESULTS

The product modeling system architecture presented above features the following:

- use of commercial CAD system for geometry modeling and all its functionality being the source of the popularity of these drawing systems,
- exchange of information by means of messages without the need to know the structure of the product model database,
- exchange of information on the level of logic product representation, and not on the level of basic geometric entities and so the similarity to the natural way of communication between engineers,
- use of object oriented methodology simplifying both the understanding of the product model and its implementation during programming
- access to the information on different level of abstract
- the possibility for modification and development of system by manager on requests from users
- running on the network
- exchange of information with other product modeling systems equipped with STEP interface

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GENERATÍVNY SYSTÉM PRE NAVRHOVANIE TECHNOLOGICKÝCH POSTUPOV

GENERATIVE SYSTEM FOR MANUFACTURING PROCESS PLANNING

Článok prezentuje generatívnu metódu ako základný prístup pre expertné navrhovanie technologických postupov. Metodológia navrhovania technologického postupu, štruktúra technologických operácií a modelovanie postupov sú základné úlohy pre exaktné generatívne metódy tvorby technologických postupov. Záver článku opisuje expertný systém EXSYS ako základný nástroj pre vývoj systému generatívneho navrhovania technologických postupov.

V článku je predstavená architektúra expertného systému, pričom veľký dôraz sa kladie na kontrolný mechanizmus. Procedurálne kódovaný kontrolný mechanizmus je riadený pomocou deklaratívnych vedomostí, ktoré opisujú ako použiť vedomosti pre plánovanie technologických postupov. Vedomosti sú reprezentované pomocou produkčných pravidiel. Na základe reprezentácie výrobných vedomostí boli špecifikované tri úrovne: výber všeobecnej štruktúry technologických operácií, reverzibilný návrh medzitvarov a prechodových tvarov; generovanie procesu technologických operácií. Prezentuje sa tu aj prototyp expertného systému. Navrhnutý systém, ktorý využíva na reprezentáciu vedomostí produkčné pravidlá a rámce, bol vyvinutý pomocou prázdneho expertného systému EXSYS PROFESSIONAL. Systém bol verifikovaný v obrábacom centre CPTOR 1, pre ktorý bol generovaný technologický postup.

The paper presents the basic approach for the expert process planning - generative method for planning of the manufacturing processes. The methodology of process plan, structure of manufacturing processes, modelling of processes are key tasks of exact generative methods of creation of process plans. Conclusion of papers describes the expert system EXSYS as a basic tool for development of generative process planning system.

In this paper a domain - specific expert system architecture with special emphases put on the control mechanism is presented. Procedurally encoded control mechanism is driven by explicitly represented declarative control knowledge, describing how to use the planning knowledge represented as production rules. On the basis of such knowledge representation three stages were specified: selection of the generalised structure of manufacturing process, reversible design of the semi finished product and intermediate shapes, and generating the machining process. The prototype of an expert system is also presented in this paper. The system combines the rule and frame technique to represent the knowledge and is built using the expert system EXSYS PROFESSIONAL as the shell. It has been verified by building the system which generates process plans for rational parts, manufactured in the CPTOR 1 machining centre.

1. Introduction

The generative method is a subject of theoretical and experimental research, and difficulties with its implementation are connected with the lack of formal description of the synthesis of activities constituting the manufacturing process. To overcome the difficulties while developing the huge technological knowledge base, a semi-generative method is often used [3].

Computer-aided process planning systems may operate in several modes. The main modes of CAPP are as follows[1]:

- *pattern generation mode* - involves the generation of system resources, such as process patterns on which the process planning is based. This mode comprises the archiving of individual processes, the generation of group representatives, development of group processes, and the development of planning principles and rules (the design of the knowledge basis).
- *process planning mode* - involves the utilisation of system resources by planning real manufacturing processes,
- *data base management mode* - involves the generation and updating of data bases available in the system.

In semi-generative method the pattern is characterised by changeable process structure. It gives more freedom to create the various manufacturing process for a given workpiece. The pattern of the process structure is determined on the basis of technological knowledge and analysis of manufacturing processes for a given set of workpiece belonging to defined class of workpiece.

On the basis pattern, after analysis assigning the workpiece to the one of the workpiece classes, manufacturing process is generated.

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2. Pattern generation mode

For a given set of similar (by processing characteristics) objects the structure of the process indicates some kind of processing order owing to increasing accuracy of surfaces being machined and also to the shape and mechanical properties of the workpiece. In this phase the structure of processes is shown.

This structure defines the sequence of activities models. Hierarchical decision nets are defined by:
- connection of activities models into a sequence of activities of higher level,
- development of decision making rules for all levels of hierarchy.

The nature of the decision process in planning is represented by the knowledge model. The decision problems are solved on several different levels and the number of level depends on the complexity of the problem. Each I-th level of details can be described by nets [2]:

$$S_I = [D_I, T_I, R_I] \quad (1)$$

where: D_I - a set of planning decision determining the rules for selection of activity models for i-th level,
T_I - a set of activities models or transition to the other planning decision for i-th level,
R_I - relations defined on the set of planning decisions $d_I, d_{I2}, d_{I3} ... \in D_I$ and activities $t_{I1}, t_{I2}, t_{I3} ... \in T_I$ for the i-th level,
I - = 1 ... N, N - number of levels

Each operation model $t_{I1}, t_{I2} ... \in T_I$ can be described using the net of the lower level.

The knowledge base has N level of details:

LEVEL I - comprises the manufacturing knowledge determining the rules for assigning the workpiece the knowledge concerning the planning of the generalised structure of the machining process.

LEVEL II - N-1 comprises the manufacturing knowledge determining the rules of the planning of the generalised structure of the process for a given object. For a given set of similar (by processing characteristics) objects the structure of the process indicates some kind of order. Phases and stages are the basis for the separation of the parts of the process structure, where the machining of the object surface subsets should be executed with the determined accuracy.

LEVEL N - comprises the manufacturing knowledge determining the rules for the planning of the structure of the manufacturing process for the range of a particular stage and phase of the process. The manufacturing knowledge on such level allows to select an appropriate model of activity, suitable for the requirements concerning the workpiece and taking into account the constraints of the manufacturing system capabilities.

The knowledge for I-th level contains:
- relations between decision nodes and activities model,
- set of decision trees for selection of the activities model,

The rules for the selection of the activities can be presented as a decision tree. The decision tree is a graph-tree, the root of which is created by the selected attribute Q of the planning task, and the particular branches represents the values of this attribute q. The graph nodes on the higher levels of the tree have assigned further attributes occurring in the classification task, whereas the nodes on the lowest level describe the corresponding activities. The actions can be described by means of the net of the lower level.

On the basis of the model presented above, two principal types of knowledge can be distinguished [2]:
- control knowledge
- classification knowledge.

The control knowledge determines the set of activities adequate to the current planning context, so it is used to determine the possible sequence of activities. Thus the role of the control knowledge is supervisory - it controls the rule-based knowledge database, applied to solve the classification task.

The control knowledge is represented by means of frames. Each net of the I-th-level is described by the frame. The frame has three columns where the first one gives the start decision nodes, the second gives the activities models and the third the end decision nodes. There are also pointers which connect frames together.

The classification knowledge can be presented in the form of a decision tree. On the basis of the decision tree $d_{I1}, d_{I2}, d_{I3} ... \in D_I$, a set of rules (IF...THEN) defining the principles for the selection of planning actions can be determined.

In the THEN part of the rule values are assigned to parameters of the procedure related with the selected activity models and the procedure is called.

The following planning actions are subsequently realised in the pattern generation mode:
- the classification of the workpiece,
- the division of workpieces into subset of workpieces types,
- the generation of manufacturing process structures for the subset of similar workpiece,
- the development of decision- making rules for process structure selection,
- the development of decision- making rules for semi-finished product design,
- the development of decision- making rules for machining process generation,

3. Process planning mode

Taking the nature of the decision process into account, the problems solved in the decision process create a multi-level decision system which can be divided into several planning subsystems. On one hand, planning because of its complexity is made in stages, from general solution concept to particular solutions by iterative actions. On the other hand, some order can be established on each level of detail because of the characteristics of the planning task.

In the process planning mode it is possible to select the appropriate variant of the machining process by defining the structure of process components and by the parametrisation of these components.

The following process planning activities are subsequently realised in this mode:

- Selection of a generalised structure of the manufacturing process
- Reversible planning of the semi-finished product and intermediate shapes of the product
- Generating the machining process

3.1 Selection of a generalised structure of the manufacturing process

The generalised structure of the manufacturing process is selected based on the processing and geometrical characteristics of the product (Fig. 1). The product is evaluated taking into consideration the values of its attributes, according to the sequence resulting from the structure of decision tree. Using such a reasoning the activity (which means the selection and transition to manufacturing process planning on the basis of the chosen structure) can be determined.

3.2 Reversible planning of the semi-finished product and intermediate shapes of the product

The elements of the generalised structure, i.e. stages and phases, are the basis for determining the so called intermediate states describing the shape and processing properties of the workpiece, which are to be achieved as the result of an appropriate (i.e. consistent with assumed phase-stage structure, see description of the Level II ÷ N-1 manufacturing knowledge) execution of the machining process. On the basis of geometrical and processing characteristics of the product and the manufacturing knowledge the intermediate shapes and the semifinished product may be determined by using the reversible (from the product to the semi-finished product) method.

This stage is realised in the following steps (Fig. 2):

- determination of the type of the semi-finished product,
- planning of the intermediate shapes of the product.

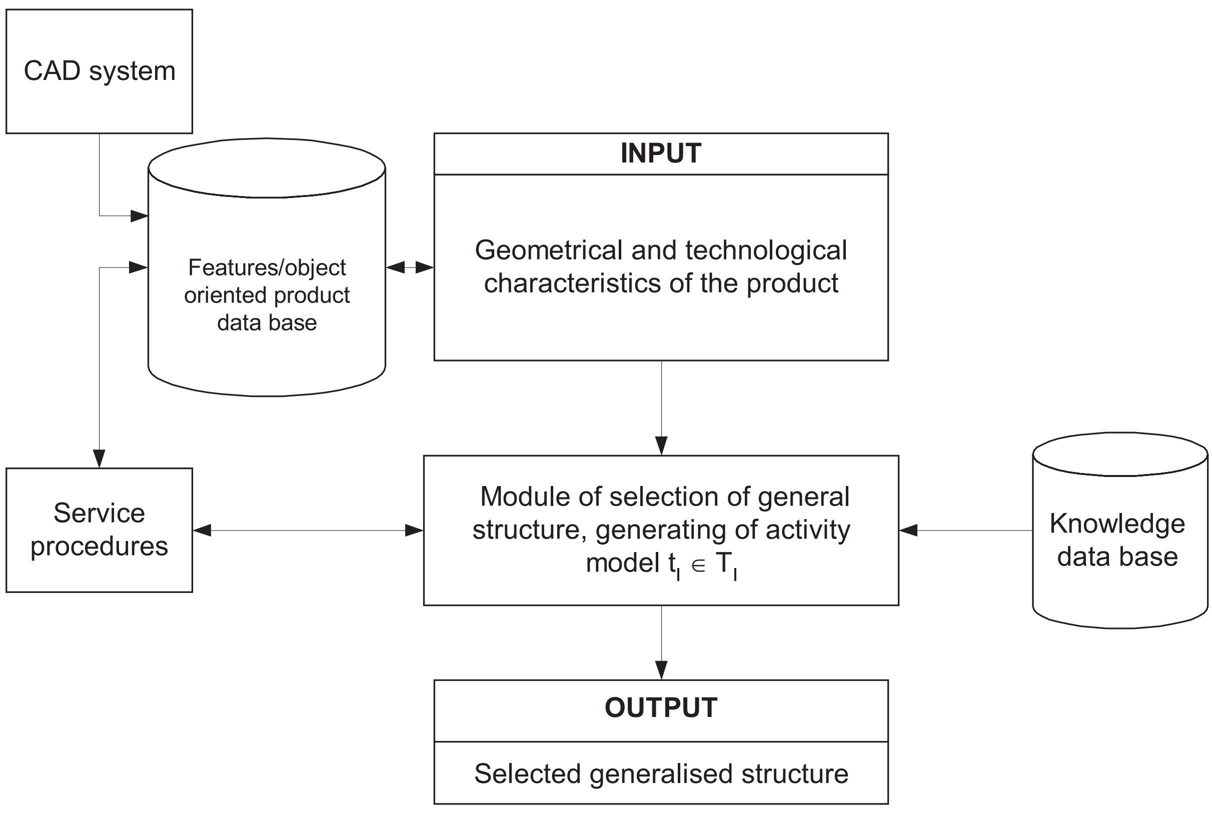

Fig. 1 Stage I- selection of a generalised structure of the manufacturing process.

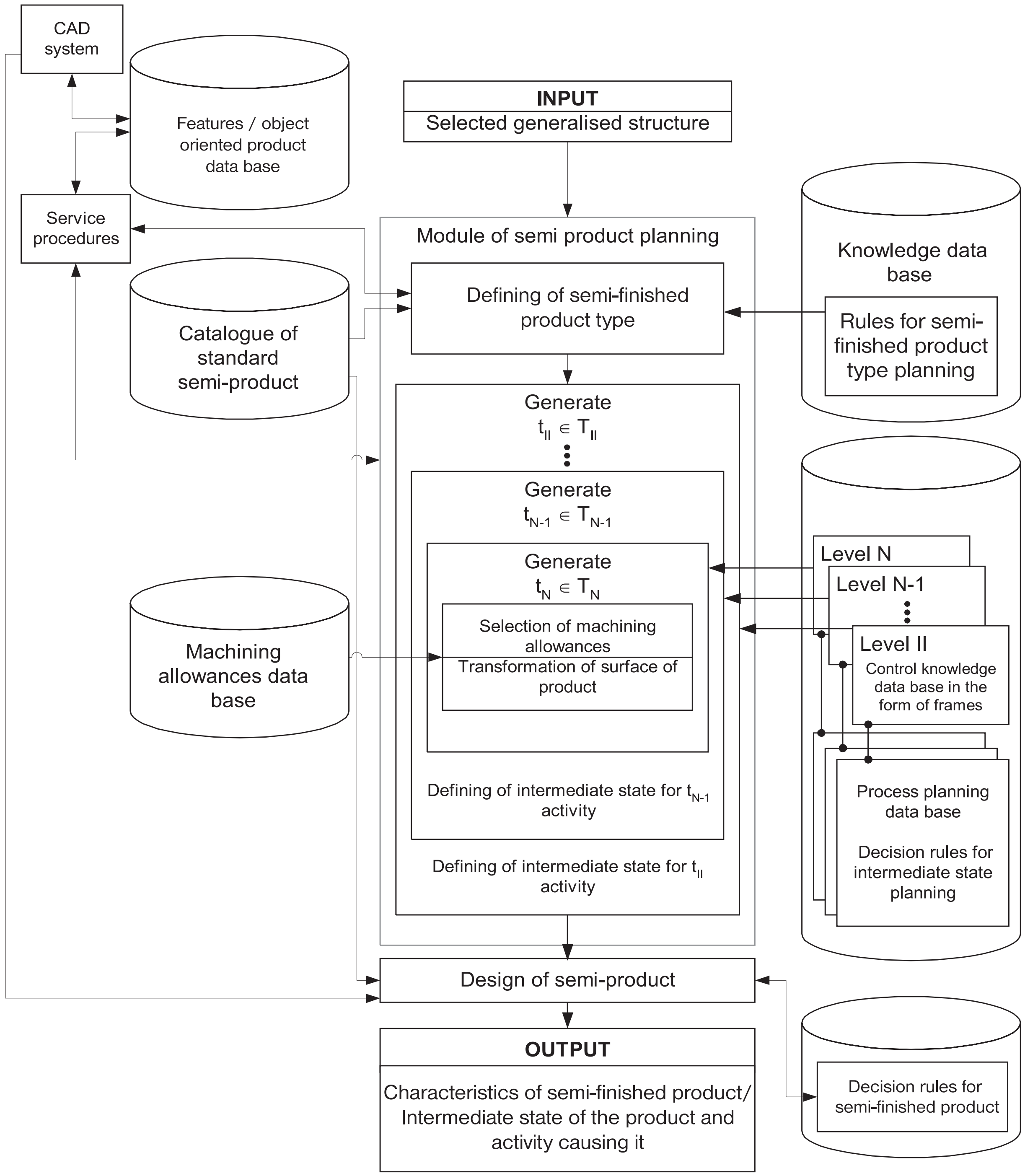

Fig. 2 Stage II -reversible planning of the semi-finished product and intermediate shapes of the product

3.3 Generating the machining process

For each step determined in the previous planning planning objective the task can be formulated in the following way: Choose the methods and means leading to an intermediate state for a given stage and phase.

For the planning objective the decision-making process will be realised in an iterative way. The process is generated in the following steps:

- identification of allowances,
- selection of the range of machining,
- selection of the workpiece fixture variant,

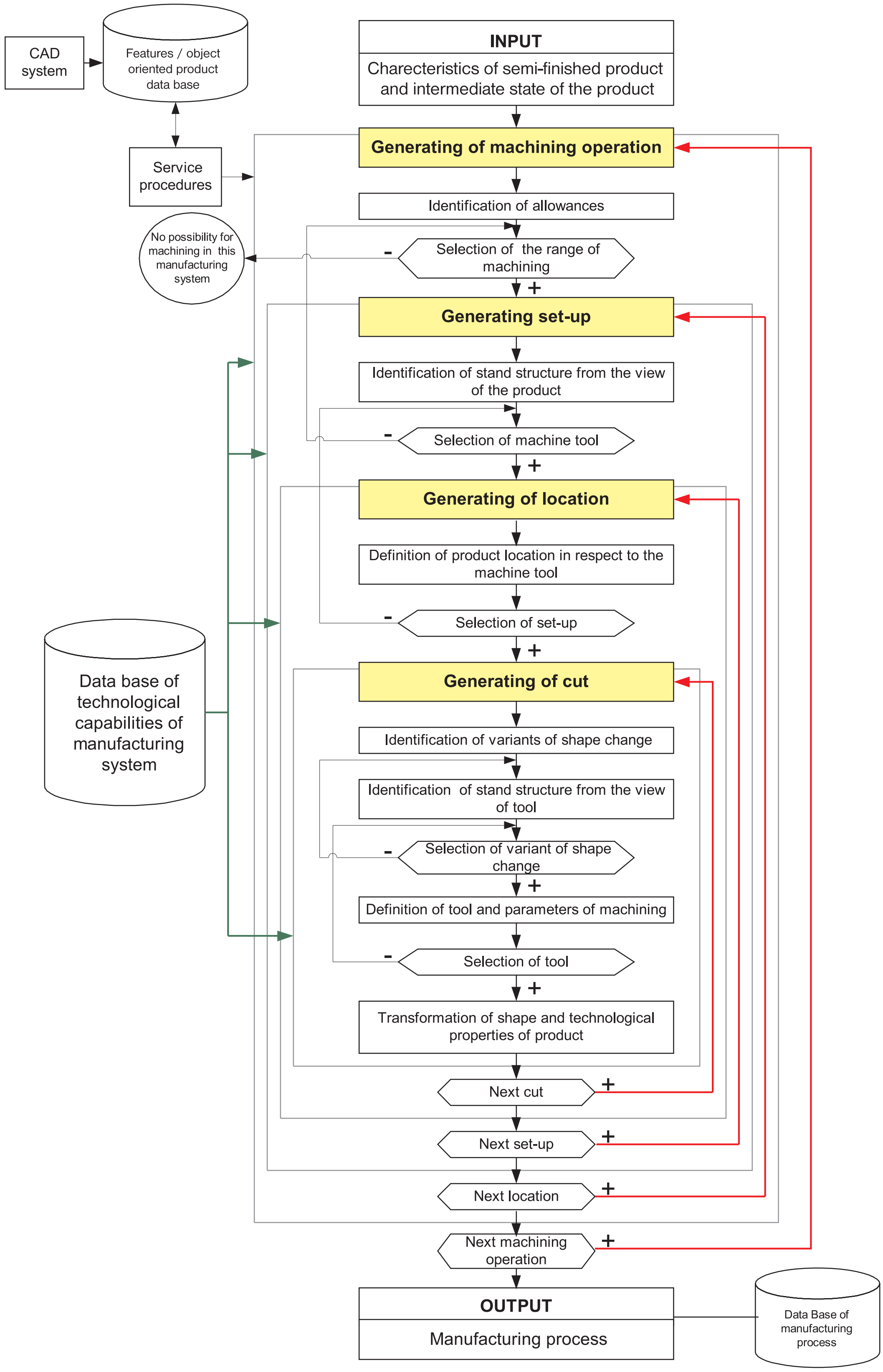

Fig. 3 Stage III- generating the machining process

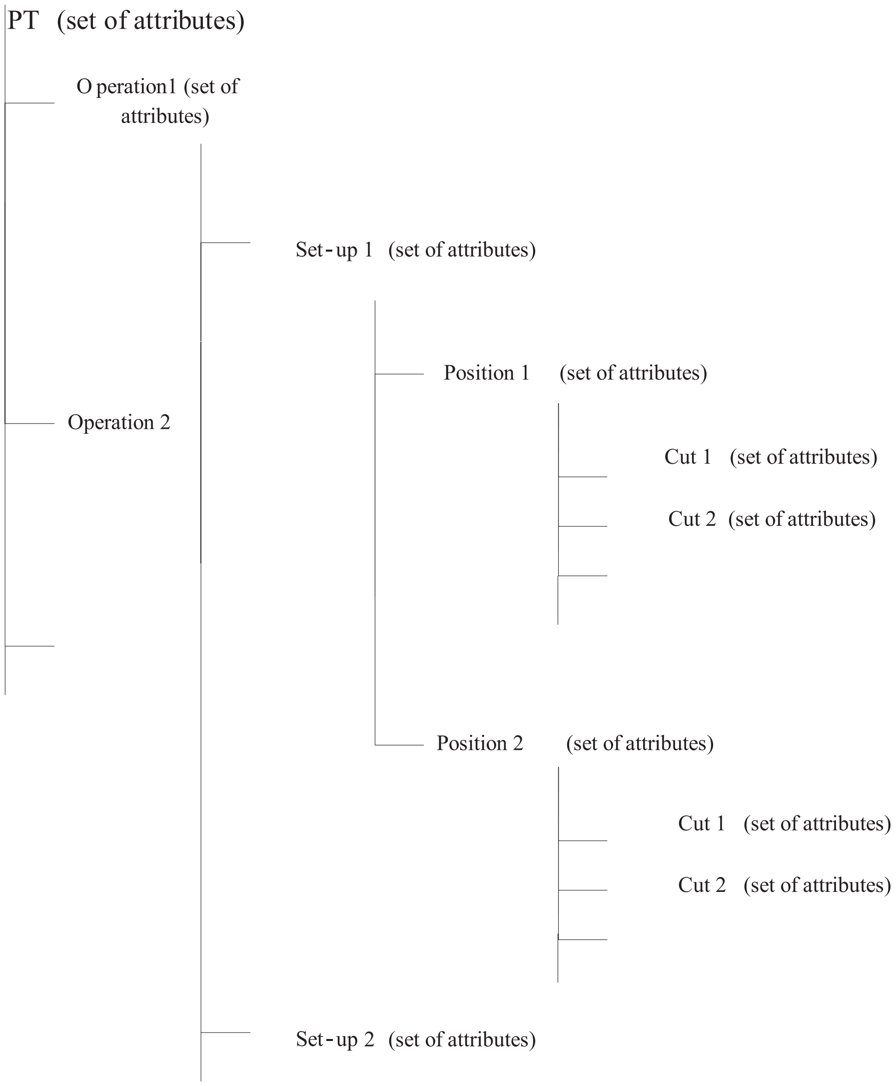

Fig. 4. The hierarchical structures of the machining process plan.

- identification of the stand structure from the view of the product,
- selection of machine tool,
- definition of product location,
- selection of set-up
- identification of stand structure from the view of tools,
- selection of variants of shape change,
- selection of parameters for the machining variant,
- selection of tool.

After defining the model of shape change and the way, in which it is obtained, the transformation of the workpiece shape and processing properties is carried out. The process will be repeated until the intermediate shape, which corresponds to the realised goal, is obtained.

In this way the process plan in the form of tree Fig. 4 for the given product is generated.

$$PT = [Operation[Set-up[Position[Cut[Pathway]]]]]$$

4. Implementation aspects

The diagram of the computer aided process planning system operation presented above was implemented using the internal programming language of EXSYS PROFESSIONAL v.4.0 shell expert system. The mechanisms for running external programs (written for the WINDOWS environment) and for the data exchange between the EXSYS and external programs were utilised. It has been verified by building the expert system for process planning for rational parts manufactured in the CPTORl machining center.

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ČINNOSTI MENIACE STAV OBJEKTU V PROCESE OBRÁBANIA A MONTÁŽE A ICH FORMALIZÁCIA

THE ACTIVITIES CHANGING THE STATE OF THE OBJECT IN THE MACHINING AND ASSEMBLING PROCESS AND THEIR FORMALIZATION

Obrábacie a montážne procesy sú diskrétne sekvencie činností spôsobujúce zmenu polotovarov na finálne súčiastky, v prípade montáže ide o kompletizovanie súčiastok do vyšších celkov. Pre počítačom podporované navrhovanie technologických postupov je potrebný dokonalý a formálny opis týchto činností. V článku sa prezentuje koncepcia formalizácie činností, ktoré menia charakteristiku súčiastky. Navrhnutá koncepcia môže byť využitá pre navrhovanie technologických postupov.

The machining and assembling processes are discrete sequences of activities causing the change of semi-products into the finished parts, and assembling the parts into the final product. In computer aided process planning the precise and formalized description of activities is necessary. In the paper a conception of formalization of the activities changing the part characteristic is presented. The proposed description may be useful for process planning.

1. Introduction

The automation of process planning procedure demands the exact recognition of the events which appear in the real machining and assembling processes. The recognition of these events and their formalized description make possible to build the events data base and allow the correct planning the structure of the process [1].

The machining processes are an ordered set of events based on the following discrete activities. In effect of these activities the object, a machined part, changes its state from a semi-product to a finished part.

The activities occurring in the machining process should be recognized and described in order to make possible the selection of right elements of the structure in the computerized semigenerative and generative process planning methods.

As it is known three kinds of activities may be distinguished [2, 3]:
- activities changing the state of machined parts by changing their geometrical and technological characteristics,
- activities causing a change of the position or localization of a part or tool,
- activities comparing the real state of the part with the demanded.

In the paper only the first group of activities will be further considered. This group is the most important in the machining and assembling process planning.

2. The machining transformer

The activity causing a change of the state of a machining part as effect of a partial change of features for a given surface or set of surfaces is called the machining transformer. Similarly, the activity creating a new object by assembling the same parts on a different level of complexity is called the assembling transformer.

In the most general formulation, a transformer describes the model of a dynamic change of the state of n-objects from which in like manner exert the forces (cutting or assembling) on the others in the determined kinematics conditions. Therefore, the transformer may be described by an ordered set of objects, their kinematics and elementary function which causes the change of their state [3]:

$$T = \{U\}, \{K\}, F \tag{1}$$

where: $\{U\}$ - set of objects
$\{K\}$ - set of kinematics relations between the objects
F - function describing the dynamic relation between the objects

A more detailed analysis of this general description of the transformers shows that above definition the set of objects $\{U\}$ and function F must be differentiated.

Machining transformer T_m is a term for the activity in which the set of objects is divided in two subsets, parts $\{P\}$ and tools (instruments) $\{J\}$. The activity of transformers concerns the set of

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surfaces $\{p_i\}$ of the given part in the state P_i causing their change to the state P_{i+1} realized by the partial machining function f_M. Therefore:

$$T_M - (\{p_i\} \subset P_i), \{J\}, \{K\}, f_M \quad (2)$$

where: $\{p_i\}$ - set of surfaces of the part in the state P_i which originate by machining change their geometric and technologic characteristics on the set $\{P_{i+1}\}$

$\{J\}$ - set of the tools (instruments) participating in the change of the characteristics

$\{K\}$ - Kinematics of part and tool

f_M - Partial function realizing the change and describing the dynamic relations between the tool and machined surfaces

So the machining process is described by the activity of the following transformers on the part in initial state (semi-product) P_P causing the final state of the part P_K. In this way, the activities of successive transformers cause the discrete change of state of the machining part. The selection of sequence of activity of particular transformers is based on technological knowledge (W) composed of rules (R) and principles (Z).

The machining process may be presented in the form of a sequence of the following changes of the state of the part occurring as a activity of transformers. Some of these states play an important role in the structure of machining process. Therefore:

$$P_p \rightarrow \{T_M\} \rightarrow P_K \quad (3)$$

$$P_P \rightarrow [T_{M1} = (\{p_1\} \subset P_P), \{J_1\}, \{K_1\}, f_{M1}] \rightarrow P_1$$

$$P_1 \rightarrow [T_{M2} = (\{p_2\} \subset P_1), \{J_2\}, \{K_2\}, f_{M2}] \rightarrow P_2$$

$$P_2 \rightarrow [T_{M3} = (\{p_1\} \subset P_2), \{J_3\}, \{K_3\}, f_{M3}] \rightarrow P_3$$

$$P_{K-2} \rightarrow [T_{MK-1} = (\{p_{K-1}\} \subset P_{K-2}), \{J_{K-1}\}, \{K_{K-1}\}, f_{MK-1}] \rightarrow P_{K-1}$$

$$P_P \rightarrow [T_{M1} = (\{p_1\} \subset P_P), \{J_1\}, \{K_1\}, f_{M1}] \rightarrow P_1$$

3. The description of the machining transformer

A more detailed analysis of the structure of transformer description (Fig. 2) shows that the set of surfaces $\{p_i\}$ connected with the general part description can further be divided into three subsets:

$\{p_n\}$ - surfaces not machined in the process, i.e. raw surfaces of the prismatic part or connecting rod,

$\{p_m\}$ - surfaces machined in the given activity of the machining process,

$\{p_l\}$ - locating surfaces, coming into contact with the locating set of the machine tool or fixture taking away some degrees of freedom as necessary in the given machining activity.

Only the set $\{p_m\}$ changes this characteristic activity of the transformers, but the selection of demanded model of the transformers depends on the kind localization of the set $\{p_l\}$ in the structure of the part P_i. The important features of the surfaces in the machining transformer are:

- the type of the surface, outside *EX* or inside *IN*,
- their fundamental geometrical shape, as cylinder, plane. This form of surface may be described using the multi-literal code p_{iii},
- localization of the surface in the main co-ordinate system X, Y, Z, or planes XY, XZ, YZ, or special positions S.

The tool occurring into the transformer models is described more precisely too. For the description of the kind of the tool, or a set of tools, the multi-literal code J_{iii} is proposed. The description is completed by the definition of the tool position. Three positions can be distinguished: vertical *V*, horizontal *H*, and inclined *A*.

Kinematics of the part and tool is described by the character of the movement, main *M* or auxiliary *A*, kind of move of a part or tool, linear *L*, rotary *O* or composed *C*. In this way, the main own move of the part is described by index *MOP* and that of the tool by *MOI*.

Similarly, the auxiliary movement is described by the index AOP for a part, and *AOJ* for a tool. The main or auxiliary translocation of the part is designated by index *MP* or *AP* and that of the tool by *MI* and *AI*.

The partial or elementary function realizing the dynamic relation of transformers is the cutting function f_M. It is characterized by a letter code indicating the typical kind of machining f_{Miii}, in relation to the tool code I_{iii}.

Further, the position of the velocity vector of the main moving $\vec{V}_{MI}$, $\vec{V}_{MP}$ in relation to the machined surface p is described. It may be perpendicular $+$, parallel ¦ or inclined $<$ [3].

The structure of the description of the machining transformer TM is presented in Fig. 1. The lack of some features is indicated by “0“ in the adequate place of the structure. A simple drawing helps to understand the description. An example of the description of the model of multitool, turning of cylindrical, external surfaces transformer is presented in Fig. 2.

The transformer model may be chosen from a set of transformers which can be realized in the given machining system, saved in the data base. The selected model is now parameterized to transform it in one of the structural elements of the machining process. To attain this, the parameterization must take into consideration the following demands:

- start localization of the part and tool in the CO system of the machine tool,
- end localization of the part and tool in the CO system of the machine tool,
- parametrical characteristic of the set of machined surfaces pm,
- parametrical characteristic of the tool,
- parametrical characteristic of the main and auxiliary motions,
- parametrical characteristic of the partial transformer function fM (v. e. velocity, way, sliding).

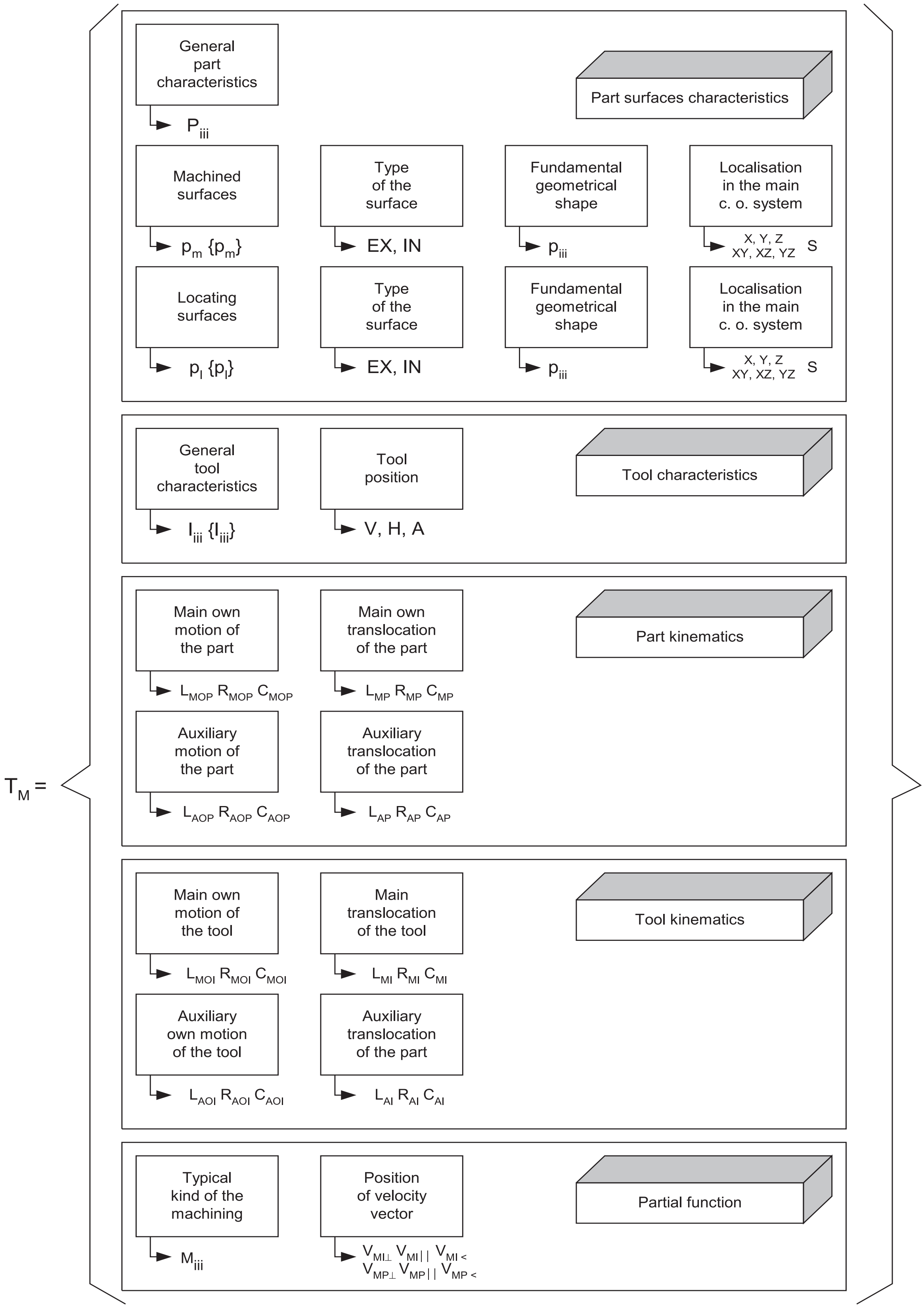
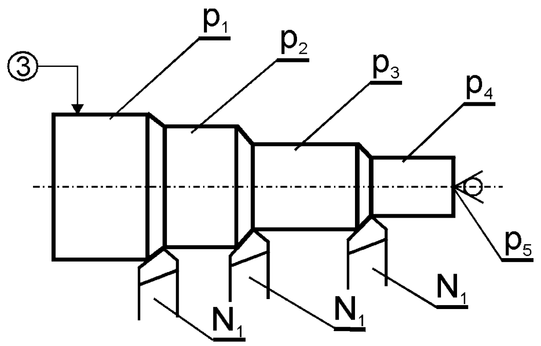


Fig. 1. The structure of the description of the transformer



$$T_M = \left\{ \begin{array}{l} \begin{bmatrix} (p_2, p_3, p_4), & EX, p_{CYZ}, Z, XY \\ (p_1, p_5), & EX, p_{1CYZ}, p_{5CON}, Z, XY \end{bmatrix} \\ \left[\{I_{NTP}\}_{1-3}, V \right] \\ \begin{bmatrix} (R_{MOP}, & 0) \\ (0, & 0) \end{bmatrix} \\ \begin{bmatrix} (0, & L_{MI}) \\ 0, & 0 \end{bmatrix} \\ \left[(f_{TNT}, \quad \bar{V}_{MI} \| \right] \end{array} \right\}$$

Fig. 2. The description of the turning transformer

4. The assembling transformer

The assembling transformer T_A is the activity in which in the set of objects participate at least two subsets of finished parts $\{P_{K1}\}$, $\{P_{K2}\}$. The activity of the transformer concerns the subsets of connected surfaces $\{p_i\}$, $\{p_j\}$ of the parts in final state P_{Ki}, P_{Kj}. In this way, a new complex object $Z_{A(i-j)}$ with different characteristic realized by the partial assembling function f_A is created. Therefore:

$$T_A = (\{p_1\} \subset P_{Ki}), \{p_j\} \subset P_{Kj}\}, \{K_A\}, f_A \quad (4)$$

where: $\{p_i\}$ - set of surfaces of the final part P_{Ki} that is connected with the set $\{p_j\}$ of the final part P_{Kj},
$\{p_j\}$ - set of surfaces of the final part P_{Kj} that is connected with the set $\{p_i\}$ of the final part P_{Ki},
$\{K\}$ - kinematics of parts P_{Ki}, P_{Kj},
f_A - partial function realizing the change and describing the dynamic relation between the parts surfaces.

The formalization of the description of the assembling transformer is more complicated than that of the machining.

In the machining process the succeeding machining transformers have already similar more or less complex structure, whereas in the structure of assembling process the transformer has a hierarchical character. Each next activity of assembling is realized generally on a more complex object. Furthermore, apart from the machined final parts, trade or special parts or sets are used during the assembly process. Kinematics of the assembling activities may be more complicated too. It is possible to state that the automation level of the assembling process is still very low, many activities are realized by the workers and exact formalization is not possible.

The automation of the assembling activities covers in great part simple robotised activities. Generally, the assembling process may be presented as follows:

$$(\{P_K\}, \{P_T\}, \{P_{SP}\}) \rightarrow \{T_A\} \rightarrow P_F \quad (5)$$

where: $\{P_K\}$ - set of machined final parts,
$\{P_T\}$ - set of trade parts or sets employed in the product,
$\{P_{SP}\}$ - set of special part or set employed in the product,
P_F - final assembled product.

The structure of the assembling process in the least level degree of hierarchy may be, therefore, described by:

$$P_{K1}, P_{K2} \rightarrow [T_{A1} = (\{p_1\} \subset P_{K1}), (\{p_2\} \subset P_{K2}), \{K_1\}, f_{A1}] \rightarrow Z_1^1 \quad (6)$$

One of the assembled parts must be treated as the basic or main part. This part is motionless in the given assembling activity.

If to the set Z_1^1 the next part P_3 or set of part $\{P_3\}$ will be assembled, then:

$$Z_1^1 \rightarrow [T_{A2} = (\{p_{Z_1^1}\} \subset Z_1^1), (\{p_3\} \subset P_3), \{K_2\}, f_{A2}]\ Z_2^2 \quad (7)$$

The hierarchical complexity of the assembling process and limited automation cause that the formalized description may be useful rather for the simple assembling activities. At first systematic of assembling kinds and methods is necessary. It is a separate, very large problem.

In some cases the elements of the presented machining transformers description may be adapted.

5. Conclusions

The above considerations allow to formulate the following general suggestions:

- in the computer aided planning the division and detailed description of main activities, especially machining and assembling activities are necessary,
- the proposed description takes into the consideration all the elements taking part in the activities transformers. It may be helpful in the complex description of other events occurring in the machining and assembling processes,
- in order to attain a better form of description and recording in the data base for the models of activities occurring in the machining and assembling process it is necessary to continue further research.

Reviewed by: A. Janáč, I. Kuric

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OBJEKTOVO ORIENTOVANÉ NAVRHOVANIE TECHNOLOGICKÝCH POSTUPOV PRE ROTAČNÉ SÚČIASTKY

AN OBJECT ORIENTED PROCESS PLANNING SYSTEM FOR ROTATIONAL COMPONENTS

Štúdia predstavuje objektovo orientovaný prístup pre navrhovanie technologických postupov pre osovo-symetrické rotačné súčiastky. Systém sa skladá z dvoch modulov: modul pre vstup konštrukčných a výrobných dát a objektovo orientovaný modul navrhovania technologických postupov. Vstupný modul je vytvorený v prostredí AutoCAD. Všetky informácie zadávané v prostredí AutoCAD je možné exportovať vo forme DXF súboru. Výstupný súbor DXF sa následne automaticky spracováva v OOPP module, aby sa vytvorili triedy objektu. Tieto triedy sú využívané sub-modulmi ako napríklad výber odoberaných objemov materiálu, určenie upínania, určenie poradia technologických operácií, výber strojov, nástrojov a kalkulácia časov obrábania.

This study presents an object oriented approach for the development of a process planning system for axis symmetric rotational components. The system consists of two modules: Part design data and manufacturing data input module and Object oriented process planning module (OOPP). Part data input module is created in customised AutoCAD environment. All the information about the input in the AutoCAD can be exported as DXF output file. DXF output file is automatically postprocessed in OOPP module to create object classes according to the input from this module. These classes are used by the sub modules: e.g., extraction of machinable volumes, setup planning, sequencing of operations, machine selection, tool selection and machining time calculation.

1. Introduction

In view of the rapidly developing international competition in the world of manufacturing, one must utilize the most modern manufacturing technologies in order to keep pace. Computer aided design (CAD) and computer aided manufacturing (CAM) have become a standard for improving productivity. However, neither CAD nor CAM have proven to be answers in themselves. For further increase of productivity and reduction of cost integration of CAD and CAM is necessary which leads to computer integrated manufacturing (CIM). Although underlying technologies, which make CIM feasible, are already available, but several building blocks are still missing. One such building block is automated process planning. Chang and Wysk (1985) define process planning as an act of preparing detailed operation instructions to transform an engineering design into a final product. Process planning is the critical bridge between design and manufacturing. Today, the production method is gradually moving toward automation. The need for dynamic responses, fast plan generation, and smooth interface between design and manufacturing functions become essential in operating the new manufacturing systems. Thus, the automation of the planning function is critical (Chang, 1990). Automated process planning or computer aided process planning (CAPP) can play a major role in successful operation of manufacturing systems.

CAPP arena has long been dominated by artificial intelligence techniques e.g., expert system (Chang, 1990). These suffer from the disadvantage of duplication, requirement for large database that makes the system implementation difficult. With the development of object oriented techniques it has been possible to takle the above-mentioned problem effectively. Object oriented techniques can improve flexibility and modularity of a system (Gu & Zhang, 1994). This paper presents an object oriented CAPP system for rotational parts.

2. Design and development of object-oriented capp system

The proposed system comprises two separate modules: the part design and manufacturing data input module and the object oriented process-planning module. Fig, 1 presents a schematic of the system developed. The input module is based on customized AutoCAD whereas the CAPP module is written in C++ using object oriented programming concepts. A detailed description of the system developed is presented below.

2.1 Part Design Data Input Module

A CAD model can contain all the detailed information about a part and thus provides information for all manufacturing functions.

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However, the language of CAD is geometry based with geometric entities such as "line", "arc", "circle" etc. to represent a finished part. Down stream in CAM, features "face", "taper", "groove", "chamfer" etc. and associated attributes are the common language. Unfortunately, computers are not intelligent enough to recognize the CAM language from the CAD language. Hence, one of the major challenges of the CAD/CAM integration is to translate the CAD language to a CAM language. This can be done by feature recognition system but it is very complex. Our aim is to develop a simpler system which incorporates manufacturing feature information more explicitly in a computer model during the design process, so as to eliminate the expensive feature recognition process.

For part description and data input to the proposed CAPP system, AutoCAD release 12 was used. The AutoCAD menu, for this purpose, was customized for inputting the manufacturing data and the features. These have to be input by the designer himself at the design stage. The main AutoCAD menu was supplemented by adding to it features such as blank, center line, external features, and internal features. The external and internal features have further been classified into sub-features. As for example, the sub-features of external feature are facing, turning, taperturning, grooving, threading, contouring, etc. Data concerning the work piece material, surface finish, and tolerance specifications can be input by clicking "feature" whereas, geometrical data is input using the original AutoCAD menu. As the part to be produced is rotational, the system would generate a 2D drawing of the part above the centerline. Complete information about each entity as well as manufacturing data is stored as DXF file. Thus, there is no need for using algorithms for translating the geometrical data into manufacturing data.

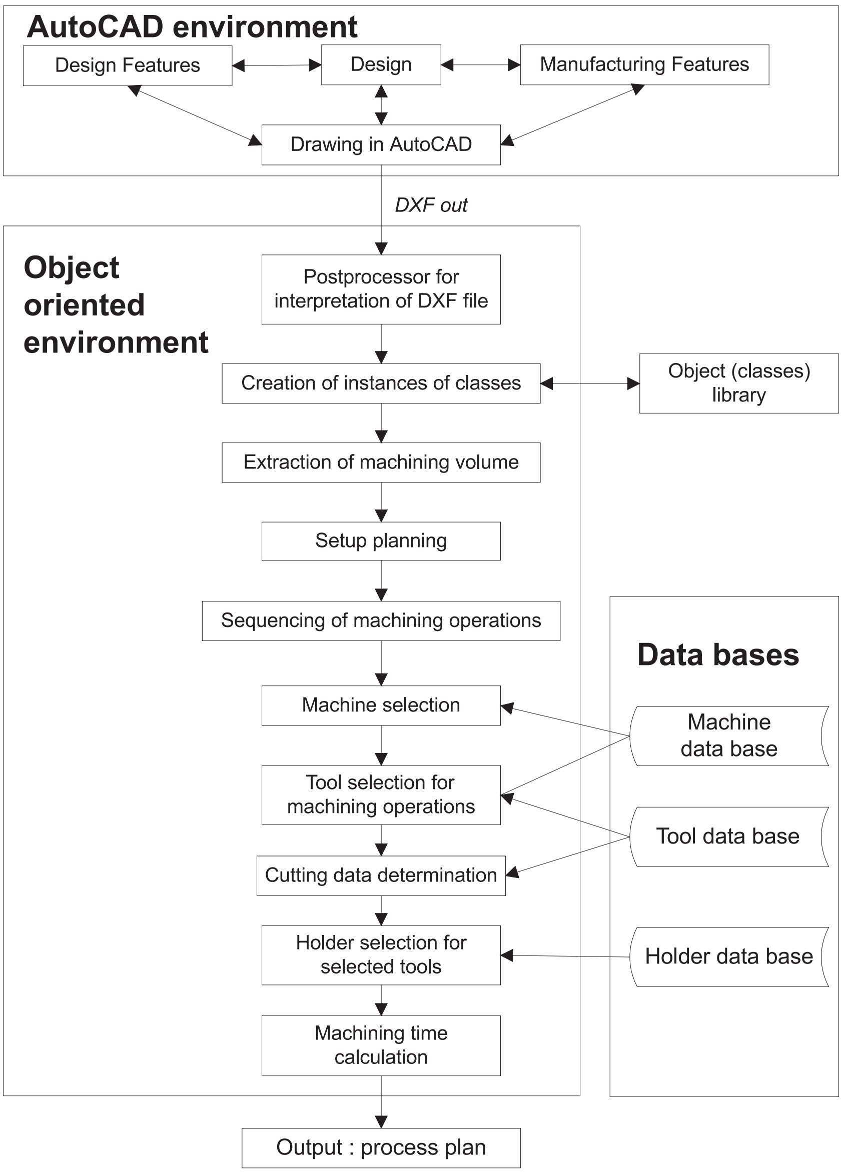

Fig. 1. Components of the proposed process planning system

2.2 Postprocessing of DXF File

DXF file is a structured long file, however, once its structure has been understood the relevant data can be extracted using conventional programming. The fundamental idea behind object oriented language is to combine into a single entity both data and the functions that operate on that data (Rumbaugh et al., 1991). Such as entity is called object. In the present system the instances of classes are defined for each feature with simultaneous accumulation of data from the DXF file.

As for example, the instance of class 'facing' contains the information concerning feature name, X, Y and Z coordinates of the feature drawn, surface finish, tolerance. For the feature 'blank' it contains the information about feature name, material type, manufacturing process and the coordinates of the drawn feature.

2.3 Extraction of Machinable Volumes

The final product shape as specified by the input data in the present case is realized in two steps. Firstly, the product is rough machined leaving behind the finishing allowance to be processed during the second step (finishing). Conclusion of the second step would yield a product of a specified shape and dimensions. For the extraction of machinable volume decision regarding how much and where to machine is to be taken so as to arrive at product shape before finishing. Knowledge of the machinable volumes would be necessary for the computation of optimum values of process parameters and the sequence of machining. Sequence of removal of machinable volumes, for rough machining, is achieved based on backward planning strategy (Shirur et al., 1998).

For preshaping, threading, grooving etc, are converted into primary features as turning and stored as an instance of turning class. When an instance of contouring is encountered, it is either converted into taperturning or turning and facing instances. Thus after combining, a component is obtained which has either facing or taperturning as instances. Removal of machinable volumes from a blank to obtain the preshaped part are found out by using backward planning strategy i.e, it starts the planning from the finished part and tries to fill the material systematically to raw stock state. At each iteration, the current state of the workpiece is compared with the finished part (goal), if a familiar pattern is found out, then the machinable volume is extracted and stored in a data file. A friend function "merge_feature" is used to access the data from class turning, facing, blank, mc_vol (Machinable volume). A loop is constructed in a function which searches for patterns of facing-turning- facing or facing-turning-taperturning or taperturning-turning- facing or taperturning-facing-taperturning and as soon as it gets it, a machinable volume is extracted and stored as an instance of class mc_vol. Thus two types of machinable volumes are extracted- rectanguler and trapezoidal. The internal features are considered as finishing feature so, they are not included in the machining volumes.

2.4 Setup Planning

After the machining plan has been finalized, a decision must be made as for the type of setup to be employed for the removal of machinable volumes during each setup. A rule based system has been developed to decide the number of setups required and the sequence of operations to be performed during a particular setup. It is desirable to have a minimum number of setups so as to minimize the manufacturing time of the parts.

The present setup planning is based on the assumption that components are held in chucks only. The rules applied in the present system are described below:

2.4.1 Finding the Number of Setups

The rules are as follows:
1. If the maximum external diameter is at the end of the component and there is no internal feature at this end, then the part can be machined in one setup.
2. If the maximum external diameter is at the end of the component and there is internal feature at this end or at both ends., than the part has to be machined in two setups.
3. If the maximum external diameter lies in between the ends, the minimum number of setups required would be equal to two.

2.4.2 Decision Making for Setup Planning

For case 2 stated above , if the maximum external diameter is at one end, then the internal feature at this end is machined in first setup and the rest of the operations are done in second setup. If the maximum diameter is at one end and there are internal features at both ends, then the internal feature at the maximum diameter end is machined in first setup and the rest of the operations are done in the second set up. If the maximum diameter is at both the end and there are internal features at both the end, then the internal feature having xl less than that of the other is machined in first setup and the rest of the operations are done in second setup.

For case 3 stated above, first of all the part features are scanned and the turning features that can he used for the purpose of clamping or chucking are identified. It is desirable to hold the part for machining at the maximum diameter. So, for this the demarcation line is found out on the end of the turning features which have diameter equal to maximum diameter of the workpiece at any position. All these values of x are stored in an array named value_x[]. Now the question comes which one to choose. For this purpose one rule is included which selects the demarcation line (value_x) which is closest to the center of the workpiece. This satisfies the stiffness constraint as well as l/d ratio decreases.

A class called setplan is created which is defined as a friend class to class turning. In the setplan class, three instances of the turning class are created, one which has all the turning features in the part, another has turning features which are located before the demarcation line as well as have its length more than the chuck width of the machine tool and third one having turning features after the demarcation line and its length more than the chuck width of the machine tool. This means that the second and third instances, i.e. turn2 and turn3 of the turning class have turning features which can be considered for holding the component.

Rules are executed to check and find out the maximum and minimum diameter in the turning features. This will aid in deciding the side that should he machined during the first setup. If the minimum diameter on the feature before the demarcation line is greater than the minimum diameter after the demarcation line, then the features before the demarcation line will be machined in first setup and turning surface with maximum diameter before demarcation line will be used as chucking surface for the second setup. In case there is no eligible surface for chucking on any side of the demarcation line, that side will be machined in second setup.

After the setups have been decided, the next step is to divide the machinahle volumes and the features into the above calculated features. At this stage, it will be decided that a particular machinable volume will be machined in the first or the second setup and whether it is located before demarcation line. Accordingly, the new coordinates of the manufacturing features and machinahle volumes are calculated and now the origin is shifted to the end of the workpiece, and the axes are defined in context of NC machine tool. Hence all the features will have value of x either zero or negative.

2.5 Sequencing of machinable volumes

The proposed system performs sequencing of machinable volumes for roughing as well as finishing operations. For this purpose the rule based system has been developed based on precedence relationships between operations to be performed and machining features. This also is aimed towards minimization of the number of tool changes involved.

The rules are described below:

2.5.1 sequencing of Machinable Volumes for roughing

The machinable volumes are defined by eight co-ordinates .e. x_1, y_1, x_2, y_2, x_3, y_3, x_4, y_4. The shape of the volumes can be triangular, rectangular, or trapezoidal. The chuck of the machine tool is on the left hand side and the other end of the part is the reference for coordinates.

The rules for sequencing are: i) The machinable volume farthest from the chuck i.e. the machinable volume, with maximum value of x_1 is machined first. ii) The machinable volume with least value of y_1 is machined last. iii) If x_1 and y_1 of two machinable volume are equal, the tie is broken by using the rule- machinable volume with maximum value of x_2 is machined first. In case of single setup machining, the last machinable volume is the volume that will be removed by the parting off. This will be saved in an another data file called part-off data file.

2.5.2 Sequencing of finishing features

The above stated rules are applied for sequencing of finishing features also. Another rule that has to be considered for sequencing of finishing features is based on feature type. This rule overrides the above mentioned rules. This rule is applicable for threading, grooving, face- grooving and internal features. It is necessary to do turning and grooving before threading, and then the internal features and then face grooving at the last. Hence, the precedence is set also by the feature type.

2.6 Selection of cutting tools and the machine tools to be employed

The decision regarding selection of machine tools and the cutting tools is based on information available in a number of data files e,g., input, sequencing, and part blank files. Fig. 2 provides an overview of the system developed for selecting the machines and toolings required. The machine data base has been developed from the specification of the CNC lathe machines of CIM laboratory of AIT. The machine database can be enlarged to include more machines if available. The cutting tool database is structured with two-dimensional array; where the row corresponds to the record of tool or insert. The structure member corresponds to the tool material, tool geometry, surface finish, tool code, tool grade, speed, feed, maximum possible depth of cut, specific force, drill diameter, drilling depth, power required etc. The system presented herein makes use of data given in Sandvik (1998).

First machines are preselected which can support the blank part size and the type and number of operations needed to machine the designed part. Preselection is done following different preselection procedure.

Then in simultaneous machine and rough cutting tool selection for preshaping section, requirements of machine selection and requirements of tool selection for rough machining for the selected machines are checked simultaneously comparing m/c speed, feed range with tool speed and feed and also comparing calculated maximum depth of cut and cutting power.

Maximum possible depth of cut is determined from the data of sequenced machinable volume data file. The maximum depth of machinable volume is determined first. This depth is compared with the maximum possible depth of cut that the sorted tool can cut in one pass. The aim is to turn

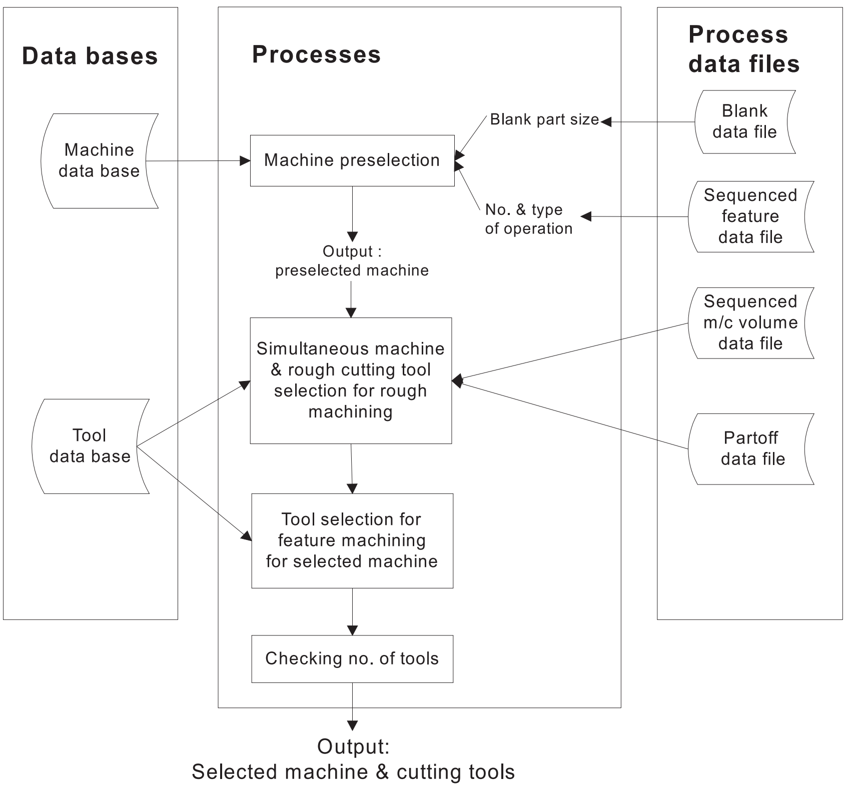

Fig 2. Overview of machine and cutting tool selection process

the maximum depth of machinable volumes in one pass. But, if the maximum permissible depth of cut of the sorted tool is less than the maximum depth of machinable volumes, then the number of pass is determined such that the depth of cut is as high as possible. Now, for this depth of cut, required power is calculated. If the calculated power is greater than the machine, then the depth of cut is adjusted. For each preselected machine power, the depth of cut is determined. The preselected machine which offers maximum depth of cut, is selected, and the corresponding tool and cutting data are stored into a array of structure.

Then the selection of tool/inserts for finishing features are done. The data of the sequenced feature data file are compared with the record of sorted tool to select a particular tool for the given purpose. These data from the feature file and machine data from class machine are matched with the data of the sorted tool record and tool record having complete match is selected.

The number of tools is determined from the selected tools and it is checked whether the tool magazine of a particular machine supports this number of tools. Each selected tool record contains the selected cutting data - speed, feed and depth of cut.

2.7 Computation of Machining Time

Cutting time for the processing of a part has been computed as the sum of roughing and finishing times of the individual features. If the part is processed using more than one setup then the processing time must include the setup change time. Determination of the setup time is quite complex therefore, in this case the setup time is taken as 200% of the total processing time of the part.

3. Conclusion

This paper describes the development of an object oriented process planning system for rotational parts. This has proved to be superior to conventional systems in respect of its ability to deal with more complex situations. The system has shown robustness and promotes reusability, The modularity of the system has proved to be beneficial in achieving flexibility and expandability. The significant features of the object-oriented paradigm are that the system can evolve over time and be modified when needed without completely abandoning the old system or redesigning it. This is an important aspect to consider when developing a process planning system since consistent changes and modifications are needed as new designs and knowledge are developed. Future developments can be made to incorporate more features and operations and towards the development of object oriented systems for non-rotational parts.

Reviewed by: J. Matuszek, J. Pilc

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Gheorghe Lazea - Alin Mureşan - Emil Lupu *

ALGORITMY SPRACOVANIA OBRAZU VYUŽÍVANÉ V APLIKÁCIÁCH ROBOTIKY

IMAGE PROCESSING ALGORITHMS USED IN ROBOTICS APPLICATIONS

Štúdia predstavuje výsledky získané realizovaním algoritmov pre spracovanie obrazu (detekcia hrán, dokončovanie obrysov, vytvorenie kostry). Spolu s uplatnenými príkladmi je uvedených niekoľko klasických ako aj dva originálne algoritmy. Spracovanie obrazu pre aplikácie robotiky si vyžaduje rýchly čas spracovania na počítači. Je skúmaná možnosť zlepšenia času spracovania klasického algoritmu vytvárania kostry (Nacacheho a Shingalova metóda) využívajúceho vopred nacvičenú neurónovú sieť. Do úvahy sa berú dva prístupy: dvojvrstvová neurónová sieť a zhluk 12 jednovrstvových neurónových sietí. Je prezentovaná a okomentovaná dosiahnutá doba spracovania daného problému.

The paper presents the results obtained in implementing image-processing algorithms (edge detection, contour closing, skeletonizing). Several classical as well as two original algorithms are presented, together with sample images from the implementation. Image processing for robotic applications requests fast computation times. We investigate the possibility to improve the processing time of a classical skeletonizing algorithm (Nacache and Shingal method) using a previously trained neural network. Two approaches are considered: a two layers neural network and a cluster of 12 single layer neural network. The processing times obtained are presented and commented.

1. Introduction

During the last five years the main field of interest of the research group within the Robotics Laboratory at the Automation Department in Technical University of Cluj-Napoca was the development of a wheeled mobile robot for indoor use. The work done until now has been supported by several grants from the Romanian Ministry of Education (see [8]) the main achievements being a mobile platform actuated by DC motors (see [5] and [6]), a stepper motor actuated micro-robot, path planning programs (see [9]) and a low-cost, intelligent ultrasonic range finding sensor (see [7]). The experience gained through these projects has shown that the sensor system is perhaps the most important in building an autonomous, useful mobile robot. This opinion is also shared by other authors, ex. [10], [4], and has led us to the decision to incorporate vision systems in our future mobile robots. In the early times of mobile (and industrial) robot research, vision could not be used as a practical approach for sensor driven robots in real time (see ex. [13]) due to the lengthy processing of the huge amount of data yielded by the vision system. But with the advent of today's new computers this is now possible. Figure 1 briefly sketches a standard architecture for a vision driven (mobile) robot.

Our first steps in implementing this architecture were to develop the "Preprocessing" and, partly, the "Recognition" modules in the figure bellow. Some of the results obtained in edge detection, skeletonizing and objects localisation within 2D images, were presented in [11]. Further algorithms can be found in [15], [3], [12], [2] and [14].

2. Object localisation

In the sequel we present an original approach to object localisation for specific objects (objects with holes - see Fig. 2). Such objects can be found quite frequently in assembly operations (peg in hole). The algorithms may also be applied to natural and artificial landmark recognition for mobile robot navigation. The image processing is done in two steps: first edge detection and contour closing followed by hole detection and localisation. We have chosen to work with binary (monochrome) bitmap images coded at byte (not bit) level. This increases the memory usage but considerably simplifies the algorithms and, consequently, yields faster processing.

2.1. Edge detection and contour closing

An edge is a boundary between two regions with relatively distinct grey levels [14]. The most used algorithms for edge detection employ local, gradient-based methods. The gradient can be computed using convolution products between a matrix defining the neighbourhood for each pixel and a gradient operator.

The edge detection and contour closing algorithm uses differential, local methods and consists of the following steps:

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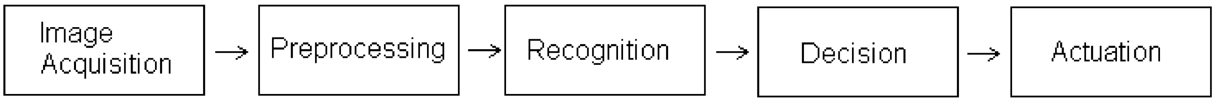

Fig. 1. Architecture for a vision-driven robot

a) Two threshold values are chosen: P1 - the minimum gradient value for a pixel for which this still is considered to belong to an edge, and P2 - the minimum grey level, such that the background grey level is bigger than P2. At this point is noteworthy mentioning that in bitmap files the standard coding is 255 for the white grey level and 0 for the black grey level. In this paper the images are presented inverted for readability reasons.
b) Using one of the following operators: Roberts with 4 or 9 points neighbourhood, Mero-Vassy, Sobel or Prewitt the gradients for each image pixel is computed (see [11] for details).
c) For each pixel a nine-point neighbourhood is built and the maximum grey level is computed.
d) Each point with the gradient bigger than P1 and having a neighbourhood with maximum grey level bigger than P2 is flagged as belonging to the edge (it gets the 255 value for the grey level).

This procedure assures reliable edge detection with strong rejection of false edges (see figure 3).

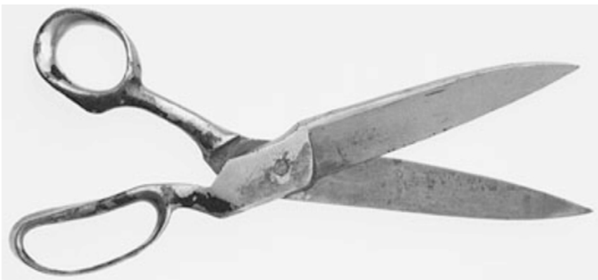

Fig. 2. Original test image

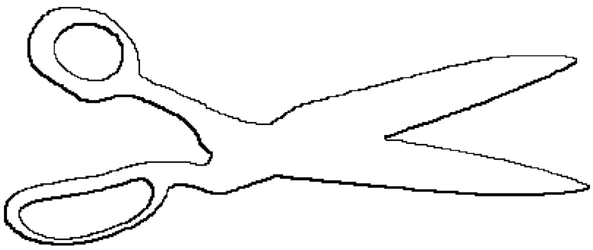

Fig. 3. Edge detection and contour closing

2.2. Hole detection and localisation

The algorithm consists of the following steps:

a) The image is scanned line by line until the first point belonging to an edge (255 grey level value) is reached. This point is being given the value of 254 for the grey level (the point belongs to an exterior contour) and the same value is written in a flag variable.
b) The image scanning continues until the next 255 level point is being hit. For this point the 5 points neighbourhood depicted in Fig. 4 is being built.

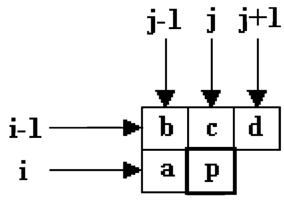

Fig. 4. 5 points neighbourhood

c) Compute max grey levels (a, b, c, d). If it is 0 this means the current point **p** is on a new contour. The flag is decremented and point **p** gets its value as the grey level. Otherwise the point p gets the value max(a, b, c, d).
d) For each of the points a, b, c, d with grey levels smaller than max(a, b, c, d) (namely x) the scanning is resumed from the point reached at step a) and each point with x grey level is being given the value max(a, b, c, d). All grey levels smaller than x are incremented. The flag is incremented.
e) Go to step b) until no point has a 255 value grey level.

At algorithm completion, the flag will yield the smallest grey level allocated, information used for finding the interior contours number. For example, if the flag equals 252, all the points with 254 grey level are exterior contour points, so there will be 254 – 252 = 2 interior contours (that is, two holes).

The processing continues with the interior contours filling algorithm and mass centre computation (for details see [11]). The results obtained for the test image are presented in Fig. 5.

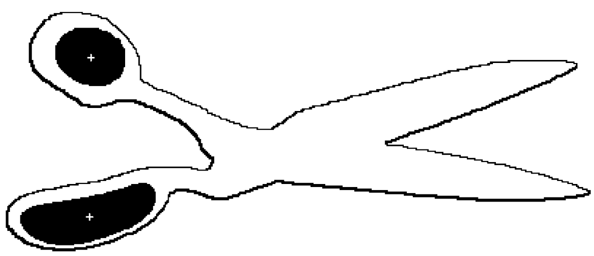

Fig. 5. Hole detection and localisation

3. Skeletonizing

The objective of skeletonizing is to reduce the representation of a region to a chain of single pixel width while preserving all other relevant features [14]. Skeletonizing is also known as thinning and the image obtained can be interpreted as a Voronoi graph with applications in path planning.

The key point in using vision with robotics is the real time implementation [16]. This became possible only in the last few years based on the newer and faster processors. Faster algorithms are also a key issue. In the present paper we investigate several ways to implement a skeletonizing algorithm. A classical implementation is presented versus two other using neural networks. The idea is to introduce the heavy computations in the training stage obtaining a fast neural network on the exploitation stage.

3.1. Modified Nacache and Shinghal's Method

Naccache and Shingal [1984] proposed a skeletonizing algorithm. After several studies, we came to the conclusion that the original algorithm must be a little bit modified in order to obtain better results. First we study 8 neighbours of the interest pixel, as shown in Fig. 6:

n3	n2	N1
n4	p	N0
n5	n6	N7

Fig. 6. Notation for the neighbours of p

An edge point is flagged if it is not an endpoint or breakpoint, or if its deletion would cause excessive erosion. Comparing the 8 neighbourhood against the windows in Fig. 7 carries out the test of these conditions.

*		d	d	d	d	d			d	d	d
	p	d		p	d		p	*		p	
d	d	d	*		d	d			e	e	e

Fig. 7. The "" denotes a dark point, and d and e can be either dark or light*

Testing the 8 neighbors for identification of the above situations is done with simple boolean expressions:

$B_4 = n_0 \cdot (n_1 + n_2 + n_6 + n_7) \cdot (n_2 + \overline{n_3}) \cdot (\overline{n_5} + n_6)$
for left edge points;
$B_0 = n_4 \cdot (n_2 + n_3 + n_5 + n_6) \cdot (n_6 + \overline{n_7}) \cdot (\overline{n_1} + n_2)$
for right edge points;
$B_2 = n_6 \cdot (n_0 + n_4 + n_5 + n_7) \cdot (n_0 + \overline{n_1}) \cdot (\overline{n_3} + n_4)$
for top edge points;
$B_6 = n_2 \cdot (n_0 + n_1 + n_3 + n_4) \cdot (n_4 + \overline{n_5}) \cdot (\overline{n_7} + n_0)$
for bottom edge points.

where a dark pixel is "TRUE" and a light pixel is "FALSE". For the thinning algorithm, we use two matrices (the first is the original image, the second is a mirror of the image). The algorithm is:

1. scan the original image (along the rows or the columns) and calculate the expressions B_0, B_2, B_4, B_6 if the pixel is dark;
2. if one or two of the expressions are "FALSE" then the pixel in the second matrix is set to "FALSE", else is set to "TRUE"
3. the second matrix becomes the original image;
4. if no new edge points were flagged during the scan, the algorithm stops.

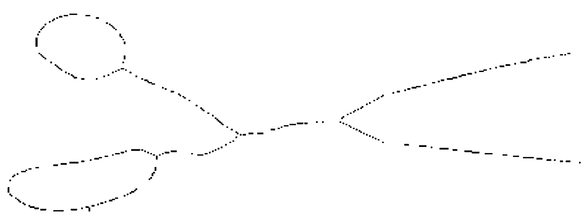

Fig. 8. Skeleton obtained using Naccache method

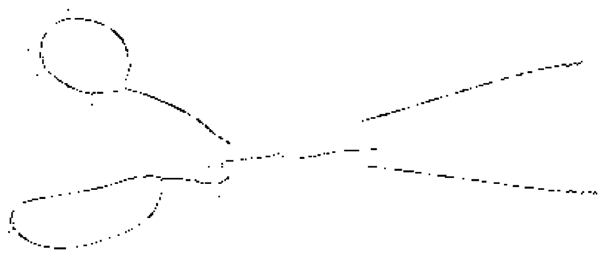

Fig. 9. Skeleton obtained using original method

We have also developed and implemented an original skeletonizing method for binary images. It consists of successive scanning of the original image on several directions and marking the centre point of the object segment as belonging to the skeleton (see Fig. 9).

3.2. Two layers neural network

Let us consider a classical feed-forward neural network using back-propagation for learning. We want to design this neural network to be able to implement the algorithm presented in 4.1. The natural solution is to choose a 2 layers neural network (figure 10). The input vector contains the eight neighbours of the pixel p and the output vector contains the desired value of p in order to skeletonize the object. Successive tests have shown that a number of eight hidden neurones is optimal.

The training vectors were obtained using the modified Nacache and Shinghal method.

In the training stage, we used a sigmoid activation function:

$$f(x) = \frac{1}{1 + e^{-x}} \tag{1}$$

In the processing stage, for minimising the processing time, the function in equation (1) was replaced by that in equation (2), but the recognition rate was maintained at 100 %.

$$f(x) = \begin{cases} 0.166 \cdot x + 0.5 & , if -3 \le x \le 3 \\ 1 & , if\, x > 3 \\ 0 & , if\, x < -3 \end{cases} \quad (2)$$

Table 1 presents the weights and biases obtained after training. The output value is given by:

$$out = f\left(\sum_{j=0}^{7} W_{1j} \cdot out_j + B\right)$$

$$out_j = f\left(\sum_{i=0}^{7} W_{ji} \cdot n_i + B_j\right) \quad (3)$$

where the f function is given in equation (1) or (2). The output is a float number, so it is necessary to apply a step function:

$$f(out) = \begin{cases} 1, & if\, out \ge 0.5 \\ 0, & if\, out < 0.5 \end{cases} \quad (4)$$

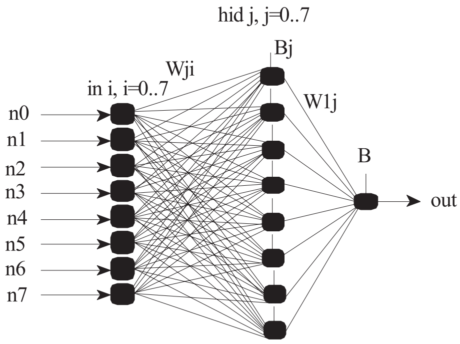

Fig. 10. Two layers neural network

Weights and biases of two layers full connected net — Table 1

	W0	W1	W2	W3	W4	W5	W6	W7	B
Hid0	7.18	0.56	2.16	-3.48	13.69	-3.62	2.02	0.54	-6.25
Hid1	-2.32	-0.68	-6.45	-0.64	-2.26	4.54	10.04	4.49	4.88
Hid2	-1.92	5.1	-12.08	2.36	1.34	-0.35	-6.11	-0.71	1.34
Hid3	-8.38	0.21	5.35	1.45	6.78	2.46	-2.52	-0.92	1.45
Hid4	9.19	-3.36	0.93	0.58	3.45	0.2	2.05	-4.7	-0.65
Hid5	6.7	0.37	5.54	1.33	-2.06	-1.23	-2.78	1.81	-4.38
Hid6	3.31	2.47	0.55	-0.99	7.86	0.89	-4.73	-0.08	-4.75
Hid7	-1.11	0.72	6.8	-1.31	2.96	2.56	2.03	1.94	-3.09
Out	-19.88	18.22	14.24	11.98	-13.4	15.2	8.96	-11.04	-0.75

3.3. Single Layer Neural Network

Another method might be the training of several single layer nets (Fig. 11) with sets of training vectors.

For each input vector a descriptor is computed:

$$k = \sum_{i=0}^{7} n_j \cdot 2^i \quad (5)$$

The nets are trained using training vectors with consecutive descriptors. This property is used in the processing stage too, the descriptor pointing to the net that memorised the input vector.

In the processing stage, the descriptor k was computed for each input vector, in order to identify the net. The net's output is given by the following equation:

$$out = f\left(\sum_{i=0}^{7} n_i \cdot W_i + B\right) \quad (6)$$

where f(x) is a simple step function:

$$f(x) = \begin{cases} 1, & if\, x \ge 0 \\ 0, & if\, x < 0 \end{cases} \quad (7)$$

The algorithms were implemented in C++ under Linux.

4. Results

We are interested in obtaining faster algorithms. A clue indicating the speed is the number of operations. Analytically we have found that the modified Nacache and Shinghal method implies 40 logical plus 3 arithmetic operations/pixel, the two layers neural network implies more than 150 arithmetic operations and the single layer neural network implies 39 arithmetic operations. We have tested all three implementations on a 510 x 412 test image on a Pentium II MMX 350 MHz processor.

The computation times are presented in table 2.

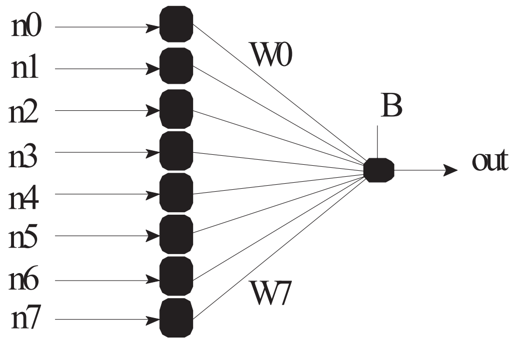

Fig. 11. Single layer neural network

Processing times — Table 2

Algorithm	Processing times
Hole detection and localisation	0.67 seconds
Skeletonizing using the original method	0.31 seconds
Skeletonizing using Nacache and Shinghal's method	0.73 seconds
Skeletonizing using two layers net and sigmoid activation function	5.11 seconds
Skeletonizing using two layers net and linear threshold activation function (equation (2))	3.54 seconds
Skeletonizing using single layer net and step activation function	0.89 seconds

5. Conclusion

As expected the two layers neural network is the slowest method due to the large number of operations.

Although the single layer neural network is optimal with respect to the number of operations, these are floating point operations and overall the computation time is longer than using the classical method. Integer approximation of weights and biases doesn't reduce processing time (both floating and integer numbers are kept on 4 bytes), but reduces recognition rate. These results show that the use of neural networks does not improve computation time over the classical methods.

Reviewed by: S. Legutko, J. Pilc

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Miran Brezocnik - Igor Drstvensek *

INTELIGENTNÉ CAD-CAP ROZHRANIE ZALOŽENÉ NA ROZPOZNÁVANÍ PRVKOV A GENETICKOM ALGORITME

INTELLIGENT CAD-CAP INTERFACE BASED ON FEATURE RECOGNITION AND GENETIC ALGORITHM

Integrácia výroby závisí hlavne od úrovne automatizácie existujúcich výrobných buniek, ktoré budú integrované do spoločného informačného systému. V prípade CIM ide o integráciu CAD a CAM. Táto integrácia tiež vyžaduje brať do úvahy aj CAP úlohy, pretože tvorí medzičlánok medzi spomenutými modulmi. Článok opisuje inteligentné rozhranie na integráciu CAD a CAP. Skladá sa z dvoch častí - rozpoznávač a vyhľadávač. Rozpoznávač preskúma CAD model a rozpozná prvky, z ktorých sa súčiastka skladá. Vyhľadávač využije výsledky rozpoznávača ako vstupnej jednotky a hľadá primeranú technologickú operáciu z databázy. Vyhľadávač použije optimalizačné princípy genetického algoritmu na to, aby našiel optimálny technologický postup pre CAD dáta.

The integration of production depends mainly on an automation level of the existing production cells that will be integrated into a common information system. In terms of CIM it means integration of CAD and CAM tasks. The integration also demands taking the CAP tasks into an account, because of their intermediate position. The paper describes an intelligent interface for integration of CAD and CAP tasks. It consists of two parts, recogniser and seeker. The recogniser scans the CAD model and recognises its features. The seeker uses the results of the recogniser as an input and searches the appropriate work operation from the technological database. The seeker uses genetic algorithm (GA) optimisation principles for finding the optimal machining procedure of the CAD part.

1. Introduction

Connection and integration of individual units into a whole is the basic fact, which seems to be woven into the structure of the world. The principles of integration can easily be detected in the basic concepts of living beings and also in the society. Self-organisation and, hence, integration is a natural phenomenon, which raises isolated activities to a higher level with a new sense on the basis of which the functioning of the whole is more efficient and more intelligent. On the contrary, disintegration means separation, non-coordinated functioning, and isolation.

With a grain of simplification, the meaning of integration can be traced also in production systems. They must act outwards as much coordinated as possible if they want to survive, however, inwards there must be enough space for variety and competition of ideas. Production systems are like large living bodies condemned to deterioration if the destructive forces in them are too great; if, however, functioning is carefully oriented, re-considered and as much integrated as possible at all levels of the company, that is almost a guarantee for successful harvest, welfare, and prosperity.

Information integration plays a very important role in modern Computer-Integrated Manufacture [1,2,3,4,5]. It has a great influence on product cost, quality, time to market and competitive position of enterprises in general. Our interest covers particularly the integration of information flows accompanying various activities in the CAD, CAP, and CAM subsystems in the CIM system. The latter cannot be efficient if there is no efficient information integration among subsystems. Sometimes there is an integration, but it is so weak and imperfect that it is not possible to realise entirely the flow of information to subsystems they would need. In such a case information gaps are in the structure of CIM.

Several analyses of information exchange show that there are decisive gaps just between CAD and CAP. CAP is a subsystem where the CAD model of a future product is changed into the process plan. Since CAP is an mediator between CAD and CAM, not only the efficient connection CAD-CAP-CAM, but also integration of the entire system of CIM depends on a global and smooth transfer of geometrical and technological data from CAD to CAP. Different authors deal with a problem of automation in production process and automation in engineering process but the thorough integration requires more than that. We need to automate the whole process from engineering to production in order to achieve an integrated dynamic environment.

The aim of our research is a design of an integrated environment for feature recognition and an automated search for an appropriate work operation to manufacture a part. Such a tool

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would enable an automated search (recognition) of features on a given model, and a simultaneous proposition of optimal work operation to the CAP system/operator [6]. In order to reach the goal of the research we used advanced techniques such as geometric reasoning and genetic algorithms [2,7,8].

Section 2 gives a short overview of possibilities for CAD-CAP integration. In section 3 an idea of the intelligent interface is presented. Sections 4 and 5 are devoted to a detail description of components of the intelligent CAD-CAP interface. We conclude with the final discussion and synthesis of the results. The guidelines for future work are also given.

2. A short overview of CAD-CAP integration

In conventional methods a technologist is responsible to analyse drawing of the future product and prepare manually the production instruction, whereas modern methods anticipate automatic data transfer from the CAD to CAP system. Modern methods include at least two different approaches:

- feature recognition,
- feature-based modelling.

Definition of features is a difficult task. One definition out of many definitions of features says that they are parts of the body that have a special shape or production property [2]. Features can be classified in several ways. The following division is appropriate: geometrical properties of features and usable properties of features. With respect to geometrical properties the features are: external, internal, explicit, implicit, and various chamfers (Fig. 1). With respect to their use the features can be: design features which are meaningful to the design and manufacturing features which are meaningful to the manufacturing. Usually, the body consists of main shape and features (Fig. 2). Often attributes are connected to features. These can be: dimensions, dimension tolerances, surface accuracies, position tolerances, mutual interaction with other features and topological information about faces, edges and vertices.

Feature recognition is a process generally consisting of two steps:

- detection of features,
- classification of features.

Regarding how the initial solid is represented, the features can be recognised in two ways:

- by means of information about body primitives (Constructive Solid Geometry representation, CSG-rep),
- by means of information about faces, edges, and vertices (Boundary representation, B-rep).

A relatively small and simple data base is the main advantage of a CSG-rep model. In addition, a sequence of machining operations can be modelled by a CSG-rep. Its disadvantage is that an identical body can be represented by different binary trees. For feature recognition the B-rep model is more appropriate than the CSG-rep, since it is independent of sequence of operations during modelling. Its disadvantage is the extensive data base and loss of history of modelling of the component. From [1, 2, 9, 10, 11, 12, 13, 14] it is possible to see the following approaches for feature recognition: syntactic methods, state transition diagrams, decomposition methods, CSG-based methods, graph-based methods, methods of external access direction, logic methods, and feature recognition by means of neural nets.

In feature-based modelling the basic entities that describe the body are already known. Their recognition, which is usually complicated and time-consuming, is no more necessary. Although

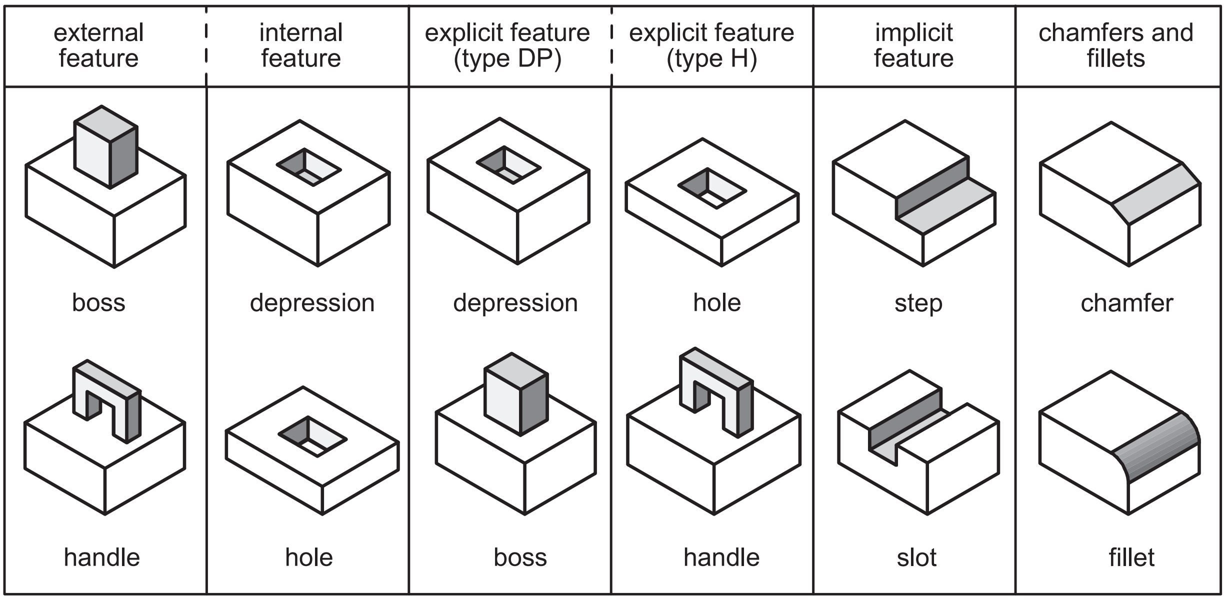

Fig. 1. Different types of features

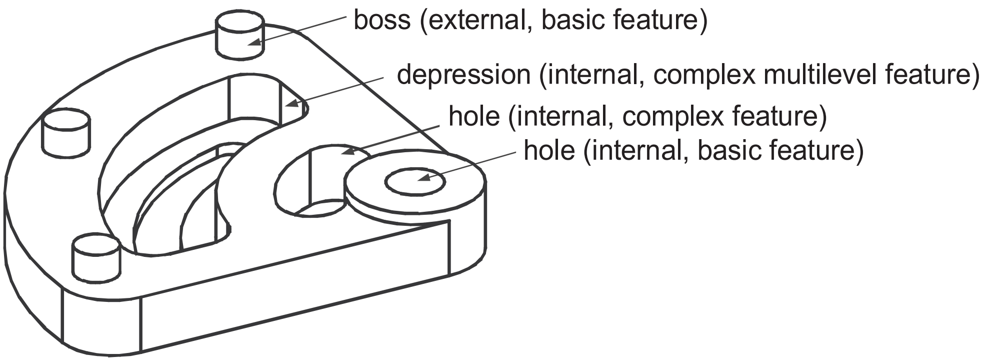

Fig. 2. Main shape of the body and features

feature-based modelling has recently become very popular, the method is not without disadvantages. The main disadvantage is that the designer is usually limited by the library of features, which narrows his concepts and freedom in modelling. In addition, almost unsolvable difficulties occur if two or more features intersect. In this case it is necessary to develop a hybrid system that includes also feature recognition. Basic information on some feature-based systems can be found in [2, 13, 15].

3. Design of the intelligent CAD-CAP interface

Although above mentioned methods for feature recognition and feature-based modelling give possibilities for more or less effective CAD-CAP integration they enable mainly geometrical data transfer from CAD to CAP. In order to achieve more intelligent system which would be able to give us a proposition, for example, which machining processes and tools are appropriate, more advanced CAD-CAP interface with technological database incorporated into decision process has to be conceived. Of course, we also need an algorithm which would be capable to select the best possible set of technological parameters among many sets of parameters available.

Our recognition-optimisation system consists of two main parts, and works in two stages. These two parts are:
1. The recogniser,
2. The seeker.

The process starts with the CAD model processing in order to analyse it's shape and all characteristic features like depressions, bosses, holes, etc. On the basis of recognised features the next part of the system takes over by evaluating the analysed shape and searching through the technological database in order to find an appropriate work operation (Fig. 3).

Main evaluation input data has been stored within the CAD model in a shape of features. In spite of the information wealth of CAD models we still need some technological data that are hidden in an external knowledge of a designer. To add these additional information to the model, we have two obvious possibilities:
- technological data could be added to the model in a form of some special signs or codes within the part file, respectively, or
- they can be added to the part file as an accompanying part definition file.

Output data of the first part, a so-called recogniser, represent the input for the next part, the seeker. It takes the evaluated geometric data from the recogniser and starts the search for the appropriate work operation through the technological database by comparing the original data from the model with the recommended data for disposable tools stored in the production system.

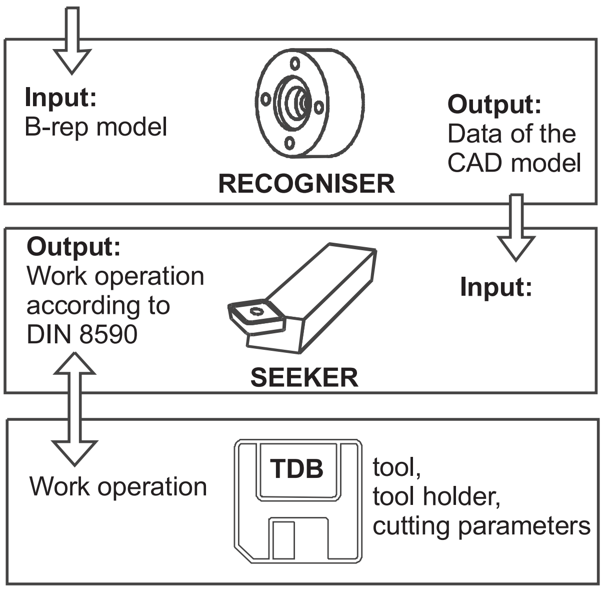

Fig. 3. The idea of the system.

4. The recogniser

In our system the initial 3D-models are represented by boundary representation (B-rep.). Since feature recognition requires symbol manipulation and reasoning, it is natural to implement it in programming languages that are suitable for such kind of processing. The builders of a majority of reasoning systems choose either LISP [e.g. 1,2] or Prolog [e.g. 1,16]. In addition, LISP is convenient for knowledge representation in expert systems [17, 18]. In our system LISP language is chosen for feature recognition. By specially developed algorithms a 3D-model of a future product is examined. Most topological, geometrical, and technological information about a 3D-model that are returned by these algorithms are LISP S-expressions.

The recogniser consists of two main parts. In the first part the features are detected, whereas in the second they are classified into internal and external ones. The detection of features is based on searching for inner loops on faces of the body, while the classification is based on analysing edge properties in the inner loops.

The recogniser is able to recognise many different types of features out of which special attention is given to the recognition and classification of explicit internal and explicit external features. Fig. 4 shows the test parts with some simple (basic) features which were recognised with the recogniser. More detail information about the special developed algorithms for recognition and classification of features can be found in [19].

For recognition of more complicated multilevel features a special algorithm is developed where 3D-model by the use of special functions is examined (Fig. 5). These functions have recursive definitions. For example, the problem of feature recognition for the Feature I can be described by means of recursive definition in LISP pseudo-code as follows:

```
(defun depression (arguments)
        (cond ((predicates) boundary_conditions)
                    (depression (new_arguments)))).
```

The recursion variables arguments and new_arguments give topological and geometrical information about faces, edges, and vertices of each sub-feature. predicates and boundary_conditions provide that multiplication of function depression has to stop when a face of sub-feature does not contain the next inner loop. In case of Feature I this is happened after the third copy of the function depression (i.e., at sub-feature number 3 which is located at the bottom of the hole hierarchy). If only one-step-depression is located on the part (i.e., Feature II and Feature III) the boundary_conditions terminate the further multiplication of function depression immediately after its first copy.

After the recognition and classification of features are carried out, their geometrical, topological, and technological data are sent off to the seeker. These information involve:

- type of the feature,
- complexity of the feature,
- geometrical data (diameter, depth, starting level, ending level, etc.),
- required accuracy and a state of the surface.

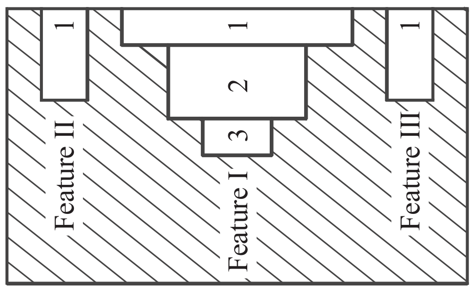

Fig. 5. Two simple features and one multilevel feature

5. The seeker

The seeker takes over the data and carries out a technological evaluation. The evaluation is realised in few steps that narrow the tool search field by defining boundary conditions based on the data gathered by the recogniser.

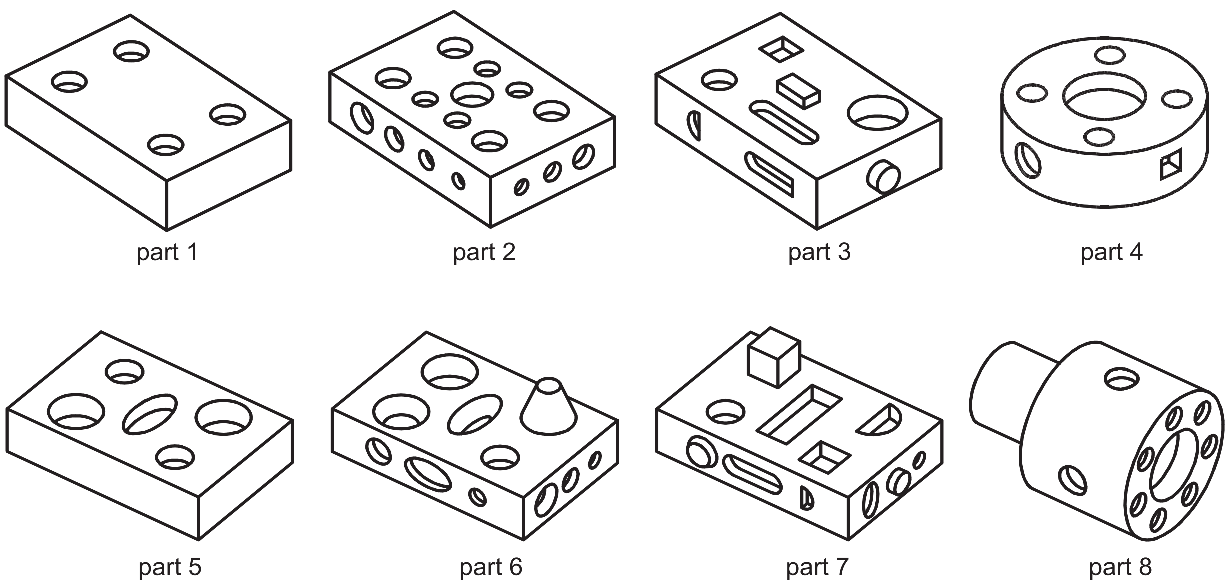

Fig. 4. Test parts for the feature recognition

The first step is a determination phase. On a base of transferred features' data a rough manufacturing procedure is determined (i.e., drilling, milling, etc.) and boundary conditions for the tool search are set (i.e., biggest allowable diameter in a case of milling), (Fig. 6). Further on the features are also checked for possible special finishing requirements. In such a case additional stock allowance condition is set.

A roughing phase is the second step of the evaluation. It checks the geometric data (diameter, depth, etc.) and sets the final geometric boundary conditions for the tool search - required cut length.

The third and the last step is a cutting phase. It prescribes the boundary conditions for the cutting parameters determination with a consideration for possible special finishing requirements. In this phase a wide cutting borders (i.e., allowable cutting depth, feedrate, and cutting speed) are set.

After the evaluation the seeker performs a genetic algorithm search for the appropriate combination of cutting parameters to reach the production demands. Sets of cutting parameters are stored in the technological database (TDB) together with the geometric data of the tool they belong to. To find the appropriate set the genetic algorithm uses known evaluation functions. These are simple functions (1), (2), and (3) that are describing dependence of costs, productivity and roughness from the cutting parameters.

$$t_1 = \frac{S_v}{v}\left(1 + \frac{T_m}{T}\right) \qquad (1)$$

$$k_1 = \frac{S_v}{v}\left(K\left(1 + \frac{T_m}{T}\right) + \frac{C_N}{T Z_m}\right) \qquad (2)$$

$$R_{max} = f\left(\sin\chi_n \cos\chi_n + \frac{r}{f}(1 - \cos\chi_n) - \right.$$

$$\left. - \sin^2\chi_n \sqrt{\frac{2r}{f \sin\chi_n} - 1}\right) \qquad (3)$$

Symbols in equations mean:
- t_1 - time needed to produce one piece,
- k_1 - costs to produce one piece,
- v - cutting speed,
- f - feedrate,
- R_{max} - maximal allowed roughness,
- χ_n - tool angle,
- r - radius of the tool tip rounding,
- S_v - length of the tool path,
- T_m - tool changing time,
- T - tool wear time,
- K - operator costs,
- C_N - tool price,
- Z_m - number of cutting edges.

The geometric criteria are simple relations among the geometric factors. For example, the depth of one cut depends of the tool height, the overall machining depth, the demanded surface quality, etc. By joining these criteria together an environment for the search for the tool and work operation is gained. The beauty of the GA approach is in the simplicity of describing the influencing factors' mutual dependence [20]. Mathematically it would represent a tough task which can only be solved by involving some simplification that would lead to a lose of important information. In GA all the dependencies can be written as a set of criteria, and evaluated simultaneously. To perform a search, the GA needs a field to search in. It is hidden in the technological database where the production resource' data are stored.

The search begins with a selection of data sets that fulfil the minimum required condition of geometrical acceptance. In further search only those resources that correspond to the features of the CAD model are taken into account. The search itself is an optimisation process by which the cutting parameters of different tools or operations are evaluated, respectively. Boundaries for the optimisation environment are set on the beginning in the three evaluation phases, when the geometric properties of the feature are technologically evaluated. Further work is a pure GA optimisation

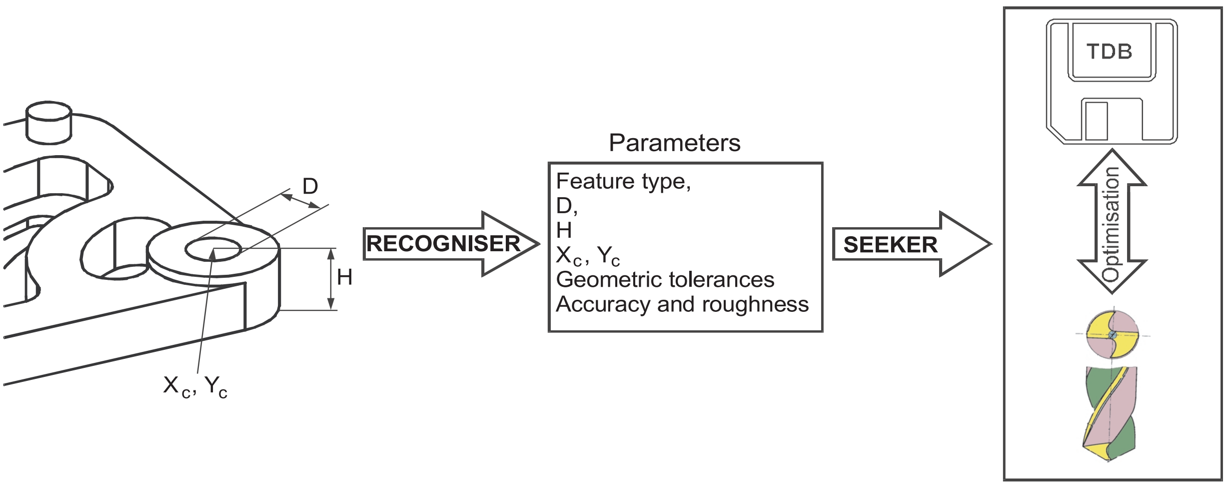

Fig. 6. Tool search procedure

performed over a field of records in the technological database as described in [21] and [22].

6. Conclusion

In market-oriented innovative production systems it is necessary to ensure as great information integration and fast adaptation to market conditions as possible. Any deficient information flow between different activities in the company, in particular between CAD and CAP, in most cases brings a lot of negative influences, which accumulate and cause that the final product is expensive and frequently of bad quality.

The difficulties have been softened by conceiving the intelligent interface between CAD and CAP. It ensures automatic information transfer about a product from CAD to CAP. The interface is based on feature recognition carried out on the solid model of a future product and genetic algorithm optimisation method. The interface intelligently examines a 3D-model of a part and determines the designer's purpose. Results from the interface are rather a preposition to the CAP engineer than an unconditional determination of a further process. As such, our interface is suitable for use in a fully automated environment as well as in conventional production circumstances. The only demand for its functionality is a reasonably high CAD level with incorporated technological database. The genetic algorithm approach used as a search method combined with the technological database becomes a very powerful and robust automation tool. It is capable of simultaneous evaluation of many different influencing factors in real time, what ensures that the results always show the state-of-the art of the production system in which it works. The test results show a great potential of our method, therefore we'll continue our work in this field to improve the interface so it can recognise more features with greater complexity and to broaden its use to other production techniques.

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METODOLÓGIA PRE NÁVRH SEGMENTÁCIE VÝROBY

A METHODOLOGY FOR CELLULAR MANUFACTURING DESIGN

Výhody, ktoré sa očakávajú od segmentácie výroby závisia prevažne od toho, ako efektívne boli realizované tri fázy jej návrhu. Ide o zoskupenie súčiastok a strojov, návrh jednotlivých výrobných buniek a spôsobu ich rozmiestnenia v dielni. Problematika bunkovej výroby vyvolala mnohé pokusy a aplikácie, ktoré vyústili do návrhu viacerých metód. Tento článok predstavuje novú technológiu pre návrh bunkovej výroby. Navrhnutá metodológia sa skladá z analýzy výroby, segmentácie výroby, špecifikácie jednotlivých buniek, kapacitného výpočtu, návrhu rozmiestnenia buniek, vytvorenia simulačného modelu a z procesu simulácie. V poslednej dobe je práve simulácia považobaná za užitočnú optimalizačnú techniku v tejto oblasti.

The realisation of benefits expected from cellular manufacturing largery depends on how effectively the three phases of design have been performed, namely part/machine grouping, developing the cell layout and cell system layout on the shop floor. This key question of cellular manufacturing has attracted numerous attempts in applying various design methods. This paper presents a new methodology for cellular manufacturing design. The proposal methodology is composed from products analysis, production segmentation, cells definition, cells capacity planning, cells layout design, building of simulation model and simulation process. Recently, simulation has been found to be a useful optimalization technique just in this area.

1. Introduction

The typical company makes thousands of different parts, in many different batch sizes, using a variety of different manufacturing operations, processes and technologies. It is beyond the capability of the human mind to comprehend and manipulate such vast amounts of detailed data. People still need to make decisions regarding how to run a manufacturing company and succeed in today's competitive environment on home and foreign markets. The pressures on management continue to escalate as global competition drives the need for producing a greater variety of high quality products, in smaller lot sizes and lower costs. These ongoing demands continuously increase the level of complexity present in a manufacturing environment. What is needed is both a strategy and a tool that can be used to achieve such a purpose.

The layout design of a manufacturing facility is one of the most important factors affecting product quality and cost. The manner in which the equipment is configurated on the shop floor affects material flow, manufacturing leadtimes, work in-process inventories, in-process quality and the manner in which work is scheduled, processed and controlled through production. Cellular manufacturing (manufacturing workcells) is a manufacturing system configuration by which these advantages may be achieved.

This paper presents a new methodology for cellular manufacturing design with utilization of simulation that recently has been found to be an useful optimalization technique in this area. Its structure and steps are shown in Figure 1.

2. Products analysis and data preparing

Products are built essentially from an assortment of produced and purchased parts, which for an assembly of complete parts are necessary. Information about products should be known before starting to design the manufacturing cell.

Products analysis is the first step for cellular manufacturing design. For example, to define a products spectrum, advantageous for cellular manufacturing, is possible by the ABC or P-Q analysis. The second step is the preparation of all needful data.

Input data for the proposal methodology are introduced in Figure 2, where the suggested structure of the data base is shown. It is advantageous for the input data to be saved into this data base.

Another way is the integration with a CAPP system that has similar parts data. In designing a manufacturing cell design is useful to use the already created database, because part families are already defined in the CAPP system according to the criteria specified by a company.

3. Cells formation

The first step of the production segmentation is the production flow analysis (PFA), that was presented by Burbridge [2]. Process plans are input data for PFA. Unsorted machine-part matrix is the result of PFA. Cluster analysis is the next step. The sorted (final) machine-part matrix is received by the cluster analysis.

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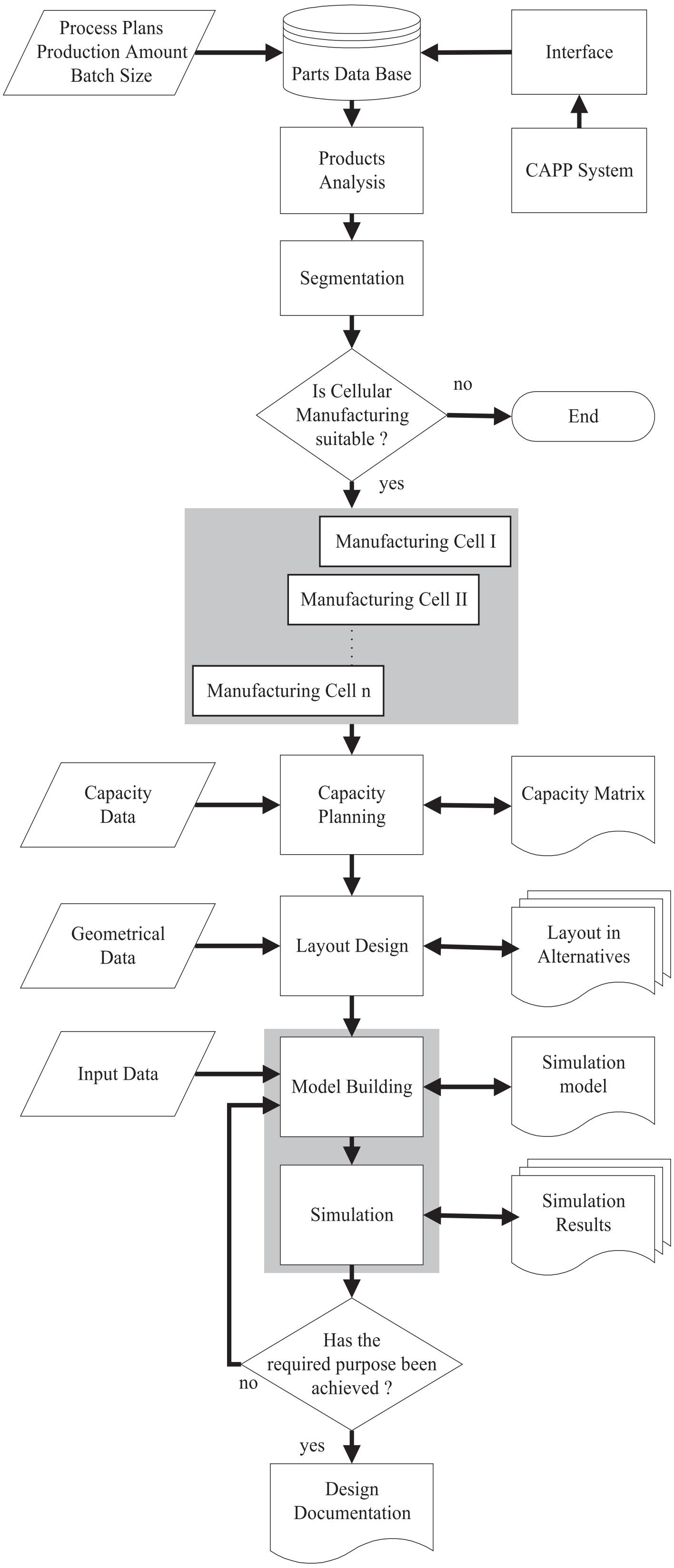

Figure 1: Sequence of manufacturing cells design

3.1. Initial machine-part matrix

The initial machine-part matrix $M[p_{ij}]$ (Figure 3) is created from the parts data base, where
i = number of parts
j = number of machines

$$pij = \begin{cases} 1 \text{ if part i visit machine } j \\ 0 \text{ otherwise} \end{cases}$$

	machine 1	machine 2	⋯
part 1	p_{11}	p_{12}	
part 2	p_{21}	p_{22}	
⋮			

Figure 3: Initial machine-part matrix

The initial matrix consists of all parts and machines which are required to be processed.

3.2. Cluster analysis

Arbitrary clustering algorithms can be used to solve the machine part grouping problem. Boe and Cheng [1] offer a detailed review of the existing algorithms. There are no clear guidelines for selecting a particular cell formation procedure given firm's goals, characteristics, environment and its internal knowledge, skills and experiences.

Cell formation is neither an easy nor uniform process. The human factor is a key function for this process, because some machines and parts can not be partitioned into perfectly separate clusters. Consider the matrix in Figure 4. As part 5 requires processing on machines 1, 3 and 4, the matrix can not be perfectly partitioned. Part 5 is called an exceptional part. An intercellular move (or an exceptional element) is required for an exceptional part.

A bottleneck machine is defined in a similar fashion as is an exceptional part. The matrix in Figure 5 can not be perfectly decomposed because machine 5 processes parts belong to more than one cell.

Exceptional parts and bottleneck machines are the sources of intercellular moves. In order to obtain the maximum benefits of a cellular manufacturing system, intercellular moves must be reduced to the minimum. Therefore, a clustering algorithm should not only transform an incidence matrix to a matrix with a desirable structure but should also minimize the number of intercellular moves.

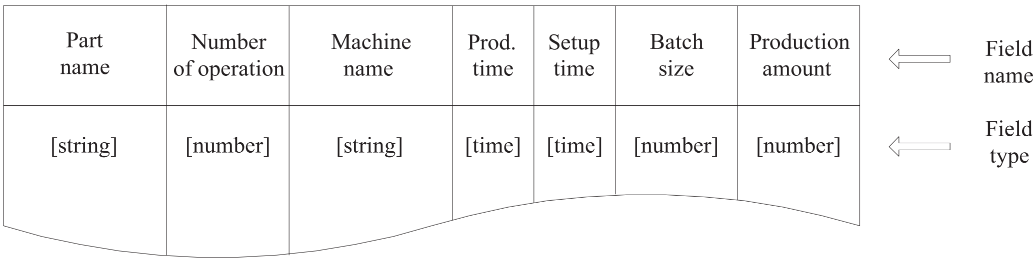

Figure 2: Data base structure of the process plans

	part 1	part 2	part 3	part 4	part 5
machine 1	1	1			1
machine 2	1	1			
machine 3			1	1	1
machine 4			1	1	1

Figure 4: Non-disjoint clusters due to an exceptional part

	part 1	part 2	part 3	part 4	part 5	part 6
machine 1	1	1				
machine 2	1	1				
machine 3			1		1	1
machine 4			1	1	1	1
machine 5	1	1	1		1	1

Figure 5: Non-disjoint clusters due to a bottleneck machine

4. Manufacturing cells definition

Several parts of families and machine groups can be identified by cluster analysis results, i.e. on the basis of the final machine-part matrix (Fig. 6). The criterion for parts formation is the similarity of routings in this case. On the basis of routhings similarity there is high probability that parts are similar in design or geometrical form (Kuric [5]).

Multiple solutions (alternatives) have to be generated for comparision at this step. Exceptional parts and bottleneck machines should also be addressed at this step. Further, if intercellular movement is large, a decision may be made whether to combine some or all bottleneck machines in one or more cells, each arranged as a job shop.

5. Capacity planning

The basic assumption in all present group formation methods is that a machine type within the group to which a component is assigned has sufficient capacity to process the component completely. If, in order to process all components assigned to a group, multiple units of machines are needed, then, they are required and allotted to the group. If a machine type is duplicated in two or more groups, each group gets sufficient capacity. Often a decision must be made whether it is more economical to duplicate a machine, and its associated processes, in two or more manufacturing cells, or to allow transport of the part between cells. Such transportation may utilize the excess capacity in one cell and thus avoid the need for an unit in another cell.

The capacity matrix (Figure 7) can be used as a basis for capacity planning that contains all needful data. The capacity matrix is the final machine-part matrix is completed by some data.

Capacity matrix elements are not the ones and zeros, as described above, but they represent a time defined as follows:

$$Tij = TPij + \frac{TSij}{BSi}$$

where: *i* - part number
j - machine number
TPij - processing time for a part i on the particular machine j
TSij - setup time for a part i on the particular machine j
BSi - batch size for a part i

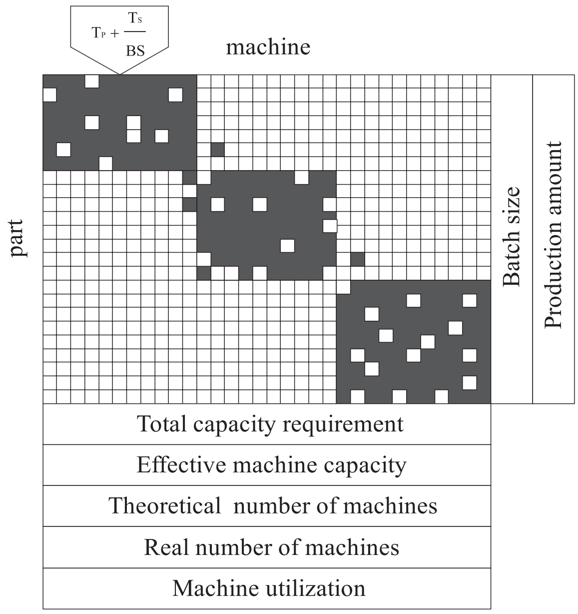

Figure 7: Capacity matrix

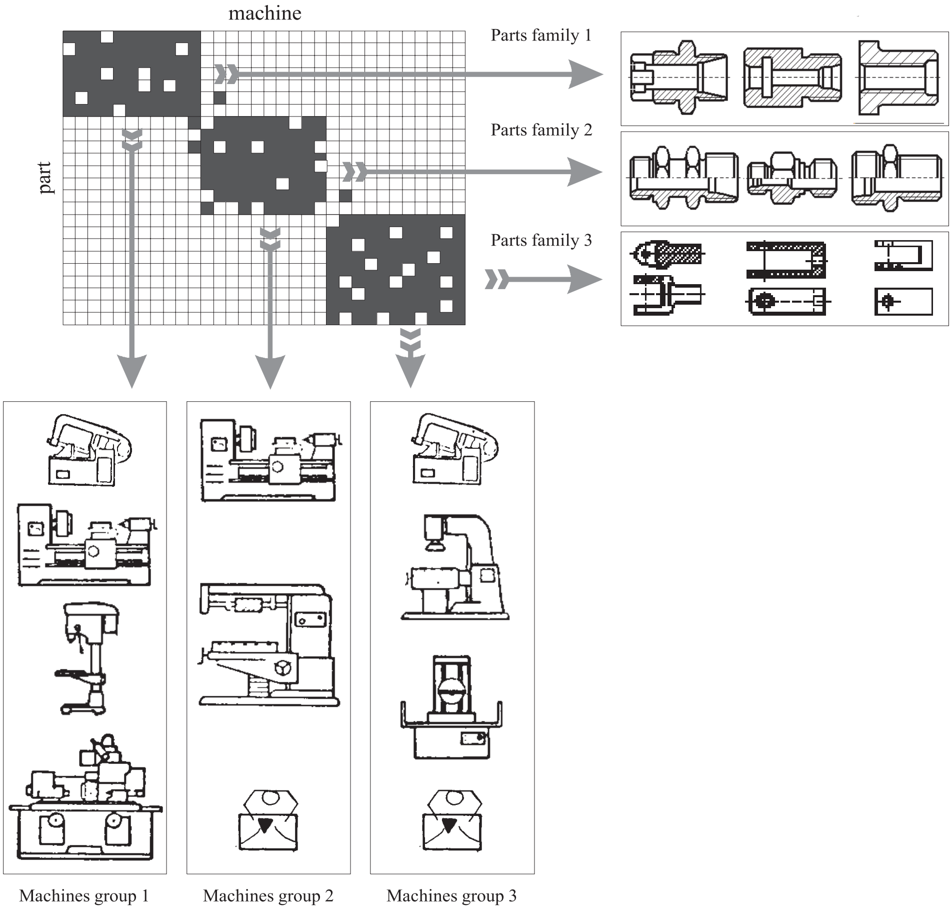

Figure 6: Schematic sequence of cell formation procedure

On the right side of the capacity matrix (columns - Batch size and Production amount) is data about batch sizes (BS) and production amount (PA) for particular parts.

On the bottom are data needed for capacity planning.

- Total machine requirement (TMR) represents a sum of times (in hours) for particular machine. TMR is defined as follows:

$$TMRj = \sum_{i=1}^{n} Tij * PA_i$$

- Into row Effective machine capacity (EMC) defines EMC for particular machine (in hours)
- Theoretical number of machines (TNM) is defined as follows:

$$TNMj = \frac{TRMj}{EMCj}$$

- Real machine capacity (RMC) represents TMC round up to interger.
- Machine utilization (MU) is defined as:

$$MUj = \frac{TNMj}{RNMj}$$

6. Cells layout design

Developing a GT cells layout is a lengthly and laborious task due to the multitude of design aspects and interrelated factors that have to be considered, and the decisions that have to be made. Therefore, it is important to organize this task through a framework for analysis. The following order steps are suggested as necessary in developing a GT cells layout.

1. *preparing layout data*
   The following data are needed for cell layout design:
   - process plans, cluster analysis results
   - areas of particular (manufacturing and handling facilities, working places, transport paths, etc.)
   - transport matrix (material flow matrix)
   - restrictions (shop dimensions, prohibited area, maximal loading of floor, etc.)

2. *developing cell layout*
   If the cell layout is not developed jointly with family and cell formation or the facility will not be organized as small job shops, the type of the layout for each cell has to be determined and a layout model developed, the layout is constructed. If

a family and cell formation was performed jointly with the cell layout, the latter may be revised at this step to account for factors which were not considered before.

3. *developing cell system layout*
   Data on exact or approximate cell shape and areas, location of input/output points, as well as intercellular flow should be available at this stage and used to the developed cell system layout. Space restrictions may preclude using specific cell shapes and the latter may have to be treated as decision variables in the layout model. The type of cell layout should be not affected in this case (Hassan [3]). Further, if space restrictions prevent accommodating all the machines of a cell in the allocated space, some machines may have to be relocated to other cells.

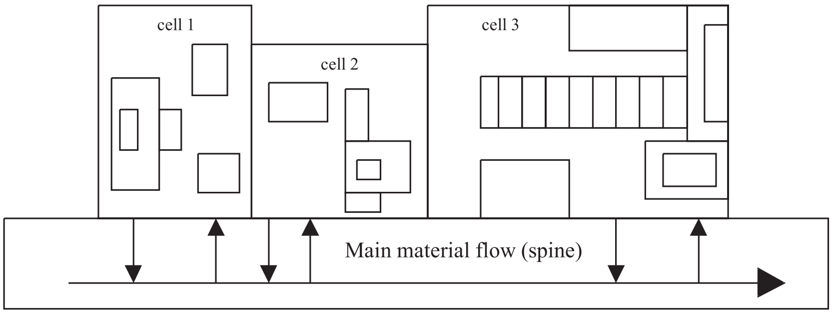

Figure 8: Topkins system layout

4. Examining the location of bottleneck machines
   Bottleneck machines may have not been properly assigned to cells at the family and cell formation stage and thus their location should be examined after constructing the cell layout and revised when a relocation improves the movement cost.

7. Modeling

Modeling is the transformation (realization) of an existing or abstract system into an experimental model. The modern object-oriented simulation systems offer to user different pre-defined objects (object library) for model building. These objects can be divided into several categories (Figure 9).

From this reason, before a model building it must be clear which objects the particular simulation system offers and how they are characterized (properties).

The following elements are usually modeled in a simulation model:
- products,
- machines,
- stores (warehouses),
- operators,
- transport facilities.

7.1. Input data

Generally, data which are required for the cell modeling may be divided into the following categories:

1. *Data which describe a structure of manufacturing cell:*
   - type number of produced parts,
   - process plans,
   - type and number of machines,
   - type and number of transport and handling facilities.
2. *Data which describe the manufacturing cell:*
   - type and number of machines in cell,

BASIC OBJECTS							
Material flow objects				Information flow objects			
movable		immovable		movable		immovable	
active	passive	active	passive	active	passive	active	passive
- Transporter	- Cointainer - Entity	- SingleProc - Buffer - Sorter - Line - Source - Drain - Local Control	- Track - Warehouse		- Attributes	- Trigger - Generator - Time sequence	- Tables - SQL interface - File interface

Figure 9: Basis objects of simulation systems

- type and number of parts produced,
- number of operators,
- model of worktime,
- control strategy.

3. *Data which describe the process in cell:*
   Manufacturing process is characterized by:
   - batch size and manufacturing plan,
   - processing time (including the setup time) of part types (batches) on particular machines,
   - machine failures, time period, (machines statistics),
   - machine capacity,
   - manufacture priority,
   - process of a batch between particular machines.
4. *Data, which define manufacturing costs in the cell:*
   - machine utilization,
   - inventory, resources.

8. Simulation

When the simulation model is created, it is possible to begin the simulation process.

Simulation data have to be processed and verified. Correct output data are achieved only by correct input data. The total consistency a real system and the simulation model is not in principle possible, the idealized model can not represent all restrictions. For this reason simulation goals and a level of strictness of a simulation model must be defined before modeling. The model validation follows after a first simulation run and results analysis. In case of need the particular system parameters are changed or the simulation model is edited and the next simulation run follows. Simulation results (statistics tables, charts, etc.) must be compared and interpreted into a legible and clear form by an simulation expert. These statistical results have to be processed into a final documentation.

The following questions may be answered by simulation:

I. Performance Measures
   - Machine utilization
   - Production rate
   - Utilization of an operator or robot
   - Utilization of a bottleneck station

II. Decision Variables
   - The number and types of machines in the work cells
   - The batch size of a particular part type
   - Sequencing of part types within the cell
   - Material handling priorities within the cell

III. Questions to be Answered
   - How many of each type of machines are required to balance production?
   - What is the best cell design for maximizing throughput?
   - What is the utilization of the bottleneck machine given by a particular sequence of orders?
   - What is the optimum sequencing of part types through the cell that mini-mizes setup?

The most optimal variant, as chosen by the simulation, resulted in the last step. In case of need, the particular changes may be made (to change a manufacturing facilities location, number, etc.) and finaly the complete documentation is designed.

9. Conclusion

This paper presents an integrated approach to the particular phases of the design of cellular manufacturing. This approach can be used for the transformation of an existing structure into cellular structure, thus for a new project on “green meadow“.

It has created a practical solution of the proposal approach. This solution is implemented into the simulation system SiMPLE++ (SiMulation in Production, Logistics and Engineering), as an application template for cellular manufacturing design.

Reviewed by: J. Matuszek, J. Košturiak

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KÓDOVANIE A KLASIFIKÁCIA AKO ASPEKT PRUŽNOSTI SYSTÉMU PRE TECHNOLÓGIU PLOŠNÉHO TVÁRNENIA

A CODING AND CLASSIFICATION AS AN ASPECT OF SYSTEM FLEXIBILITY IN SHEET METAL MANUFACTURING

Priemysel vo zvýšenej miere čelí potrebe rýchlo a účinne odpovedať na stále sa meniace požiadavky trhu. Táto potreba je čiastočne spôsobená uvedením vysokého stupňa pružnosti do všetkých priemyselných fáz, hlavne do spracovania. Myšlienka skupinovej technológie(GT) sa vo veľkej miere aplikovala do oblasti rezania kovov. V mnohých prípadoch sa dosiahli, čo sa týka produktivity, značné výsledky. Avšak doteraz je len málo správ o práci s použitím GT pri technológii plošného tvárnenia. Na vzostupe sú plošné kovové časti vyrobené v procese plošného tvárnenia s/bez plastickej deformácie (stláčanie, perforovanie, ohýbanie atď.) Tento sa stáva jedným z hlavných výrobných procesov. Jeden z možných dôvodov obmedzenej aplikácie GT pri technológii plošného tvárnenia by mohol byť chýbajúci vhodný systém kódovania a klasifikácie. Z uvedených výsledkov vyplýva, že navrhovaný koncept GT by zvýšil flexibilitu systému výroby.

Industry increasingly faces the need to respond rapidly and effectively to ever changing market demand. This need is partially met by introducing a high degree of flexibility into all industry phases, especially manufacturing. Group technology idea has been widely applied to the metal cutting area. In many instances, significant productivity gains have been achieved. However, very little work has been reported in applying GT in the sheet metal manufacturing. Sheet metal parts produced in sheet metal process with/without plastic deformation (pressing, punching, bending, etc) are on the increase. These processes are becoming one of the major manufacturing processes. One possible reason for the limited GT application in sheet metal manufacturing could be the lack of a suitable coding and classification system. Results indicated here say that the proposed GT concept would increase production system flexibility.

1. Introduction

In today's competitive environment market computer integrated manufacturing and computer integrated systems must be flexible. In these systems we use computer technology to integrate manufacturing activities such as design, production and process planning and control, programming, production automation, etc. The flexibility of manufacturing system is one measure of its ability to adapt to market demand, technology changing and production process conditions. Zelenovic has described flexibility as the probability that a given production system structure will adapt itself to changing environmental conditions within a specified time and within the limits of given design parameters. Flexibility has value only when there is uncertainty in these changing conditions [8].

In GT-concept, workpieces with similar characteristics are grouped into families in order to facilitate design and manufacturing processes, quality control and assembly. For design applications, a part family would involve a group of workpieces with similar shape or with some other similar design attributes. If such part families are available, the effort in designing a new part can be greatly reduced if the part is similar to the existing one. Also, the same principle is valid in activities as manufacturing process, assembly, quality control, etc.

There is no detailed explanation here about other advantages for using group technology concept. Also, in this article will be elaborated no other developed classification system based on GT concept which are well known in scientific circles.

The system classifies the sheet metal part spectrum into groups with defined similarities and/or features with the aid of a computer system in order that information and knowledge regarding the search for similarity features can be retrieved if required. This is the only chance to avoid that one known construction is permanently newly invented with an exploding multitude of variations. Falling back on the existing know-how leads to a standardization of the sheet metal part spectrum and thus to a reduction of the part variety. The period of the product development is shortened by the use of available data in the technically planning areas and the costs for the data administration and maintenance are reduced. And, not at the end, the system flexibility was significantly increased [1], [2].

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2. SMA-COD-SHEET metal alphanumerical coding system

The system developed in this chapter, SMA-COD system is basically alphanumerical system but the code structure is based on the hybrid code. In the first design stage (genuine design) it is an alphanumerical code; in the second design stage (detailed design) it becomes a hybrid code. Its code structure is shown in Fig. 1. It uses integer values to define various attributes and is composed of 11 digits. Digits 1, 2 and 3 represent the part shape.

Part shape is considered to be the main attribute of a coding system. First digit defines the basic shape (primary shape) and is used in genuine design and primary productibility estimation. Second and third digits are dependent on the first digit. These two digits posses 99 combination (01. 02. 99) and define all features in every basic class. These digits are only used in detailed design level and finally productibility estimation [6], [10].

Digit	1 ÷ 3	4	5	6	7	8	9	10	11
Attributes	Shape	Thickness of sheet	Length	Relation value	Process	Tools	Materials	Tolerances	Heat treatment

Figure 1. Structure of SMA-COD System

Since the primary factor in the sheet metal manufacturing is part geometry, part classification based on shape is a key attribute in SMA-COD system. Tool cost, one of the major costs in sheet metalworking, is mainly dependent on part geometry. In addition, most defects are caused by inappropriate die design. In SMA-COD system one attempt is mode to group all possible geometry shapes that can be produced by sheet metal working.

The basic shapes defined by first digit are classified in ten categories as follows:

Code	Attribute: **Basic Shape (description)**
0	Flat surfaces
1	Simple bending
2	Complex bending (multiple bends)
3	One and more punched simplest holed
4	Shallow formed and embossed regions
5	One and more punched complex holed
6	Lanced and formed louver
7	Simple bending and punched simplest holed
8	Simple bending, shallow formed and embossed regions
9	Simple bending, lanced and formed louver

All of these classes have possibilities to form new subclasses (minimum 0, maximum 99) defined by second and third digit. These two classes definitely defined geometry shape of workpieces and were built by experts for sheet metal designer and manufacturer for concrete production program and kind of workshops, or kind of using computer aided design system.

The fourth digit shows the range of gauge thickness available for the four alloy types, which represent almost all the materials used in sheet metalworking (defined on the ninth position). This digit is the most important factor for manufacturibility of workpiece. The thickness of sheet are classified as follows:

Attribute: **Thickness of sheet metal (4 th Digit)**

Code	Value
0	0.13 mm $<$
1	$0.13 \le \delta < 0.28$ mm
2	$0.28 \le \delta < 0.76$ mm
3	$0.76 \le \delta < 1.07$ mm
4	$1.07 \le \delta < 1.52$ mm
5	$1.52 \le \delta < 3.05$ mm
6	$3.05 \le \delta < 5.08$ mm
7	$5.08 \le \delta < 10$ mm
8	$\delta \ge 10$ mm

The fifth and sixth digits are supplementary codes for shape. The size of part length and part width expressed as relational value (relation between length and width), are important factors for manufacturing costs. A large size increases production cost exponentially, especially the costs of dies and manufacturing equipment. The sizes are classified as shown in Fig.2.

The seventh digit defined the main manufacturing process need to obtain for requirement geometry of workpieces. There are two basic sheet metal processes. One is the passage operation that involves cutting or tearing the sheet metal by methods such as punching, notching or blanking. The other is the nonpassage operation that involves plastic deformation of the metal by methods such as bending, hemming or curling. Based on this consideration the processes are classified as follows [1]:

Attribute: **Processes of sheet metalworking (7 th Digit)**

Code	Definition (description)
0	Bending
1	Hemming
2	Curling
3	Punching
4	Notching
5	Blanking
6	Miscellaneous
7	Press brake operations
8	Bending and Punching

With these seven attributes conditions for definition of all processes in sheet metalworking are obtained. This attribute is a main difference of the coding system in machining removal processes.

The eighth digit defines the kind of tools. This factor is one of the most important values for cost and flexibility of process and

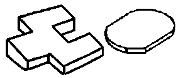
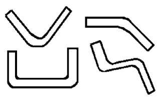
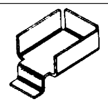
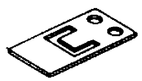
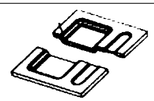
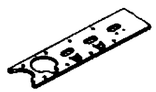
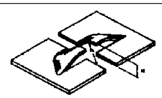
C/F	Basic Shape		Thickness of sheet (mm)	Basic dimension between basic A-lenght (mm)	The relation Process dimensions A/B	Tools	Materials	Tolerances (mm)	Heat treatment	
	Form, shapes, features									
0	1	1.1	4	5	6	7	8	9	10	11
0	Flat surfaces		0.13 mm ≤	A < 20	A/B = 1 ... < 2	Bending	Cutt-off dies	Steel, low carbon, commercial quality	T < ± 0.10	Not required
1	Simple bending		$0.13 \leq \delta < 0.28$	20 ≤ A < 50	2 ≤ A/B < 4	Hemming	Part-off dies	Steel, low carbon, drawing quality	±0.10 ≤ T < 0.25	Normalizing
2	Complex bending (multiple bends)		$0.28 \leq \delta < 0.76$	50 ≤ A < 150	4 ≤ A/B < 8	Curling	Blanking dies	Stainless steel T 304	±0.25 ≤ T < 0.50	Annealing
3	One and more punched simpliest hole		$0.76 \leq \delta < 1.07$	150 ≤ A < 250	A/B ≥ 8	Punching	Drop-through dies	Aluminium 1100 soft	0.50 ≤ T < 0.75	Quenching
4	Shallow formed and embossed regions		$1.07 \leq \delta < 1.52$	250 ≤ A < 500		Notching	Piercing dies	Aluminium 1100 half hard	0.75 ≤ T < 1.00	Martempering
5	One and more punched complex holed		$1.52 \leq \delta < 3.05$	500 ≤ A < 1 000		Blanking	V, U, W, and Z double Wiper double V-die	Aluminium 3003 hard	1.00 ≤ T < 1.25	Tempering
6	Lanced and formed louver		$3.05 \leq \delta < 5.08$	1 000 ≤ A < 5 000		Miscellaneous	Progressive dies	Copper soft	1.25 ≤ T < 1.50	Austempering
7	1 + 3	1 + 3	$5.08 \leq \delta < 10$	5 000 ≤ A < 15 000		Press brake operations	Others	Copper 1/4 hard	1.50 ≤ T < 2.25	Case hardening
8	1 + 4	1 + 4	$\delta \geq 10$	A ≥ 15 000		0 + 3		Titanium Grade 2	2.25 ≤ T < 5.00	Others
9	1 + 6	1 + 6				Other		Titanium Grade 4	T ≥ 5.00 mm	

Figure 2. Alphanumerical coding scheme for sheet metal parts

estimation of productibility. The codes for tools are assigned as follows:

Attribute: **Tools for sheet metalworking (8 th Digit)**

Code	Type of tool
0	Cut-off dies
1	Part-off dies
2	Blanking dies
3	Drop-through dies
4	Piercing dies
5	V, U, W, Z, double dies
6	Progressive dies
7	Others

Formability depends on various materials as well as part geometry. The ninth digit represents material. These four alloy types represent almost all the materials used in sheet metalworking. In the stage of detail production and process design the exact material definition is feasible with supplement digit on a tenth position which is connected with the ninth digit and depends on them. In that case system SMA-COD has 12 digits. Material classification is in the order of manufacturability and use in industry.

Attribute: **Material (9 th Digit)**

Code:	Characteristic:
0	Steel, low carbon, commercial quality
1	Steel, low carbon, drawing quality
2	Stainless steel, T 304
3	Aluminium 1100, soft
4	Aluminium 1100, half hard
5	Aluminium 3003, hard
6	Copper, soft
7	Copper, 1/4 hard
8	Titanium, Grade 2
9	Titanium, Grade 4

The tenth digit represents the tolerance level. Clearly, close tolerances require more accurate manufacturing processes. To present a sheet metal part design that is ready for processing, assembly and inspection, the dimensional tolerance information is added to the feature definition. On the eleventh digit SMA-COD System provides a code for heat treatment. (See Fig. 2)

3. The design efective manufacturing structure on the base GT-Concept

After the design of the sheet metal products start three steps in building effective manufacturing structure as follows:

Step 1. The designing operational groups
- *Phase 1.* Classification of workpieces/products (award code number for every parts)
- *Phase 2.* Forming module elements (all products with the same code number)
- *Phase 3.* Defining operational manufacturing group (all elements with similar characteristics- part family group)

Step 2. Development of group technology process
- *Phase 1.* The design, forming or choosing complex part (all relevant technological data are incorporated in this part)
- *Phase 2.* Defining the group technology process (the same or similar technology process and other technological aspects)

Step 3. Forming autonomous working cells

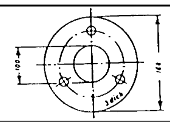
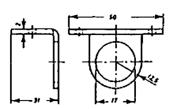
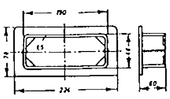
That is an independent part of the whole production system with ability that in a defining space, with technology equipment and skill workers, produces complete one or more family groups [7].

4. Factory application

In one factory test 32 sheet metal parts were casually chosen and used in the methodology developed and explained in main

The final characteristics for forming operational groups

Table 1.

No	Parts	Sign	Code number of complex part	Number of parts in one group	Figure of complex part
1.	Flat parts with simplest hole	OG 1	752184151	16	
2.	Simple bending parts with hole	OG 2	152181251	13	
3.	Complex bending sheet metal parts with hole	OG 3	243101261	3	

aspect in chapters 2 and 3. After using the three explained steps three operational manufacturing groups (OG) with the characteristics shown in Table 1 will be formed.

From Table 1 we may see that using the developed GT approach great simplifications in process planning (design, technology, tools, etc.) were obtained because, now, instead of developing manufacturing process for 32 products we may use only 3 operational groups with 3 complex parts.

In the results of flexibility improvement in the new concept of testing system (Re-Engineering of existing system) was achieved

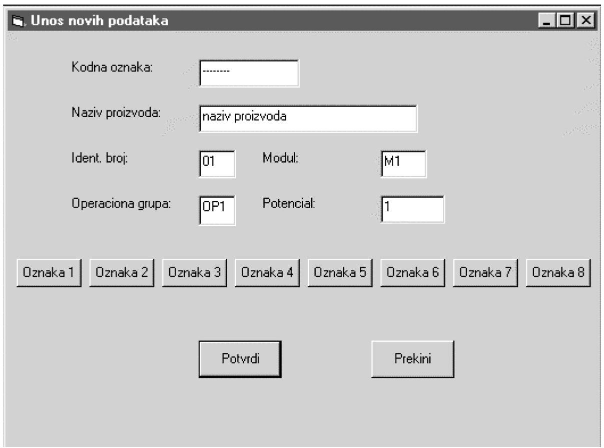


Figure 3. The screen layout for data entrance

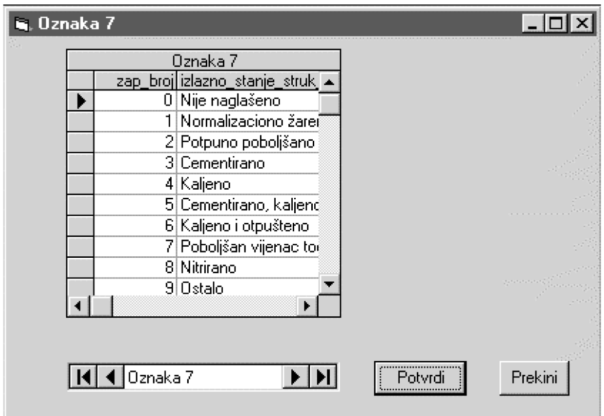


Figure 4. The screen layout of main material division

FS1=0,062 in comparison of FS=0,034 for the real existing production system. The measurement of flexibility was calculated on the base equation:

$$Fs = 1-(1-f_{ts}\,(f_{ks}\,(f_p)\,(1-f_{pr})$$

where: f_{ts} - technology component of system flexibility
f_{ks} -capacity component of system flexibility
f_p - flexibility of space structure,
f_{pr} - flexibility of technology process.

5. Computer application

For practical implementation the developed and presented models in factories and laboratories were built. Software, called CODI was written in computer language Visual Basic 5,0. For creating data base MS Access 97 were used. This program allows for technology coding of parts in designing phases, forming module and operational groups and calculations of potential level similarities with complex part in every technology groups. Also, there is no problem for adaptation of this program for different coding digits in different cases as some special characteristics in different factories or different technologies. For installation of this program configuration of WIN 95 or WIN NT were needed and for memory request personal computer type Pentium with 32 MB RAM suffices. The developed software can be installed as one sub-program of the well known software as I-DEAS, CATIA, Auto-CAD etc. It is also possible to connect this software with technology solutions of data bank, tools, machine tools, clamping devices, program instructions with CNC, etc. In the Fig. 3 and 4 are presented two computer screens of developed software for automatically (computer) coding and classification [11], [12].

6. Conclusion

A designer needs computer-assisted tools to design products that can be readily manufactured without costly and time-consuming redesign to improve manufacturability. Therefore, a CAD-CAPP-CAM system for sheet metal design, planning and manufacturing is developed under these considerations. To be successful, manufacturing strategies increasingly rely on flexibility, which is presently considered as an important attribute of any modern technology.

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ŠTRUKTURÁLNA SYNTÉZA AUTOMATIZÁCIE PRE KOMPAKTNÉ VÝROBNÉ SYSTÉMY

COMPACT MANUFACTURING SYSTEMS STRUCTURAL SYNTHESIS AUTOMATION

V článku sa uvažuje o problémoch navrhovania moderných výrobných systémov podľa konceptu „štíhlej výroby". Je uvedená definícia kompaktného výrobného systému (CMS), a z toho vyplývajúce pôvodné princípy získania priemyselnej kompaktnosti. Na základe týchto princípov ponúka autor techniku skonštruovania CMS sformulovanú do integrovaného algoritmu. Výsledok výrobného a operačného cyklu semiotického modelovania bol stanovený na základe autorovej verzie simultánneho predvedenia, ktoré sa realizuje v CAD stredisku vo Vitebskej štátnej technickej univerzite. Prediskutovaná je konfigurácia počítačovej siete strediska, ako i model dát o súčiastke. Na konci článku sú predstavené projektované a vytvorené CMS: kompaktná dielňa podniku, CMS reverzného inžinierstva, CMS rýchleho prototypovania založeného na metóde automatizovaného laserového rezania; CMS prípravy výroby (Rýchle prototypovanie & výroba nástrojov); Stredisko CAD

In the paper the problems of collective designing of modern industrial systems in the „Lean Production" concept are considered. The definition of compact manufacturing system (CMS) is given, and the original principles of industrial compactness maintenance have resulted. On the basis of these principles the author offers the technique of designing CMS, formalized up to an integrated algorithm. The result of industrial and operating cycle semiotic modeling was fixed in a basis of the author's version of simultaneous designing, which is realized at the CAD Centre at Vitebsk state technological university. Both the configuration of the Centre computer network and a model of the design data are discussed. At the end of the paper the examples projected and created CMS are resulted: the compact shop of the machine-building enterprise; the CMS of Reverse Engineering; the CMS of the Rapid Prototyping on the basis of automated laser cutting; the manufacture preparation CMS (Rapid Prototyping & Tooling); the CAD Centre.

1. Introduction

During each industrial system operation two opposite tendencies are detected. One of them consists of lowing production costs at the expense of production stabilization by the mass release of homogeneous goods. On the other hand, the quick response on the change in a market situation and achievement of competitive advantages requires the strategy of maximum increase of a production variety within the existing limitations resources of the manufacturing framework. It is the tendency of artificial rise variety of possibilities for a maximization of probability of a choice optimal (concerning the received profit) business solution. As a result, any industrial firm has transition and stationary phases of its operation, which are sharply distinguished from each other by a level of variety (or stability). Increase of a relative share of expenses of resources at a transition stage in a production cycle and actualization of a problem of rational use of all industrial potential of the firm are objective features of the present stage of global industrial development.

The task of effective rise of a production variety with the fixed technical structure of manufacturing was solved traditionally by the flexible manufacturing systems application. However, the known structural, morphological and space-temporary redundancy of flexible manufacturing systems causes not only a quick response to the change of the orders stream, but also (in some more greater degree) to high cost of creation and operation of manufacturing systems. The attempts at essential lowering expenses of the equipment without narrowing of a range of manufacturing system technological possibilities have resulted in the concept of compact manufacturing. The compact manufacturing system (CMS) is a human-machine complex combining a curtailing in space and time with a minimum level of a structural and resource redundancy, supported by highly intellectual tools of computer aided designing and management [1].

2. General principles of CMS creation

The main principles of CMS organization are the following [2]:

I - Conformity structure of CMS to its purpose;
II - Localization of functional invariant;
III - Recursive decomposition of CMS hierarchical structure;
IV - Functional sufficiency of the CMS components;
V - Optimal parity of expenses on a functional invariant and variable adapter;

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VI - Evolutionar local change of structure CMS at the expense of the equalizer adaptive reorganization;
VII - Reflection of stages of system development in its structural components.

The principle (I) in the concentrated form expresses that, first, the purpose (Z) is the main sister creation factor; secondly, the object in view can be achieved, to some extent, by creation and/or use of set of the CMS structures {St}; thirdly, the achievement of the objective is carried out by selected CMS structure by means of execution hierarchically organized functions (F):

$$Z \Rightarrow \{F\} \Rightarrow \{St\}$$

The principle (II) allows, on the basis of principle (I), separate common essential (invariant) units of the multipurpose CMS purposes objectives, functions and structures sets:

$$Inv\ \{Z\} \Rightarrow Inv\ \{F\} \Rightarrow Inv\ \{St\}$$

The principle (III) provides presence of invariant and adaptive modules at each level of hierarchy structure of system:

$$St\ (CMS) = \bigcup_{i=1}^{N} Inv_i \cup adp_N$$

The principle (IV) regulates a degree of parametric implementation of any hierarchy level functions above the necessary minimum value for CMS purpose achievement, since any exceeding of this value leads to the unjustified increase of expenses at CMS creation and maintenance:

$$L_f = [L_f] \Rightarrow L_E = L_{E\ opt}$$

The principle (V) determines the best variant of an allocation of resources at the implementation of the constant and variable parts of the CMS according to their functional importance:

$$\frac{L_3\ (Inv)}{L_3\ (adp)} = \frac{R\ F_{inv}}{R\ F_{adp}}$$

The principle (VI) of the evolutionary approach to the decision of tasks of development and modernization CMS allows to carry out permanent a structural adaptation of CMS to varied external conditions:

$$St\ (CMS)_0 \Rightarrow St\ (CMS)_1 \Rightarrow \ldots \Rightarrow St\ (CMS)_T$$

The principle (VII) together with principle (VI) determine the CMS structure in each given moment of its functioning time:

$$f : [St\ (CMS)_0 \Rightarrow \ldots \Rightarrow St\ (CMS)_T] \rightarrow St\ (CMS)_T$$

3. CMS design stages

The process of creation of CMS as a complex technical system consists of three main stages: CMS macro-design; CMS structural and parametric synthesis; CMS adaptive structural adjustment.

The macro-designing stage includes marketing and a CMS macro-technical shape creation. The task of marketing research is the definition of the nomenclature of production of CMS normal (profitable) operation during the designed period. The search of potentially profitable production is carried out by finding "areas of activity" in the space of economic activity and forecasting of dynamics of their change.

As a result of the primary analysis of the market on the basis of the different information sources some set of the goods whose production probability will be highly profitable during the designed period comes to light. Simultaneously, the capacity of target segments of the market is predicted.

The selected sorts of production are analyzed with the purpose of definition of a degree of their technological generality. The standard technological processes of their manufacture are compared (Fig. 1). The importance of technological generality is expedient for estimating with the help of the relative given expenses on operation:

$$K = C_{Mi}\ t_i \ / \sum (C_{Mi}\ t_i),$$

C_{Mi} - given minute expenses for operation, ti - absolute duration of operation.

The secondary analysis of the market will further be carried out with the purpose of creation of the best set connected (by technological invariants) sorts of production. The CMS profile

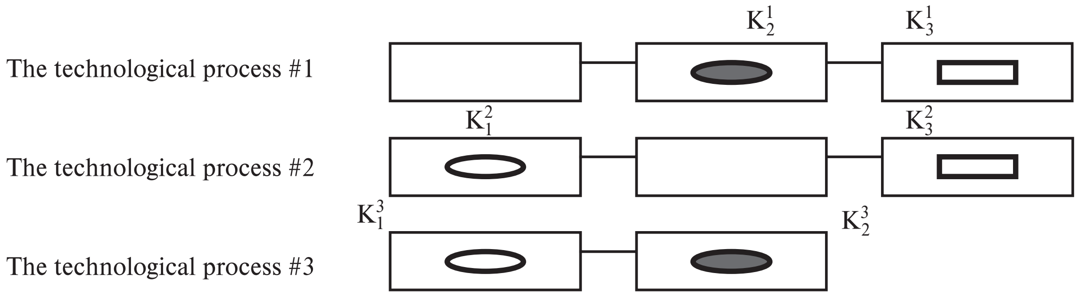

Fig. 1. The invariant components of technological processes

thus is formed. At the last stage of the macro designing the CMS general specification is formed.

The structural synthesis is carried out on the basis of the principles of CMS creation considered earlier and the use of results of the previous design stage. The structure of CMS equipment complex has brightly expressed its modular character. During the choice of CMS equipment the task of parametric synthesis is solved. The numerical values of parameters nominals are determined by functional-cost analysis of the whole system.

I. CMS MACROSTRUCTURAL SYNTHESIS

I.1. CMS structure formation

1. Search of areas of activity in the whole space of economic activity.
2. Analysis of character and prospects of that activity (fast or slow growth or recession).
3. Definition of a set of potentially favorable production (products and services).

I.2. CMS technical shape formation.

4. Search of typical technological processes of manufacture of the selected kinds of production.
5. Analysis of a degree of similarity of structure of typical technological processes of manufacturing of different kinds of production.
6. Formation of competing sets of production.
7. Choice of the best set of production.
8. CMS industrial program formation.

II. CMS STRUCTURAL SYNTHESIS

9. Planning organizational structure of generalized technological processes and CMS.
10. Allocation of CMS technical means functional invariant.
11. Optimization of technical parameters of the CMS process equipment invariant (base).
12. Analysis of dynamics of the adapter structure change in a complex of CMS technical means.
13. Optimization of functional and technical parameters of the CMS process equipment.

III. ADAPTIVE STRUCTURAL ADJUSTMENT

14. Market conjuncture operative monitoring.
15. Reconstruction of the adapter of CMS technical means.

Fig. 2. The integrated algorithm of CMS structural synthesis

After CMS input in operation the process of its design continuous in form of its perfecting so as the varying conditions of the external (market) environment make necessary adaptive structural adjustment of the industrial system. The procedures of the third design stage in general, repeat the first two stages, however their results have more local character, being limited by changes of structure and parameters of the adapter, not mentioning the unit of a technological invariant. During CMS operation the information on a parity functional and cost parameters of invariant and adaptive units is stored. It allows to select more precisely the best parity of expenses at the implementation of CMS functional units with the help of the principle (VII). The integrated algorithm of CMS structural synthesis is given in Fig. 2.

4. The CMS concurrent design intelligence system

The designing of such complex technical system as CMS requires simultaneous work of a large team. The acceptance of the agreed solutions usually increases common project operating time owing to the realization of various procedures on coordination of share intellectual efforts and integration of individual solutions. In this situation the problem of the design process productivity rise without loss of quality of designing is solved at the expense of wide use of modern information technologies and computer network systems [3]. The participants of design conferences working in a dialogue with the computer have access in a real time scale to anyone to necessary information and program resources of firm and also possibility of dialogue with the colleagues both inside and outside of collective. For intensification of processes of thinking and information interchange it is possible to use associative units (basic psychological images). Such possibility is opened by hypermedia technology which allows to link not only word but also it is possible to store files of any type of data (figures, sounds). There is a possibility of simples and reliable connection with each other of data items irrespective of their format, that especially it is important with creation and use of design databases. The participants of collective designing are joined by a local network and have access to the global network. Many procedures such as search, collection and preliminary analysis of the commercial information and formal forecasting at a marketing research stage, search of standard technological processes, primary grouping (classification) of production is expedient to carry out with the help agent-based systems. The intellectual agent will form the active information filter connecting the global network with a local network of collective designing. A similar methodological approach was applied in research Centre of computer aided design (CADC) at Vitebsk State Technological University (Fig. 3).

CADC specializes on realization of educational, practical and theoretical operations on creation and maintenance CAD systems of products, technological processes and industrial equipment of mechanical engineering and light industry. It is quite possible to examine CADC as the manufacturing system and the common technique of designing CMS is applicable. The CADC specificity as the CMS consists only that it production (knowledge, programs and data) has intellectual and information character. It is necessary especially to mark that CADC is the powerful tool of CMS collective designing on the basis of application of network computer information technology.

Nowadays the employees of the Centre develop a compact system of new products of light industry manufacturing. It is based on technologies of reverse engineering, rapid prototyping and manufacturing.

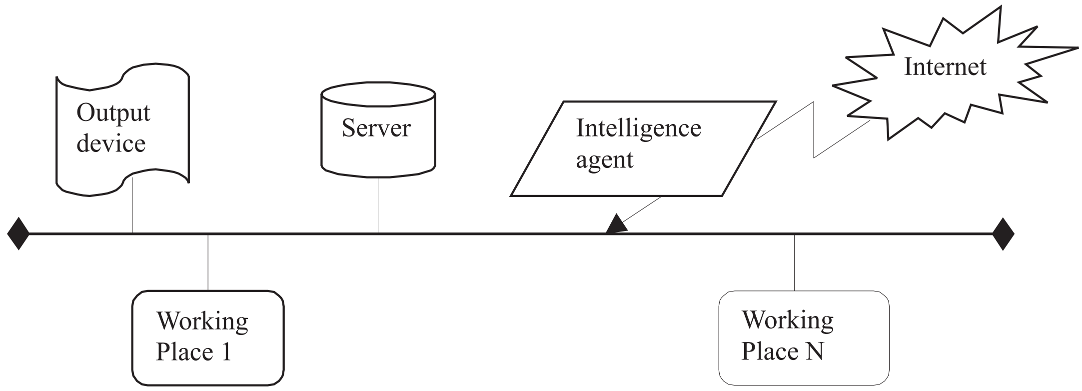

Fig. 3. CAD Centre network configuration

5. The CMS examples

5.1 Cybernetic simulation of CMS (compact shop of the machine-building enterprise) hierarchical structure

The industrial system can be presented as "a black box" with output variable *Y* (production); an entry variable *X* (resources) and unguided effects or disturbance *f* (changes of the orders stream) (Fig. 4). Examining thus CMS as the object of a control it is possible to apply a known method of control with disturbance compensation. It consists that in a control system the special block of disturbance compensating - the equalizer is entered (Fig. 5). The modern theory of invariance allows to determine the conditions of independence (invariance) output variable *Y* from revolting effects *f*. Really, with addition to the industrial system of the equalizer, in which the disturbance f will be transformed in $-f$ and effects on CMS, the compensation turns out, since $f - f = 0$. In result, despite of the constants of the orders stream change, the main (invariant) CMS part functions in the stable (given) mode of the greatest efficiency.

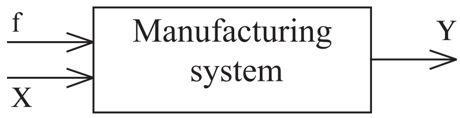

Fig. 4. Classical model of the manufacturing system

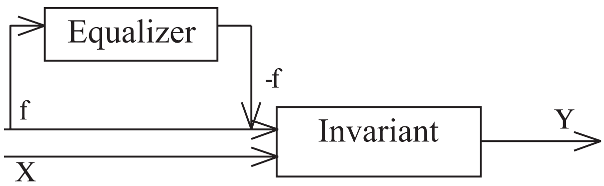

Fig.5. CMS cybernetic model

So the CMS structure consists only of two functional, structural and space isolated units: an invariant and adapter (equalizer). Last of them realizes compensating (adapting) functions-technologies.

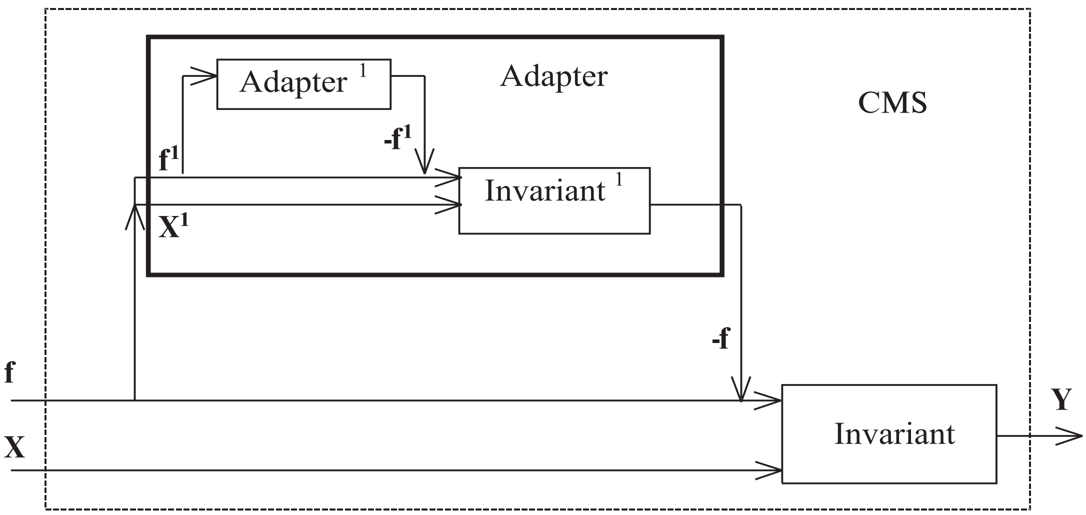

Fig.6. Recursive model of CMS hierarchical structure

The existence in the system organization the invariant and adapting components is characteristic of all levels of CMS hierarchical structure (Fig. 6). At an organizational level the inverse form of a marketing research adapts an existing configuration of the industrial system (as invariant) for the usual conjuncture of the market. At a functional and technological level quasi-optimal technological processes adapt an available CMS equipment complex (invariant) for production, which manufacture is theoretical profitable. At a structural and arrangement CMS level, for example, with operation of the automatic line for moulding or punching, the system of the changeable equipment operating manufacture adapts the high-efficiency specialized equipment (invariant) for change of a configuration of products. At a level of technical devices technological equipment to the machine tool (invariant) or the stamps to a press (invariant) execute the function of the adapter in realization of technological processes, no less than changeable original parts in relation to standard (normalized) units in modular stamps. In the technological complexes (Rapid prototyping systems etc.) the function of the adapter is executed by the computer in relation to universal program to controlled process equipment (invariant) realizing high technologies.

5.2 CMS of the Reverse Engineering

The developed technique of concurrent design has found practical application with Reverse Engineering CMS creation and operation on the basis of the automated laser technological unit. It may be used for the recursive copying (or reverse engineering) of irregular surfaces during the new forms of industrial, architectural and art design computer aided creation process. The information-input module 1, information processing and control module 2, and industrial module 3 are included in this system configuration (fig. 7). It is offered to use video-system for 3D objects digitizing. The modern video systems combine low cost with sufficient accuracy and provide high efficiency and speed of transfer of the information in the processing module.

The configuration of offered video system includes a video camera, projector, rotary table and personal computer. The projector is equipped with a slide with the image of a coordinate grid with the units, which located from each other on equally distance. The digitizing process includes a shooting of object, on which light strips of the slide inserted in the horizontal located projector are imaging, by the video camera established by angle to a horizontal plane. The 3D-stage information is imported from the video camera to the computer. In the computer the software organizes the information in digital models of objects. The object digital model making elements are the scanning object surface points coordinates in the chosen spatial system of coordinates.

The module of information processing and management is functional invariant of all system. The interrelation between system making modules is carried out by it. Also in this module the computer model is developed.

The industrial module carries out the objects manufacturing. It realizes Rapid Prototyping technologies. The technology of level-by-level synthesis is most productive. This process is automated. The flat elements are cut out on coordinate table automatically. The flat elements correspond to the layers of the computer model. The layers parallel connection allows monolithic products making. The method of flat elements cross connection of allows 3D object skeleton assembly.

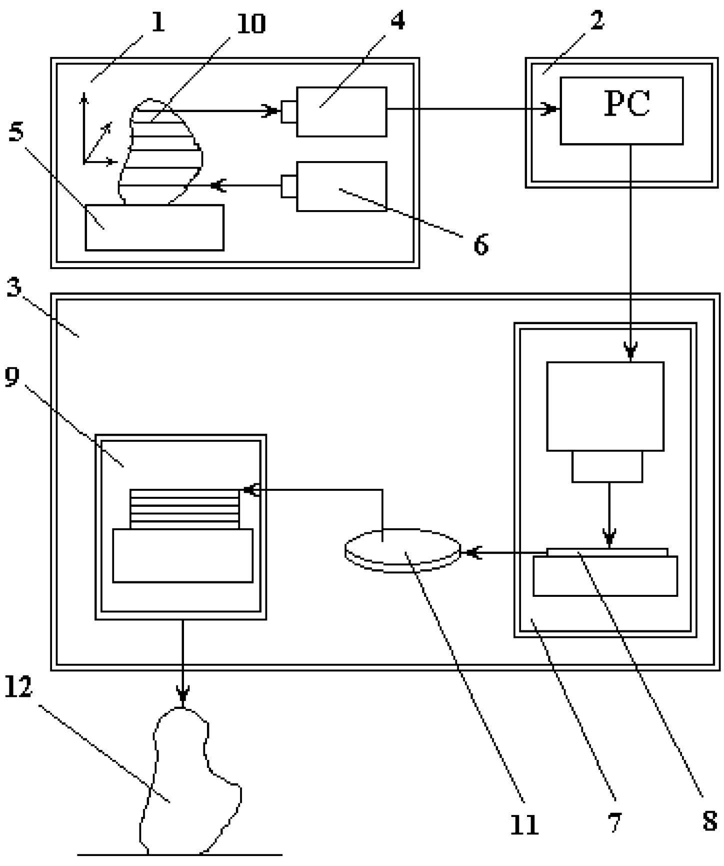

Fig. 7. A compact reverse engineering system configuration
1. The information input module; 2. The information processing module; 3. The industrial module; 4. The video camera; 5. A coordinate table; 6. A projector; 7. A laser cutting installation; 8. A cutting material; 9. An assembly unit; 10.Initial (analogue) object; 11. A cutout layer; 12. A ready object.

5.3 Rapid Prototyping CMS (on the laser cutting basis)

Use of universal laser physical-technical effect and easily adapted to the orders stream changes program-technical complex (on the basis of the personal computer) allows to make a wide gamma of industrial products (table 1).

Laser CMS application area

Table 1.

The products type		The products sort	Industry or other sphere of activity
Plane		Patterns, templates	Tailoring, foot-wear, dry goods
		Incrustation	Furniture, art
		Layings	Repair firms, shop
Relief		Signboards,	Art, advertising
		Stamps	Graphic arts, dry goods
Volumetric	Modular	Special furniture	Furniture
		Exhibition stands	Advertising, design
	Shells	Components for sport vessel and airframe	Sport, tourism
		Foundry models	Moulding
	Continuous	Matrixes, form	Products from plastic and ceramics production
		Stamps	Pilot production
		Models, card	Cartography, training appliance

Structure of the laser industrial system consists of:
- CO_2-Laser (power consumption 800 W);
- The optical channel;
- Control system (personal computer), allowing to carry out direct conversion of the graphics information about a detail (standard file of graphics exchange *.dxf) in signals of handle of coordinate desktop;
- Coordinate desktop.

The made system has the following technological parameters:
- Processed materials: plastics, wood, textiles, natural and artificial leather;
- Overall dimensions of products Up to 1700 x 1200 mm;
- Width of a source material Up to 20 mm;
- Technological accuracy Till 0.05 mm;
- Technological speed Up to 24 M/mines;
- Overall dimensions of installation 3000 x 2000 mm.

The application laser CMS for manufacturing of the complex 2D, 2,5D and 3D object of the machine-building, light and other industries allows to reduce sharply (up to 5 ... 8 times) time and cost of designer and technological preparation of competitive production manufacturing.

This CMS may be used for Rapid Manufacturing of the moulding equipment (stamps).

6. Conclusion

The "Lean Production" concept can be practically realized in compact industrial systems. The maintenance of manufacture compactness becomes possible by use of the CMS designing principles, which are offered in the paper.

The developed technique of the CMS automated structural synthesis is based on a wide use of modern information technologies. Now it is applied at the Centre at Vitebsk State Technological University for CMS simultaneous designing for different industries.

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POČÍTAČOM INTEGROVANÁ PRUŽNÁ VÝROBNÁ BUNKA

COMPUTER INTEGRATED FLEXIBLE MANUFACTURING CELL

Článok opisuje pružnú výrobnú bunku (FMC) vytvorenú v rámci projektu INCO-Copernicus: „Modelovanie výrobku a procesných dát pre FMC-PPDM-MC" (CP-960052). FMC je integrovaná pomocou počítačom podporovaných systémov ako: CAD, CAD/CAM, PPC a SFC, čím je umožnený informačný tok medzi nimi a realizáciu celého výrobného cyklu vo FMC. V pružnej výrobnej bunke je možné obrábať rotačné a prizmatické súčiastky. Použitie simulačných systémov FACTOR AIM a Roans umožňuje uskutočniť simulačné experimenty, ktoré poskytnú dáta pre optimalizáciu návrhu výrobku a výrobných dát pre FMC.

The paper describes the flexible manufacturing cell (FMC) created in INCO-Copernicus Project. „Product and Process Data Modelling for FMC - PPDM-MC" (CP-960052). The FMC is integrated with computer systems as: CAD, CAD/CAM, PPC and SFC, which makes the flow of information possible between them and the demonstration of the full manufacturing cycle in the FMC. In the flexible manufacturing cell rotating and prismatic parts can be manufactured. Using simulation devices FACTOR AIM and Roans enables to make simulation experiments, which provide the data for optimisation of product and process data design in FMC.

1. Introduction

In a market economy, the survival of the organisation depends on its ability to react to changes in production. Specific factors such as quality, state of the art technology and low cost in relation to production are crucial to the success of the organisation. It is for the reasons that the organisation must do all it can to foster these specific circumstances. Flexible Manufacturing Systems (FMS) enable high quality production, short production cycles, quick implementation of new products and low level of production in progress reserves, which can all assist in improving the competitiveness of the organisation.

The project resulted in design and implementation of a model FMC consisting of a number of CNC machines, material handling devices and transfer devices, together with the necessary tooling, planning and control software. The software includes Production Planning and Control and CAD/CAM software. The fully operational cell enables demonstration, modelling and investigation of the flow of parts, materials and information in the FMS and is useful for small and medium sized enterprises equipped with CNC machine tools and devices.

The model FMC is created in the European research project "Product and Process Data Modelling for FMC - PPDM-MC" (CP-960052). It focuses on the issues of modern manufacturing: production planning and control (PPC) for flexible manufacturing systems (FMS), CAD/CAM systems, and simulation.

The PPDM-MC project resulted in the construction of flexible manufacturing cell, with the purpose of modelling the flow of information, materials and products. By designing and implementing this model FMC, the project achieved the following goals:
- to provide example a showcase of FMS technology and its applications for Central Eastern European industry,
- to intensify co-operation between industry and academia,
- to develop appropriate courses for students.

The implementation of FMS was accomplished in three main stages, namely:
- Planning,
- Design,
- Implementation.

A computer simulation technique was also used to model the FMC at the design and implementation stages.

2. The design of model flexible manufacturing cell

The model FMC was planned for rotary and prismatic parts. The parts to be machined were selected. The treatment technology, technical requirements, terms of production, quantity of series, and other relevant factors were also defined. The planning chart of FMC is shown in Fig. 1.

The design of FMC included the detailed design of all subsystems. This was provided in two stages. The first stage

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defines the type of systems (single DNC, DNC lines, FMC, FMS). The second stage outlines the layout of the cell (number of machine tools, transport devices, placement of machines, the methods of storage, manipulators, tools, controlling systems etc.).

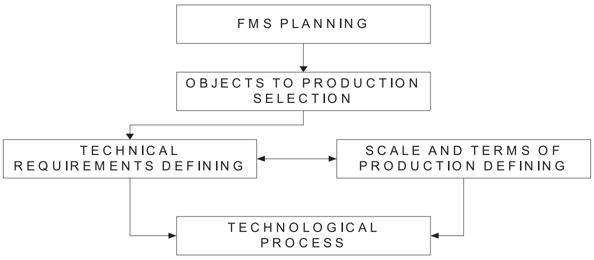

Fig. 1. FMS planning

The FMS implementation was undertaken as two tasks (Fig. 2.). The first task is that of software implementation, which is connected with the controlling system implementation (DNC system, production schedule, production controlling, process monitoring, process inspection, tools monitoring etc.). The second task was that of the implementation of production system (designing of tooling, manipulators specification, treated materials and object transport system, tools system, inspection system, machine tools).

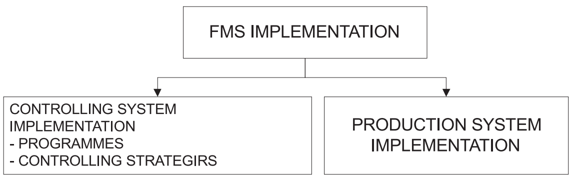

Fig. 2. FMS implementation

3. Structure of model FMC

The computer integrated flexible manufacturing cell consists of two numerically controlled machine tools (CNC lathe and CNC milling machine), control and measurement position and group of semi-products and finished parts stores. The workpieces are passed to processing by a robot, installed in a conveyor system, which is programmed in five axes (Fig. 3).

Robot is on-line programmed using TeachBox or special operational software. Controlling programmes are divided into two parts. The first one contains robot positions in the workspace, second one contains the orders for robot positions and additional orders like: interval of time, opening and closing the robot jaws, etc.

Communication between the HOST computer and robot is through RS-232 connection. In each programme for robot the safety robot arm position is included. That position is also the starting and finishing position for each programme. It is selected in such a way that if there is any collision the arm would not have any collision with the machines, or with any of the storages. At the end of each controlling programme there is an order added, which causes the sending of the signal to in/out card. The signal on the card is returnable and it is informing the Manager FMS programme that the programme is finished. The Manager programme can indicate the next programme, which is controlling, for example, milling machine. Starting on the next programme is connected with sending the programme with positions and orders from the HOST computer to the robot.

Fig. 3. FMS Laboratory at PUT

The robot in FMS station is moved among all manufacturing stations and storage units. The crossing system contains: a special table with all the FMS stations placed on, a linear guide with the table for robot and controlling system mounting.

The crossing system is on-line programmed, or using the special operational software, which uses MRP2 inner regulator language. Thus, it is possible to programme unrestricted numbers of start and stop robot positions.

Palettes are used as stores for semi-finished products and treated objects. One store is added as an inter-operation store. Each palette has several positions for placing the objects. Palettes can be modified, allowing different objects to be placed on them. The machines co-operate with the robot which is placed on the linear slide. The parts ready for machining are taken from a pallet by the robot to the machine where they are processed according to their process plans.

The model FMC contains the following devices:
machines: - CNC MIRAC lathe and CNC TRIAC milling machine,
industrial robot: - MITSUBISHI - model RV - M2,
material transport unit: - pallets, linear slide for the robot and
auxiliary devices: - manual measurement tools, cutting tools, clamping devices and other devices necessary for the FMS.

The flexible manufacturing cell enables data preparation, which is essential for production and enables their modelling. The cell is integrated with such computer systems as: CAD, CAD/CAM, PPC and SFC, which makes the flow of information possible between them and the demonstration of the full manufacturing cycle in the FMC. The structure of the cell, its integration and the flow of information are shown in Fig. 4.

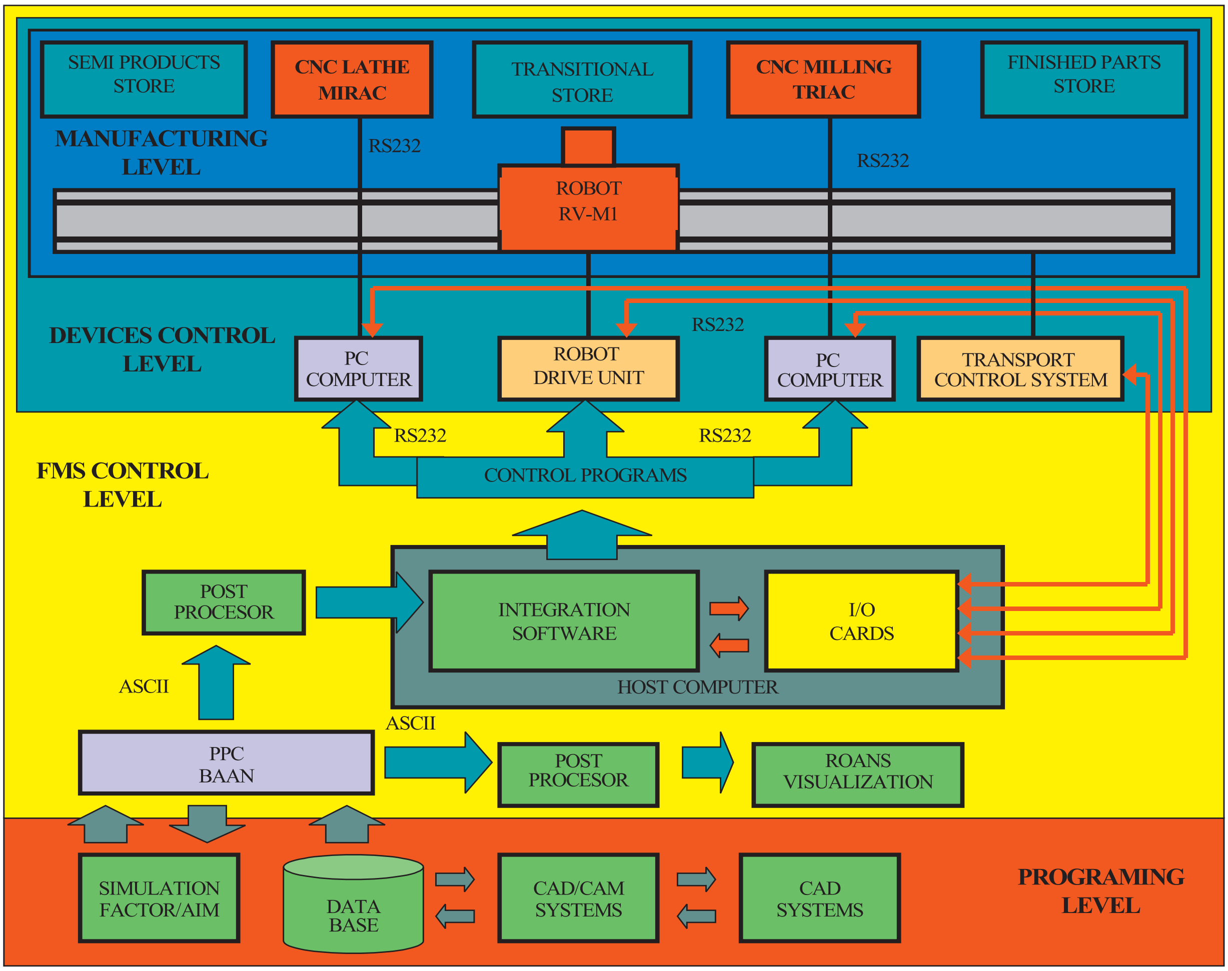

Fig. 4. Connections scheme of hardware and software within the FMC

The model FMC functions in the integrated computer environment. Three levels can be distinguished and controlled with the help of various computer systems. The manufacturing level is served by controlling computers and technological devices that supervise work. The superior level which controls the manufacturing process in the cell is operated by a host computer with the help of a Manager programme which uses information generated in a PPC system. The manager software integrates all technical components in a model FMC. The software is open and it means the possibility of adding another device, e.g. a measuring machine robot and CNC machine. The programming level includes the computer systems: CAD, CAD/CAM, databases and a simulation program.

Rotating and prismatic parts can be manufactured in the flexible manufacturing cell.

4. Data flow in FMC

The system works on the basis of algorithms and models of the flow of information and scheduling of manufacturing tasks as well as algorithms of digital signal processing (DSP), drawn up by the research team. Planning of orders in FMC is based on methods MPS (Master Production Scheduling) and MRP (Material Requi-rements Planning) methods and for small batch production, manually.

For planning and controlling the order the integrated PPC system BaaN IV is used. System BaaN is based on Dynamic Enterprise Modelling (DEM) rule.

The schedule of data flows between planning and controlling system and simulator placing the orders based on the time of their starting up are shown in Fig. 5.

BAAN IV was selected as the PPC system for designed demonstration FMC. The level of integration between PPC system and simulation devices depends on a specific situation. Simulation running is performed by realising the orders entering the FMC, each order determines a part, number of parts, process plans, priority and other data which are to be processed in simulation running. This data are used in the environment of simulator by more detailed definition. The following simple procedure is used

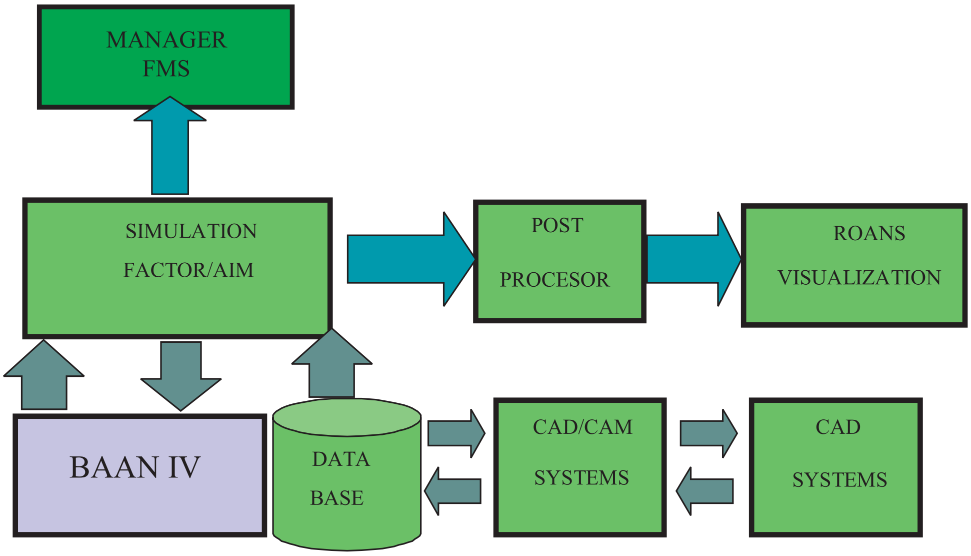

Fig. 5. Data flow between planning and controlling system and simulator

for importing orders to AIM 8.0. The orders which have to be simulated in AIM 8.0 are exported from BAAN IV in ASCII file format ASCII file exported from BAAN IV is imported to the AIM 8.0 databases directly (using user insert programmed in C++) or by using MS Access 7 (AIM 8.0 databases standard).

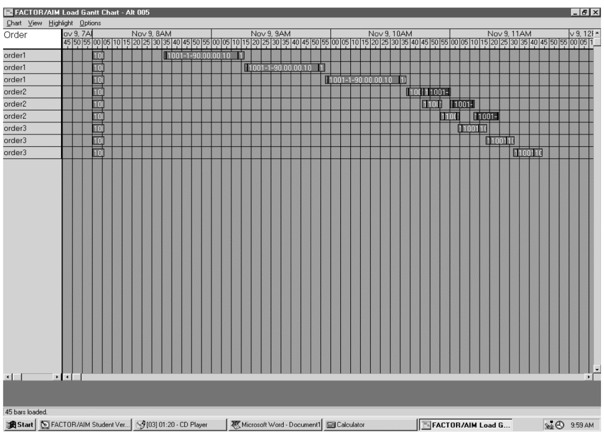

Fig. 6. Example of AIM simulation output - order Gantt chart

AIM 8.0 allows the user to build simulation models very effectively in a user friendly environment. It enables to perform most of the studies required in industrial simulation and also provides high calculating performance and power utilities for evaluation of simulation running results. AIM 8.0 provides a lot of possibilities for evaluation of the data acquired from simulation experiments. This section does not show all of them. AIM 8.0 simulator will be able to perform most of studies required by end users of FMS technology. The type of study and required results will be defined in discussion between the end user and AIM 8.0 simulation expert. The results shown in this section were taken from the simulator as a demonstration. The simulation model is able to provide more detailed results in relation to the requirements of the end user.

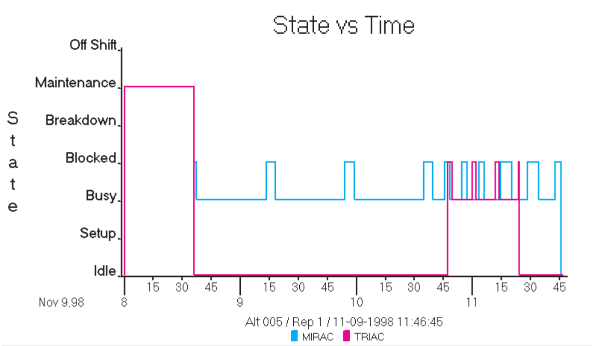

Fig. 7. AIM simulation output - time graph

5. Integration of CAD/CAM systems

Technological equipment used in FMS is numerically controlled. For objects treatment it was necessary to prepare controlling programmes. For CAD/CAM adaptation to FMS, postprocessors were made, which enable to generate NC programmes for the used CNC machine tools. The database of NC programmes has been also prepared (Fig. 8).

Three groups of objects have been proposed: rotating objects treated on a lathe, prismatic objects treated on a milling machine, and rotating objects treated on a lathe and milling machine. For each group of objects the technological process programming method has been chosen for numerically controlled machine tools. That programming method choice is closely connected with programming tools used by the Poznan University of Technology, and with those used in industrial companies from partner countries.

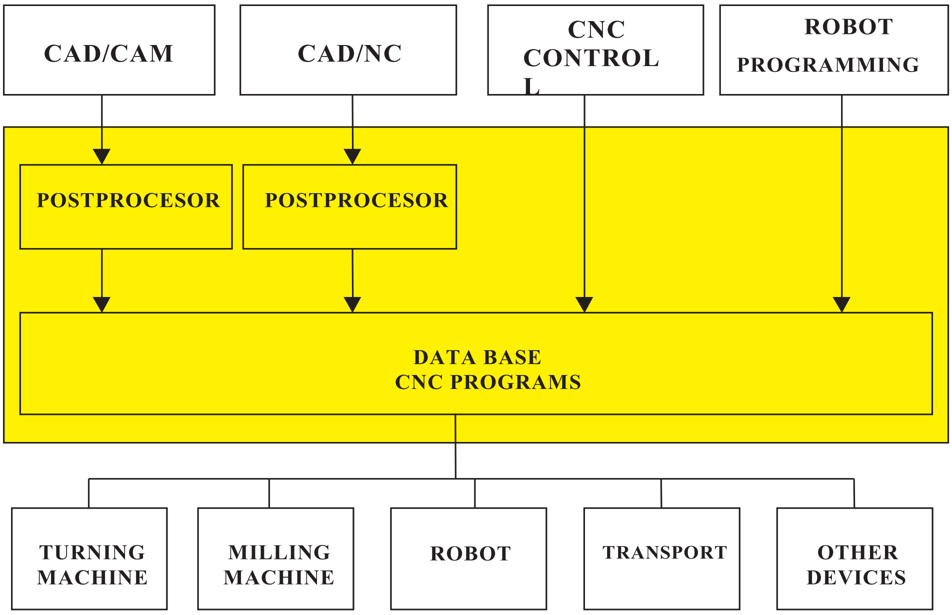

Fig. 8. CAD/CAM systems connections with FMC devices

6. Conclusion

Flexible Manufacturing Systems (FMS) are systems that have already found applications in manufacturing enterprises. These systems are large and designed for big and rich companies. Flexible manufacturing cell (FMC), realised within the confines of INCO-COPERNICUS/ESPRIT Programme, together with other scientific centres and industrial partners takes into consideration the specificity of the market and the situation of small and medium-size companies.

The simulation devices FACTOR AIM and system Roans enable to make simulation experiments. The modelled processes can be shown in a graphic form, using a network to the centres of technology exchange situated near SMEs. The system will be used to run project works regarding products design, to draw up manufacturing processes and production planning numerically to controlled machine tools work in the cell of the FMS type (but not only), and also to train students and the technical staff of a particular enterprise.

Reviewed by: J. Matuszek, J. Štefánik

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Adamczyk Zbigniew *

INTERNET - MOŽNÝ PRÍSTUP K VÝVOJU TECHNOLOGICKÉHO PROSTREDIA CAM SYSTÉMOV PRE MALÉ A STREDNÉ PODNIKY

INTERNET - ENABLE APPROACH TO DEVELOPMENT OF TECHNOLOGICAL ENVIRONMENT OF CAM SYSTEMS FOR SMES

Na zlepšenie ekonomických aspektov CAM aplikácií, hlavne v oblasti malých a stredných podnikov je potrebný nový prístup pre vývoj CAM systémov. Technologické prostredie je jeden z faktorov ovplyvňujúcich efektívnosť využívania CAM. Článok predstavuje prístup ku tvorbe distribuovaného technologického prostredia dostupného v prostredí WEB.

A new approach to CAM system development is necessary to improve economical aspects of CAM applications particularly in SMEs. Technological environment is one of the factors influencing effectiveness of CAM exploitation. The paper present a promising approach to creation of distributed technological environment available on the Web.

1. Introduction

Effective exploitation of CAM system is a very important feature particularly for small and medium enterprises (SMEs). Therefore, a new approach to CAM development is necessary to improve economical aspects of CAM products addressed to SMEs. Considering CAM class software products addressed to SMEs two group of products should be taken into account, i.e.

- CAM system solutions available on the market
- Technological environment of CAM system supporting CAM usage.

To fulfil SMEs requirements new CAM systems should be easy in exploitation, with a friendly designed man- machine interface, as powerful as possible, with functions configured on request according to a problem to be solved, extendable, not only to buy but also to rent, able to solve technological problem at as low cost as possible. In other words, a new generation of CAM systems should be adapted to new forms of manufacturing process organisation, which has to assure high productivity, flexibility and ability to fulfil customers' expectations as quickly as possible. However, there is a difference between SMEs expectations and available on the market, costly and sophisticated software products, developed according to quite a different philosophy. Technological environment is one of the main factors influencing effectiveness of CAM exploitation as well. The distributed technological environment (DTE) available on the Web will support SMEs in NC programming, making possible technology transfer and distributed collaboration of SMEs. The Internet technology applied to DTE establishing assures cost-effective, easy available, open technological environment on the Web. The approach supports flow of technological experience inside big organisations using Intranet or between SMEs using Internet. The distributed technological environment concept is very promising for SMEs which will be supported by constant and independent development of Internet technology with a growing number of services. The Internet databases, recommendations of cutting parameters selection, group and typical technology available on the Web will support SMEs in manufacturing process preparation thanks to distributed and low-cost support. The Internet technology makes possible CAM exploitation on different hardware and software platforms what practically means wide access to technological environment of CAM systems.

Another feature of CAM system desired by SMEs is openness to easy customising to real SME machining environment which assuring adaptation of technological performances of CAM system to factory requirements and decrease costs of its application.

2. Low-cost NC Programming system KSP-OSN/WIN for SMES

The interactive NC programming system KSP-OSN/WIN is developed in the Institute of Metal Cutting (IOS) in Cracow, Poland. The system shows necessity of system reconfiguration and customisation. It takes into consideration new circumstances appearing in manufacturing philosophy and to meet SMEs expectations [1], [2], [3].

Industry exploitation of the KSP-OSN/WIN system also showed importance of customisation of technological environment of

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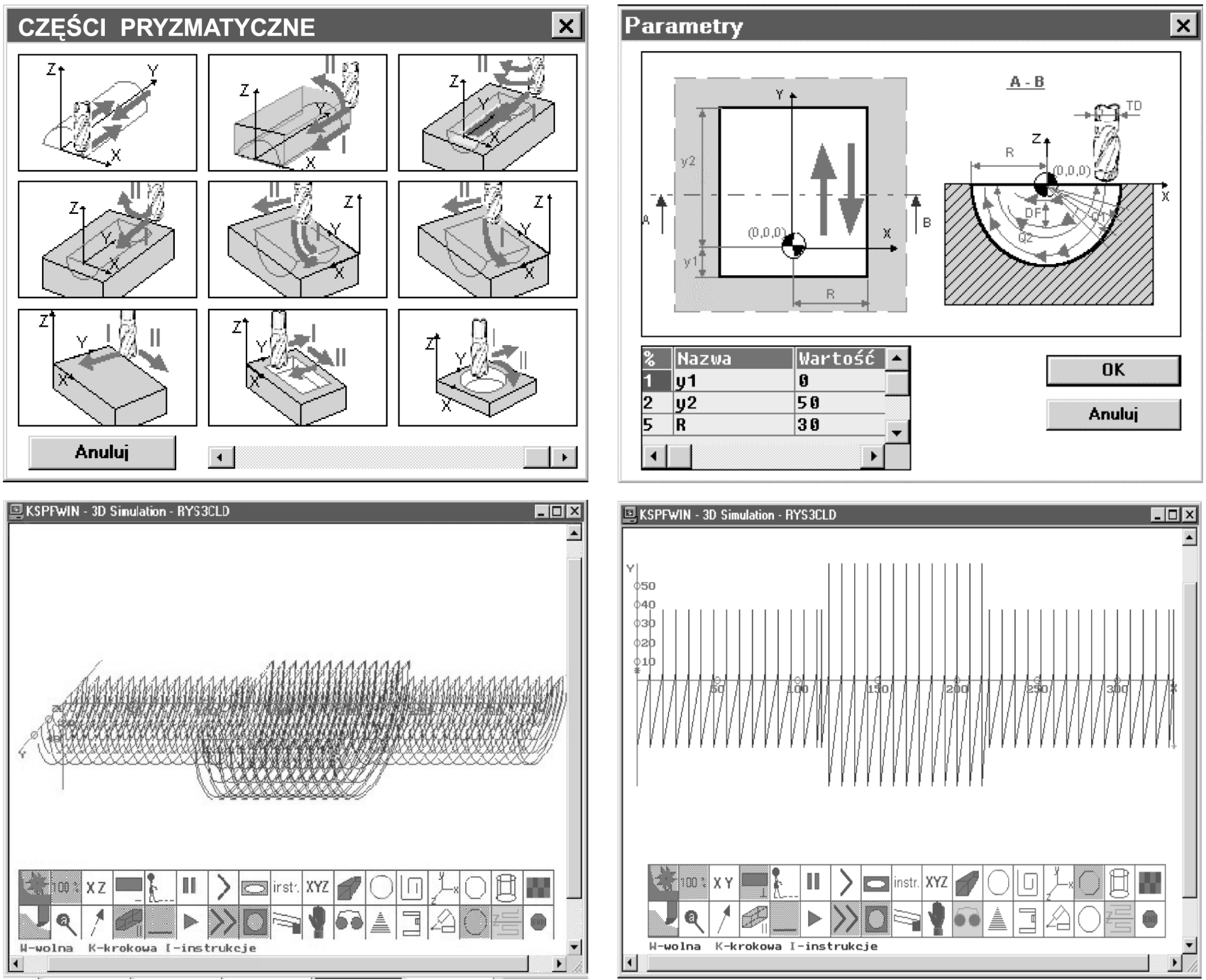

Fig. 1. Programming method of 3D machining in interactive NC KSP-OSN/WIN system.

CAM system and its influence on effectiveness of exploitation. Facing the above mentioned problems, R&D works have been undertaken in the IOS to develop a new generation of interactive NC programming system KSP-OSN/WIN with distributed technological environment using up-to-date information technology.

The objective of the KSP-OSN/WIN system transformation is:

- Replacement of monolithic architecture of the KSP-OSN/WIN system by open component-based architecture using Microsoft Common Object Model (COM) [4] and Distributed Common Object Model (DCOM) standards [5], [6], [7]
- Development of virtual version of the KSP-OSN/WIN system in which exploitation properties of the system will be formed by customers according to requirements necessary to technical problem to be solved in constantly changing manufacturing environment (machine tools, tooling and tools, etc.),
- Development of Internet-enable features of the KSP-OSN/WIN system suitable for distributed manufacturing. The Internet-enable version of the KSP-OSN/WIN should be available to rent by SMEs, not only to purchase
- Development of distributed technological environment including former implemented Internet tool databases for KSP-OSN/WIN.

The last aspect of a new approach to KSP-OSN/WIN development will be discussed below as a very important from SMEs point of view.

3. New approach to technological environment development for KSP-OSN/WIN system

3.1. General remarks

Technological environment (TE) of a CAM system has to contain all information and data necessary for NC programming presented in a friendly way and available remotely from the CAM system. Incomplete data, decrease efficiency of CAM system exploitation. Therefore TE should contain among others:

- machine tool databases,
- cutting tool and tooling databases

- tool manufacturers and factory recommendations of cutting parameters selection,
- general-purpose technological components databases supporting NC program designing process.

DTE also contains group technology (Fig. 12) for CNC lathes implemented in Internet technology and available in user browser. This new approach of technology presentation makes easy access to parametrised technological chasses that assist designing process of CNC programmes.

Distributed technological environment (DTE) available on the Web will support SMEs in NC programming, making possible technology transfer and distributed collaboration of SMEs. As a first step in DTE creation Internet tool databases for the KSP-OSN/WIN system have been established.

A traditional access to data presented in the form of tables in catalogues is unconvenient and decreases CAM effectiveness of exploitation. Effective management of tool sets, circulating on the workshop, needs introducing into CAM system tool reservation and monitoring functions presenting tool position and its exploitation features at any time during its life what is helpful in NC program preparation. Cutting parameters used in machining process have to be selected to assure high productivity and economics of machining process for selected cutting tool and machine tool applied. To do it reliably, recommendations of cutting parameter selection have to be used. Correct selection of cutting parameters for previously selected cutting tool and machined workpiece material assures the tool life requested in the given conditions of machining and quality of cutting process. NC programmer has to get an easy and friendly access to cutting tool manufacturer recommendations at each stage of machining process planning. Unfortunately, the most often issued recommendations are not complete and user experience is necessary in cutting parameters selection. Hence, the recommendation supports only a system user in decision making process in the final cutting parameter selection but the user is responsible for the selection. A wrong decision will result in low effectiveness of cutting process or lower degree of reliability of cutting process.

3.2. Internet-enable tool databases

To improve cutting tools selection for the machining process to be performed and cutting parameters selection to be used during the exploitation of the KSPT/WIN and the KSPF/WIN systems the Internet-enable databases have been developed as the first step in distributed technological environment establishment for standard and component-based KSP-OSN/WIN system [11], [12], [13], [14]. An example of internet database KSP-IBD/WIN for NC lathes is presented below.

Searching of the databases can be started either from BAILDONIT [8], [9] tools database or from PAFANA [10] inserts database. In the BAILDONIT inserts database recommendations of insert shape selection is available. A lot of Web pages illustrate the recommendation of insert shape fitting to machining operation considered which are on the top of the Web document hierarchy (Fig.2), according to P, S, C clamping system and external or internal machining. When clamping system, for example P, and external machining are selected, one obtains a set of documents presenting tools and inserts available in the production programmes and recommendations of insert shape fitting to shape of a machine workpiece. Using the active area with image of an insert, one comes to the table containing dimensions of the selected inserts and grades available in BAILDONIT production programme (fig. 3).

Selection of the insert type makes possible to come to the next phase of database searching, i.e. chipbreaker and shimes selection on the basis of documents called out from the help system. In the same way the information about clamping system elements can be obtain-

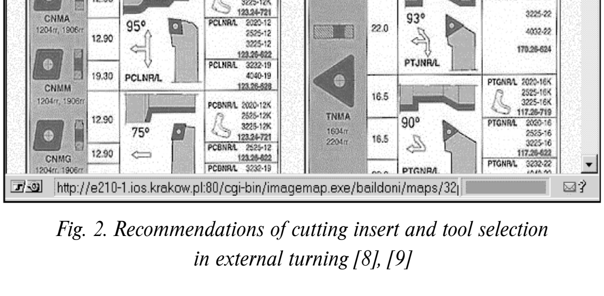

Fig. 2. Recommendations of cutting insert and tool selection in external turning [8], [9]

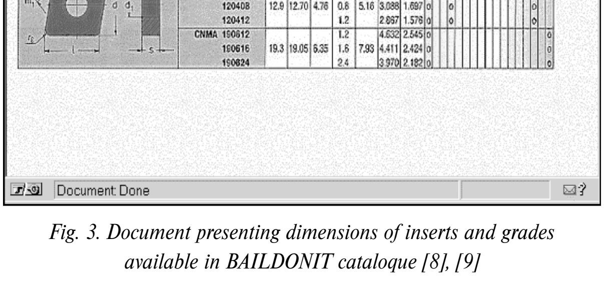

Fig. 3. Document presenting dimensions of inserts and grades available in BAILDONIT cataloque [8], [9]

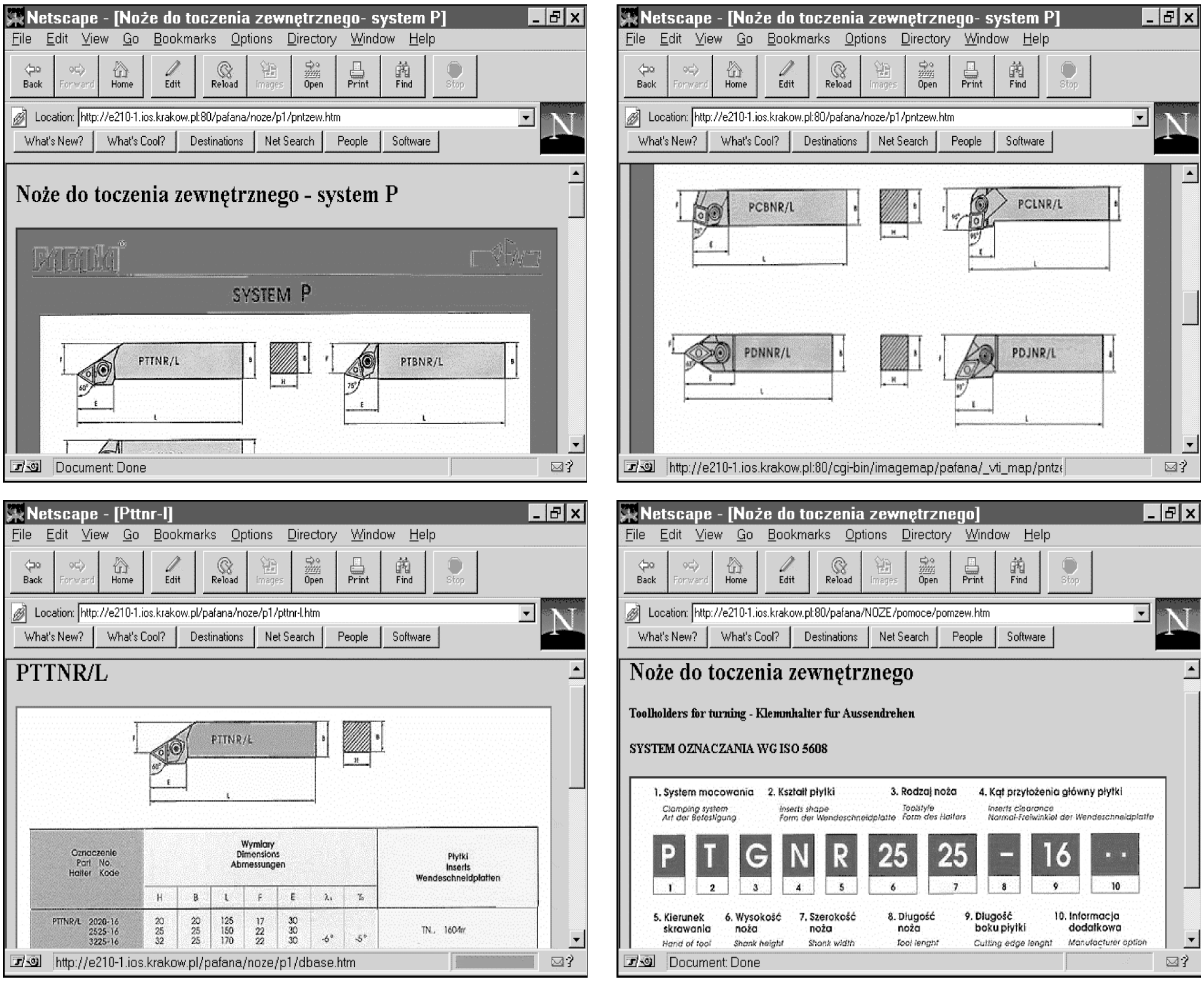

Fig. 4. Document presenting assortment of tools for P clamping system in external turning [10].

ed. The selection of the insert grade can be done directly from the table containing insert dimensions. The selection of coated or uncoated inserts can be supported by recommendations included into the help system. When teh final selection of cutting inserts is finished, the database operator can get back to the dimension table. When the designation of the insert is completed and prepared to later print out of a tool list the next tool selection procedure can be started as the switching to PAFANA tool database is possible and tool selection can be made (Fig. 4). The Internet-base solution of databases shows a hierarchical structure of the HTML documents linked together forming a tree of database searching. The database searching of HTML user interface makes easy as reviewing database contents presents system user only the alternatives which are available at the considered level. Web pages contain a certain number of make active areas and pushbuttons which possible bidirectional communication between Windows applications and Internet environment.

Similarly, after the completion of a tool selection process, cutting parameters recommendations can be called out supporting the operator in selecting the recommended cutting parameters for selected cutting insert and material to be machined (Fig. 5, 6). Cutting data are entered as well to the intermediate table and can be exported to the KSP-OSN/WIN system on operator's request and placed in the NC program being created.

The Internet database (IBD) is available in the KSPF/WIN interactive NC programming system for milling machines and machining centres from TECHNOLOGY menu (Fig. 7, 8, 9, 10). Cutter selection for programmed machining operation is possible from the first document presented just after coming to the IBD. Bitmaps present cutters available in database. Cutter selection is supported by recommendations and data description of recommended range of cutter application including insert geometry and cutter diameter. As the main cutter parameter angle Kr is used according to BAILDONIT catalogues [8], [9]. After the selection of a cutter type clicking active area of the document user comes to the dimension table of the selected cutter.

At this level of the IBD documents searching system operator can select:

- cutter revolution direction (R or L),
- cutter dimensions

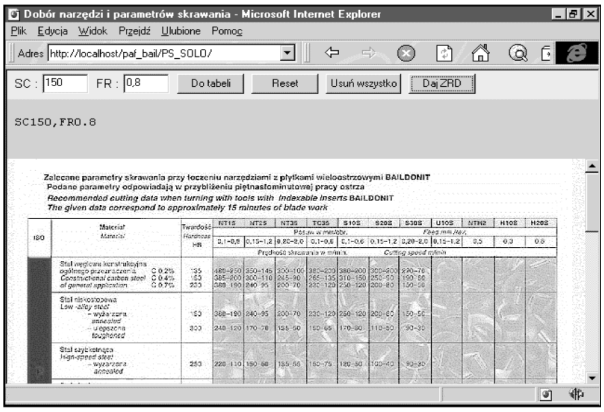

Fig. 5. The Web page supporting cutting parameters selection in turning [8], [9]

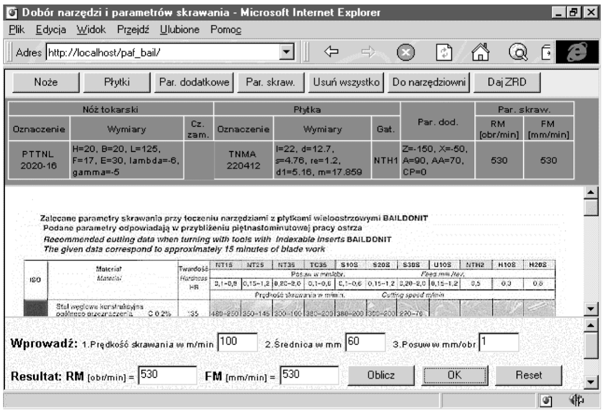

Fig. 6. Cutting parameters selection supported by company recommendations [8], [9]

Fig. 7. The Internet database for interactive NC programming system KSPF/WIN for milling machines and machining centres

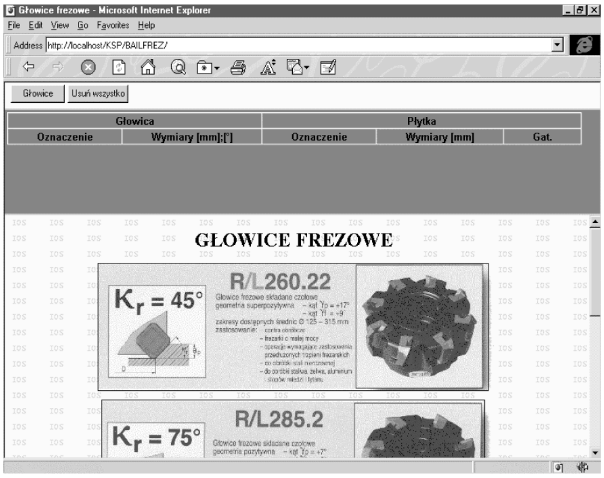

Fig. 8. The HTML document presenting cutters available in the KSPF-IBD/WIN database [8], [9]

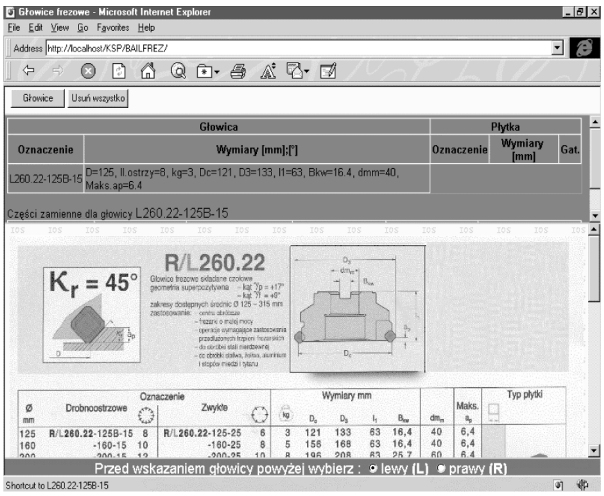

Fig. 9. The HTML document presenting dimension table of cutters [8], [9]

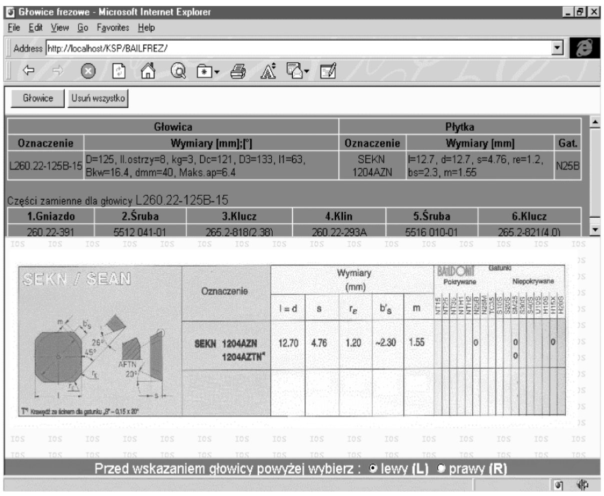

Fig. 10. The HTML document presenting dimension table of inserting [8], [9]

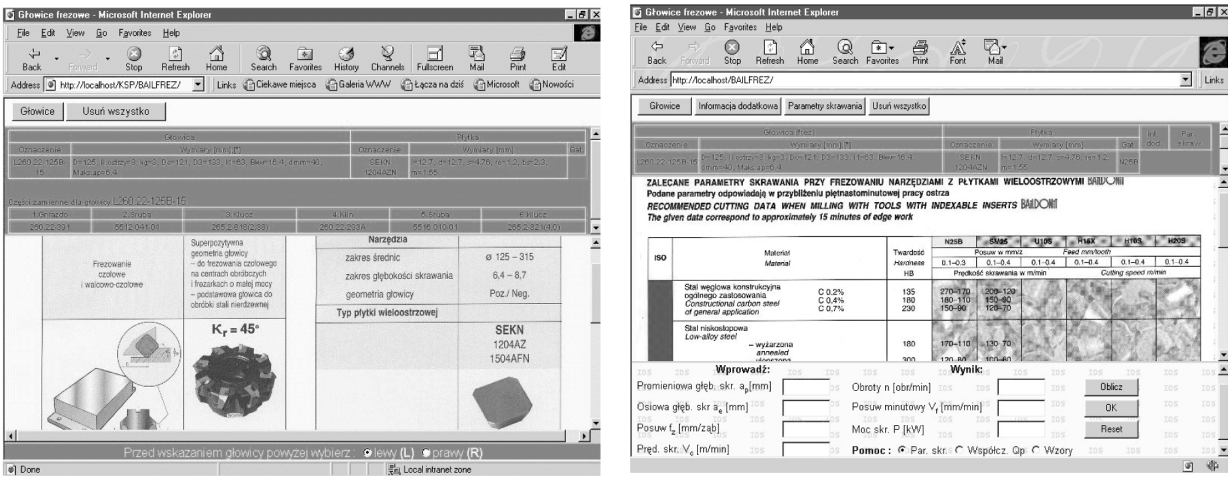

Fig. 11. Cutting parameters selection in KSPF/WIN system supported by company recommendation.

After the completion the data can be sent to the intermediate table which contains the data prepared to later print out (Fig. 9). And finally, the insert dimension and insert grade can be selected from the next document (Fig. 10). Also spare parts necessary to assemble the tool can be added to the intermediate table. The help system incorporated into the database system searching available from the presented document supports the IBD operator in searching of database in a friendly way.

One of the most important features of the CAM system is the possibility of a cutting parameters selection. A lot of system implementations are based on Taylor's formula in different areas of applications, specifying workpiece materials to be machined and listing cutting tools for which the the coefficients in Taylor's equation are known. But cutting tool manufacturers usually issue only recommendations giving the ranges of recommended cutting parameters, i.e. cutting speeds and feeds without any Taylor's coefficients Taylor's coefficients make any kind of process optimization impossible. Tables containing recommended cutting parameters are also divided into HTML documents on the Web server which are structured by hyperlinks forming a tree of document searching. The cutting data selected for a given machined material and a cutting insert are entered by a system operator to dialog boxes on the WWW pages and transferred to the KSP-OSN/WIN system. The examples of pages supporting cutting parameters selection and assuring database communication with the KSP-OSN/WIN system are presented in Fig. 11.

The method of cutting parameter selection mentioned above means the computer assisted process but not its automation. A great number of data presented in different ways, their incompleteness, make an approach to the problem more effective. The operators' knowledge, his experience and skills are useful in a decision making process. The final selection of the cutting parameters based on the operator's interpolation and extrapolation can be used additionally.

3.3. General-Purpose Technological Environment

Efficiency of the KSP-OSN/WIN system exploitation can also be increased by consolidating general-purpose technological components with KSP program reducing programming effort.

As an example of the above mentioned approach Internet group technology can be presented in the SMEs technology domain. Some HTML documents [14] of Internet group technology for interactive NC programming system for CNC lathes are shown in Fig. 14. The workpiece icon corresponding to workpiece shape to be machined.

After assigning workpiece dimensions to parameters in KSP language one obtains NC program which can be viewed and corrected by a NC programmer. To customise the typical technology to real machining conditions the programmer has to interact with the Internet tool database to select the cutting tool and cutting parameters adequate to workpiece material to be machined and complete the NC program. The Internet-enable group technology is implemented for three classes: shaft, sleeve, disk. It means that about one hundred typical parameterised NC programs are available to support a NC programmer in the machining process design.

3.4. Customised Factory-Formed Technological Environment

Technological performances of the KSP-OSN/WIN system can be extended by a set of specialised and customised KSP components written in the problem oriented - language KSP and ISO components written in ISO code of CNC controller for a given CNC machine tool on which the machining process is to be performed. Untypical machining operations, as probe measurement cycles, palette positioning, etc. can be programmed in advance as KSP or ISO components, thus forming a customised technological library of product-oriented technological components.

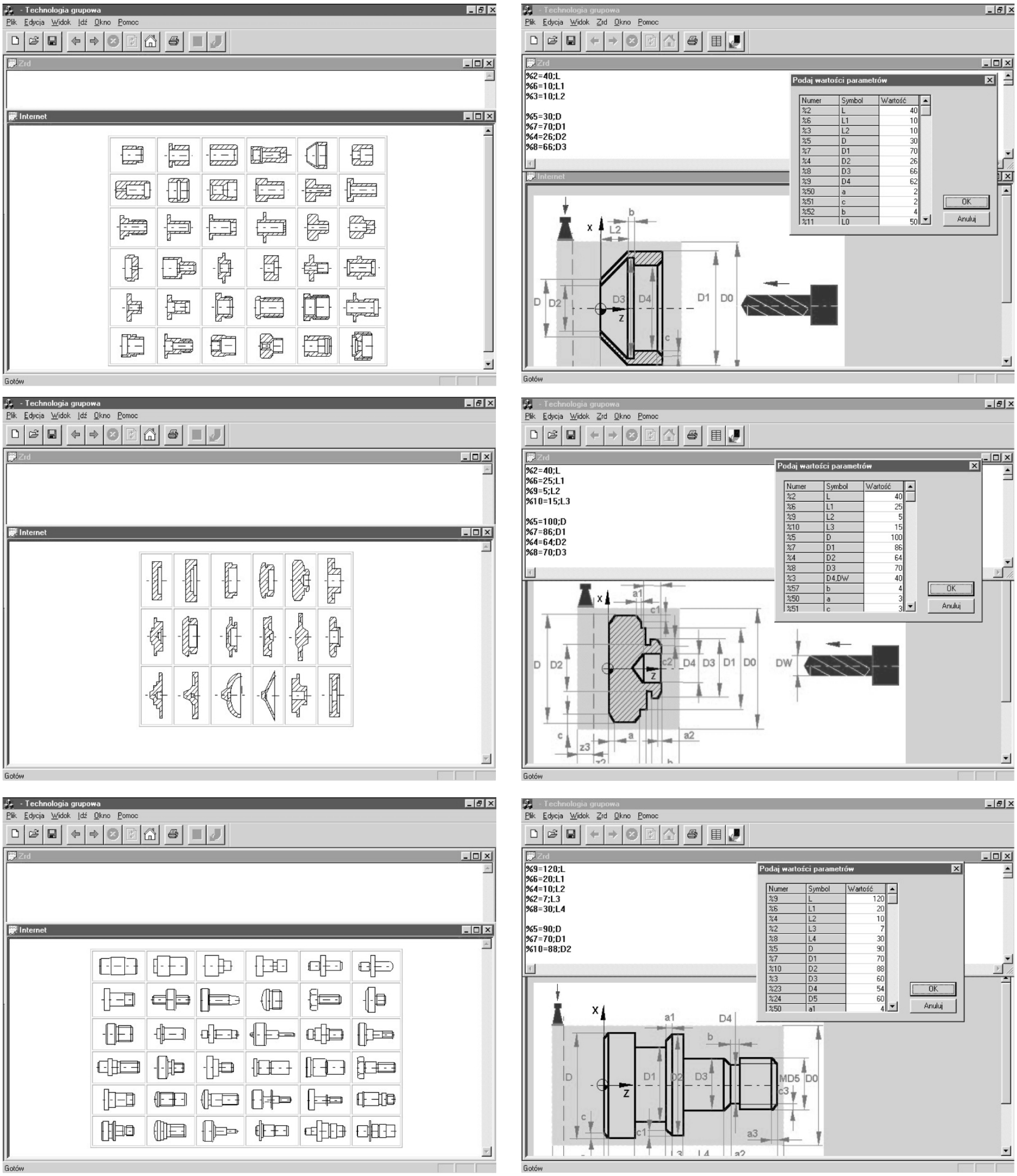

Fig.12. Examples of documents of the Internet-enable group technology for turning operations

In this approach the following several customising levels can be distinguished:

- Custom-oriented functionality of the system is formed by specification of software components necessary to program a machining operation to be performed,
- KSP-language problem-oriented technological components, implemented in advance by the customer himself, to meet specific technological requirements of the manufacturing processes,
- ISO code problem-oriented technological components implemented also in advance, typical for machine tools and CNC controllers M-G functions used by customers.

The library of KSP and ISO oriented technological components can be created by customers themselves on the basis of practical experience or can be supported by technological research centres like the Institute of Metal Cutting, developer of the KSP-OSN/WIN system.

4. Conclusion

The new technology applied to DTE establishing assures cost-effective, easy available, open technological environment on the Web. The approach supports flow of technological experience inside big organisations using Intranet or between SMEs using Internet. DTE is open. Both tool databases, cutting parameter selection and parameterised technology can be entered to the DTE on the basis of CAM system exploitation and as a result of customisation of CAM users according to real needs. The distributed technological environment is very promising concept for SMEs which will be supported by a constant development of Internet technology. Internet databases, recommendation of cutting parameters selection, group and typical technology available on the Web will support SMEs in manufacturing process organisation and low-cost exploitation. Another advantage of the Web technological environment is its extendibility and centralised maintenance. Upgrades installed on the Web server are immediately available to all customers. Besides, Information technology makes exploitation on different hardware and software platforms possible what practically means a wide access to the technological environment of CAM systems. The problem of SMEs support is noticed and the trial of its solution is undertaken in the frame of 5th Framework Programme of the European Community for Research Technological Development and Demonstration Activities in which special SMEs support is arranged.

Reviewed by: D. Prostredník, A. Sládek

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Toma Udiljak - Karlo Obrovac - Igor Ištef *

CAD/CAM SYSTÉM PRE OBLASŤ VÝROBY VÝSTELIEK DO TOPÁNOK

CAD/CAM SYSTEM FOR INSOLE PRODUCTION

Úchvatný pokrok v medicíne zvýšil požiadavky na vysoko výkonné počítačové systémy, ktoré by zabezpečili podporu na merania a vizualizáciu, s vysokým stupňom presnosti a vysokými požiadavkami kladenými na plánovacie činnosti a aplikácie špecifických lekárskych postupov. Ortopédia, ako jedna z oblastí medicíny, bola obohatená o nový prístup pri návrhu a aplikáciách protéz vo forme využitia CAD/CAM. Článok dáva prehľad o biomechanických vlastnostiach nohy, ktoré priamo predurčujú vlastnosti budúcej výstelky. Kvôli jednoznačnosti každej nohy, princíp univerzality, napr. masová výroba výsteliek do topánok, nedáva očakávané výsledky. A preto sa dáva prednosť výrobe výsteliek podľa klinického a pedobanografického nálezu jednotlivca. Článok predstavuje fázy výroby výsteliek použitím CAD/CAM. Opisuje vyvinutý CAD/CAM systém, umožňujúci účinnú koordináciu všetkých fáz výroby. Systém bol vyvinutý aplikovaním Open GL, Visual C++ a Visual Basic. Skladá sa z piatich modulov: databáza, modul na spracovávanie a prezentáciu zmeraných dát, modul na prezentáciu RTG obrázkov nôh, modul na modifikáciu a prispôsobenie štandardizovaných výsteliek a postprocesor.

Impressive strides in medicine enhanced a necessity for highly advanced computer systems which would provide measurement and visualization aids with a high degree of accuracy, and high standards for planning and application of specific medical procedures. Orthopaedy, as a medical branch, was enriched for a new approach in design and application of orthoses and prostheses, CAD/CAM. This paper gives an overview about biomechanical characteristics of the foot, which directly implies the features of the future insole. Because of the unity of each foot, the principle of universality, i.e. mass production of insoles, does not give the expected results. Therefore, the advantage is given to production of insoles according to the clinical and pedobarographic finding of the individual. The paper presents the phases in production of insoles by applying CAD/CAM. It describes the developed CAD/CAM system, enabling efficient interfacing of all production phases. The system is developed by applying Open GL, Visual C++ and Visual Basic. It consists of five modules: data base, module for processing and presentation of measured data, module for presentation of the foot RTG pictures, module for modification and adjustments of standardized insoles, and postprocessor.

1. Introduction

The human foot contains, within its relatively small size, 26 bones (the two feet contain a quarter of all the bones in the body), 33 joints, and a network of more than 100 tendons, muscles, and ligaments. It is a complex yet marvelous structure of living machinery, and is designed to transport us through life and provide us with the mobility to ensure our survival. Other than the heart, there is no other structure that takes a beating like the foot. Its strong, flexible, and functional design enables it to do its job well and without complaint. The foot is stuffed into a variety of dark and cramped spaces, forced to go places and distances it might not normally choose for itself. Relegated to the bottom of the totem pole, it hardly ever requires personal attention and sometimes is denied even personal hygiene, yet manages to "carry on". Yes, it's quite a structure and performs its "feats" of strength, and eventually falls prey to natural abuse. It is for all intent and purpose, a locomotive structure, capable of initial shock absorption, performing in most cases at least 8,000-10,000 times per day. There is a lot of moving parts, each working in conjunction with the rest of the system. Some feet have lots of available motion and others have little. Certainly, some feet work better than others and fall prey to fewer problems but, all feet are prone to normal wear and tear and depending on usage can be pushed to problems sooner. Everything starts as the foot makes its first contact to the ground (with the heel). Motion in the foot takes place in preparation of weight being transferred through the body and into the foot. As this process continues, two things happen 1) the arch of the foot moves towards the ground and 2) the muscles try to control the speed and depth at which the arch moves. Eventually, the arch falls as close to the ground as possible. At this very moment in time is when the foot is at its weakest, most unstable and vulnerable to the forces passing through (a bag of bones as it were). Every joint is twisted to the max, which in turn allows the body above to also move in correlation to this instability and vulnerability. The "soft tissue" (muscles, tendons, ligaments) are also

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straining because they too are being stretched and off their best "track". As this mechanical action repeats heat builds up (called inflammation). This marvel of engineering, however, is designed to perform this task, repeatedly in fact. The body will release endorphins to "cool" the heat build up, it will adjust the entire system if it recognizes a "pattern" of inefficiency. This adjustment may in time produce a recognizable inefficiency further promoting a "new" adjustment. Meanwhile heat continues to build and build until the system's endorphins can no longer manage the upper limits. Here then starts the process of trying to reverse the pain. Self-treatment, modern medicine, old world medicine, external devices, and maybe even prayer all methods used and abused to treat a "step in time"(3,4).

The foot can be divided into two anatomic portions: forefoot and rearfoot. The forefoot is composed of the bones and joints, located forward to the midtarsal joint. This includes the bones that help form the arch of the foot, the cuneiform bone, navicular, metatarsals, and the bones of the toes, the phalanges. The rearfoot is located underneath and posterior to the midtarsal joint, and is composed of the calcaneus and talus. The most important joints in the normal function of the foot during movement are the metatarsophalangeal joints of the forefoot and the subtalar joint of the rearfoot, which functions differently during certain portions of the gait cycle, at one point acting as a rigid level and at another time as a mobile adapter to the terrain. The soft tissue components of the foot include the muscles, tendons, ligaments, fascia, and fat pads, all of which have specific functions during standing and walking. The pull of the muscles and tendons produce joint movement, and the ligaments help provide stability between the bones. The plantar fat pad has two components: the heel fat pad and the fat pad beneath the heads of the metatarsal bones. Both act as cushions that distribute the pressure of the underlying bony structures to the weight-bearing surface (1, 2).

The gait cycle is divided into two phases: the swing and the stance phase. During the swing phase, the foot is completely off the ground and is preparing for heel-strike, which is the initiation of stance phase. The stance phase, which represents the weight-bearing phase, is divided into three periods: contact, midstance, and propulsion. The contact period begins with heel-strike, at which point the extremity receives weight to the rearfoot, and the vertical ground reactive forces are increased. During the midstance period, the vertical ground reactive forces are very decreased, and the body's weight is fully loaded on the foot in a static distribution, converting it from a mobile adapter to a rigid lever necessary to produce forward propulsion. The propulsive period begins with the heel lifting off the ground and continues with the weight excursion being carried across the hip and knee joints and developing into plantar flexion of the foot, and than the first toe lifts off the ground.

The highest plantar forces develop at the beginning of stance phase, when the heel strikes the ground, and at the end of the same period, when there is propulsion of the foot from the ground. An inability of the subtalar joint to absorb the shock produced by the heel-strike or of the forefoot to distribute the high forces required for propulsion can result in the development of high foot pressures, [1].

Figure 1. Measurement of foot pressure

2. Foot orthoses

The purpose of orthopedic insole is to reduce the feet pressure beneath the level that can cause biomechanical disturbances or lesion of foot tissue and to limit the total range of motion available to the foot as it coils to the ground (called "pronation"). Although just a small part of orthotics, the insoles are necessary for the orthotic shoes and for all other orthosis whose goal is to enable as adequate distribution of plantar pressures as possible, and to reduce those pressures beneath the level that can cause biomechanical disturbances or lesion of foot tissue.

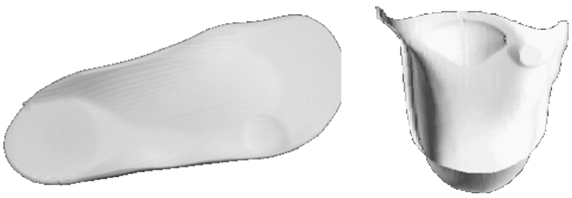

Figure 2. The samples of the insole

How really insole works? For proper answer it is necessary to look back in the time when the foot was not the only organ between the human and the ground. In those times foot also served as an organ for catching. From, so far, unknown reasons, few million years ago, our ancestors pass on the two-footed walking, and started the journey from Africa towards theirs and our today's homelands.

However, from the anthropological point of view, the period of few million years is not the period in which the morphological and functional feature of any organ could be so much changed that we could talk about complete adaptation on new conditions. Considering bipedal model of walking, the foot function is one of the youngest achievements of human kind. The foot becomes an organ that should simultaneously enable the carrying of body weight, propulsion of walking, and alleviation of the forces and stability of the whole body. The development of cognitive capabilities of our ancestors, initiate the development of foot protection what could be considered as early footwear. It helped them to do their duties longer, easier and in various weather conditions. The shoes became unavoidable article, and started to take over the basic foot function.

Unfortunately the development of shoes design was more influenced with fashion, and less with biomechanical needs, what resulted in some negative tends (present even today), especially in design of ladies shoes.

With development of civilization, almost all urban surfaces are hard covered what significantly increase the forces acting on the foot. The static foot hardships, except those caused by disease or genetically determined, became pandemic problem. As an answer on the foot pains, the first orthosis, that had the most characteristics of today's insoles, was designed at the beginning of this century. Even without enough knowledge about foot stresses, and by using the method of trial and error, it enabled the walking with far less symptomathology. It is also the time when the first scientific papers about static of the normal foot and distinction between normal and abnormal were published. Some of the theories were defined, that are valid even today. Such one is TRIPOD theory that says that the foot relies on the ground in three points that are mutually connected with arcs. Although the TRIPOD theory has a lot of opponent, there is still no firm proof that can dispute this theory. There are also some attempts to realize the devices that could measure the forces between the foot and ground. First measuring devices were very innovative, but simple and with poor reliability and accuracy. Optical pedobarography was a significant improvement, but the treatment of individual patient and design and production of custom made insoles, was enabled with development of CAD/CAM and contemporary measuring devices with needed level of reliability and accuracy. The measuring of plantar

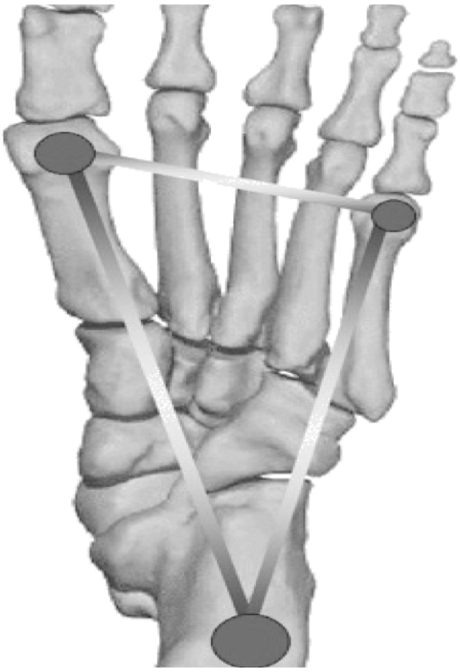

Figure 3. The TRIPOD theory

pressures proof to be very important for the persons with disturbed sensing system (5).

In Western societies, the main cause of the insensate foot is diabetes mellitus, while in poor Far East countries is Hansen's disease. The other conditions in which studying of plantar pressure distribution might be helpful include rheumatoid arthritis, sports medicine, orthopaedics, and pathologic changes of foot shape elicited by biomechanical abnormalities.

The components of feet work together, sharing the tremendous pressures of daily living. An average day of walking, for example, brings a force equal to several hundred tons to bear on the feet. This helps explain why feet are more subject to injury than any other part of body.

Foot ailments are among the most common of our health problems. Although some can be traced to heredity, many stem from the cumulative impact of a lifetime of abuse and neglect. Studies show that 75 percent of Americans experience foot problems of a greater or lesser degree of seriousness at some time in their lives; nowhere near that many seek medical treatment, apparently because they mistakenly believe that discomfort and pain are normal and expectable.

Pronation is a series of motions in the foot designed to absorb shock and prepare the foot to propel us forward. Pronation begins when the heel hits the ground. Pronation reaches its maximum when the whole foot is on the ground and has gone through its entire range of motion. It is at this moment, when the foot is stretched to the maximum, that the breakdown process begins. Running compounds this by stretching even further. Inflammation (biomechanical inflammation) and structural breakdown (e.g. bunions) begins to accumulate through life of walking and running. This repeated stretching and trauma builds upon itself eventually become INJURY. We are not all affected the same way. Some of us develop arch or heel pain (plantar fasciitis), some develop unstable ankles, some develop runners knee and of course many other symptoms can develop especially low back or hip pain resulting from a "functional shortage" (5).

A variety of factors dependent on time and trauma dictate how we will respond to "biomechanical malalignment" (which we know as pronation problems). We all have biomechanical malalignment, a human machine designed to break down over time. Each of us is vulnerable to the "natural condition" of our own biomechanics.

Most prescription orthoses do this. In fact many non-prescription supports do it too. However, the closer the orthoses is to the individuals own functional prescription, the more comfortable it will be to get used to, to wear, and above all else produce results. Foot orthoses unfortunately do not offer an instant resolution. Some people do respond quickly, although this is the minority. Some people are more complex for whatever reason and they may take up to six months to begin to respond favorably. The majority of people feel a 40-60 % minimum average improvement in their symptoms within 8 weeks; (this is not the same as being cured). As time continues it is possible to feel like progress has stopped or that the pain is coming back. As you wear the orthoses you begin to absorb the prescription so you may start to feel the residual inflammation and tension temporarily. If orthoses are comfortable and you are able to wear them most of the time they are working.

The healing of biomechanical inflammation takes time. It can take 1-2 years for an orthoses to generate its maximum effective range of healing. As foot flexibility increases, the optimal position of alignment will change (due to reduction in tension and inflammation). Then regardless of your symptoms you need to get another prescription in order to keep your feet and body working to their best efficiency. If your orthoses work correctly you can expect 2-3 changes in your lifetime. Most of these changes should occur in the first to the second year. The next change should be very gradual over the next 4-6 years. After that changes may or may not occur. If they do it will take a long time.

So to clarify is there an orthoses so ideal as to prevent foot problems it. Depends on what problems we are looking to prevent. If we are looking to prevent injuries from inadequate training, excessive distances, increasing mileage too quickly, anatomical or functional abnormalities, accidental sprains or strains, uneven surfaces, and aging, probably not. But if there are biomechanical reasons for something to eventually happen e.g. structural (like a bunion or heel spur), then it is possible to, at least, slow down the process and possibly prevent this from occurring enough to not let it be a problem in your lifetime.

Research in the field of gait analysis and orthotic function has become an area of great interest as computer generated gait analysis.

2.1 Overview of Foot Pressure Measurement System

Of the greatest importance in insole design is introducing in foot static condition on which the orthosis will be applied. It has been a long way from pioneer works of Beely to the today state-of-art and in-shoe pressure measuring devices that show plantar pressure distributions. Such devices have provided that thousands of diabetic and neuropathic patients walk today almost without risk of plantar ulceration development.

Force, or ground-reactive force, is defined as the total or net load acting on the foot against the supporting surface, and pressure measures the amount of force applied over a unit of area and is calculated by dividing the total force by the area on which it is applied. There is no homogeneous distribution of the pressure under the foot, especially during walking when high forces are developed under certain areas of the foot. In healthy subjects these high forces can easily be distributed in large areas of the foot, and this is the main reason that body weight and the size of the foot do not relate to foot pressures and are usually not high. In pathologic conditions, inability to distribute high forces is one of the first noticed abnormalities and leads to the development of high foot pressures.

2.2 The Methods for measurement of the forces and pressure

There are a number of methods for force and pressure measurement. One of the possibilities to classify measuring methods is following:

- *semiquantitative* - a number of measuring methods could be classified in this group. They extend from earliest methods back in 1882, up to the methods that relay on application of video cameras. Some of the methods and devices are still used in clinics. The major limitation of these methods is impossibility to give the quantitative data on both, the force and pressure distribution.
- *quantitative* - the application of quantitative methods started at the beginning of 70-ties. They enabled to establish the relationships between some foot diseases and plantar foot pressures (for example the relationship between body weight, plantar foot pressures, and foot ulceration in diabetic patients). It was a big stimulus for further improvement in insole design and production.
- *optical pedobarograph* - this is a method for measurement of dynamic plantar pressure. This system has high spatial resolution, which allows the accurate measurement of high foot pressures under small areas of the foot with satisfactory repeatability and reliability. The optical pedobarograph has been used widely in the study of diabetic foot problems. The main disadvantage of this system is that it is limited to measurements of pressures of bare feet and does not allow the evaluation of in-shoe pressure (7).
- *computer-assisted foot pressure measurements* - developments in computer technology over the last two decades have enabled the development of microprocessor-like recording systems that can measure in-shoe foot pressures. Some of the most known systems are: EDG System, EMED System (Novel Electronics which yields an accuracy of ± 5-10 %), the F-Scan System (Tekscan), [7], etc.

Today is possible to measure plantar pressures with high accuracy, and that is the base of computer design of orthopaedic insoles and other orthoses.

According to acquired cognition about static and dynamical foot stresses and their connection with foot topography and most frequent foot diseases, orthopedic insole could significantly improve the distribution of foot pressures. Generally speaking, the insole could be of big importance for pain relief caused by disease or genetically determined difficulties. In certain circumstances the insole could even be successfully used to make some corrections in the musclosceletal system of human, which otherwise could cause a serious consequences for human health. So far applied technologies for insole production could not fulfill the expectations, while the whole process was quite dependent on the skill of orthotist. Feedback information on insole quality was mostly verbal. It was not possible to analyse the effects of little smaller or little bigger modifications on insole, because repeatability was minor, and experiments, considering technology for insole production, were very expensive and unreliable. The application of computers and new technologies has enabled the new approach to insole production.

3. CAD/CAM System for design and manufacturing of insoles

The application of computers and new technologies has enabled the new approach to insole production. The efficient insole design could help in pain relief caused by disease or genetically determined difficulties. Repeatability, desired modifications and even production are no more big obstacles for experimental work. The whole procedure is more determined, the skill of orthotist is no more of vital importance, because it could be "algorithmisied" and transferred into the software for public use. The new possibilities for establishing models of pressure distribution, new methods of numerical analysis could be applied, and insole production is very much supported by engineering knowledges.

3.1 Design of CAD/CAM system

The goal of CAD/CAM system is to provide the means for qualitative, fast and inexpensive manufacturing of insole [8]. During clinical checkup, the physician establishes the foot problems and defines the way to solve them. CAD/CAM system should be able to offer to the physician and orthotist the "tools" for converting the standard insole (template) or the foot casting into the insole that will be response for achieving the wanted effects. The developed CAD/CAM system, figure 4, consists of three modules:

- Input module
- Module for modification and final adjustments
- Postprocessor

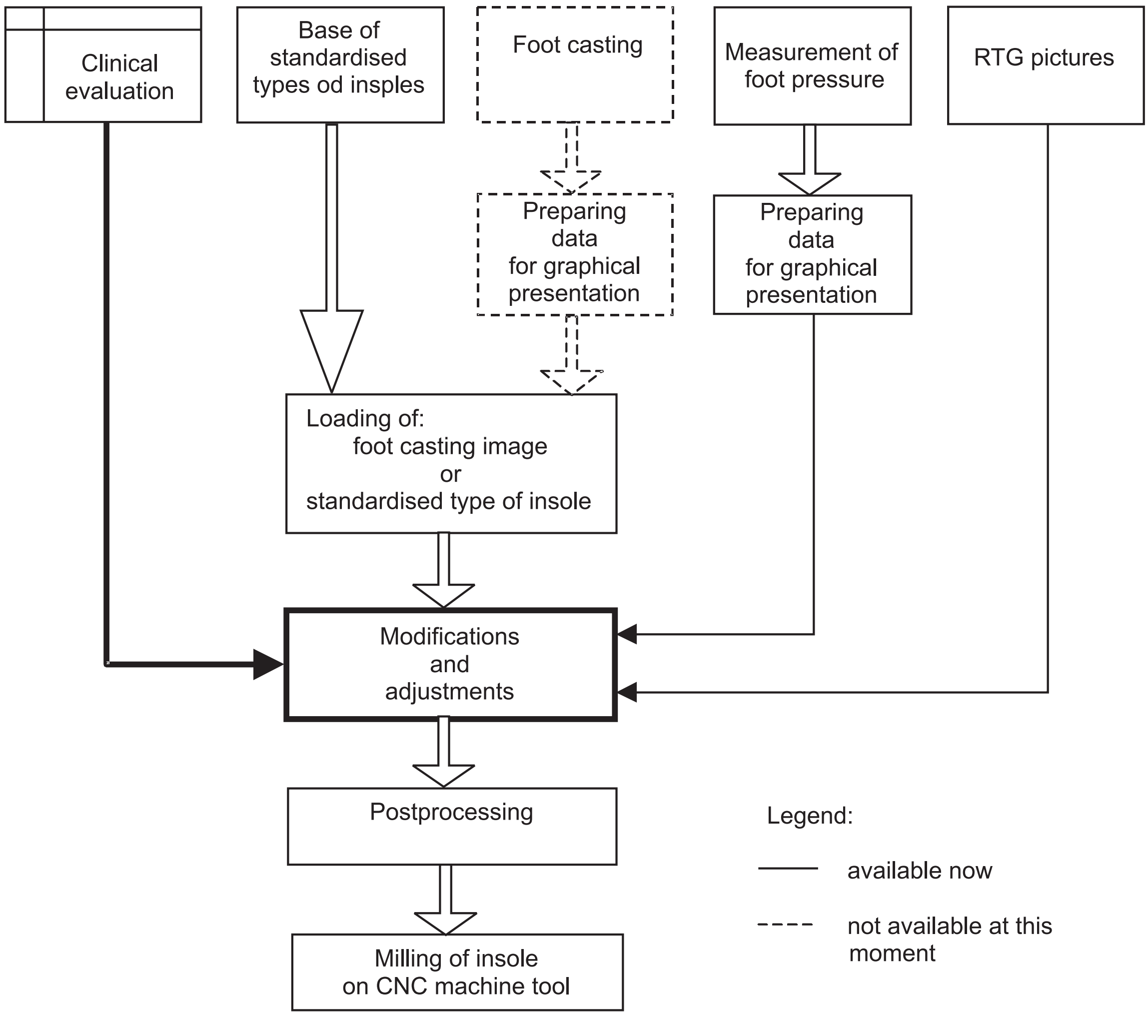

Figure 4. The phases in insole design and manufacturing

The input module of CAD/CAM system is capable of loading and graphically presents the data from foot casting, the data for standardized types of the insoles (templates), and data from the plantar pressures measuring device, Fig. 5. Some foot diseases and deformations could not be properly treated without RTG pictures. The module enables various manipulation of the images, like moving, rotating, different kind of presentation (point, surfaces, lines), depending on the designer, who can also decide to remove the picture from the screen.

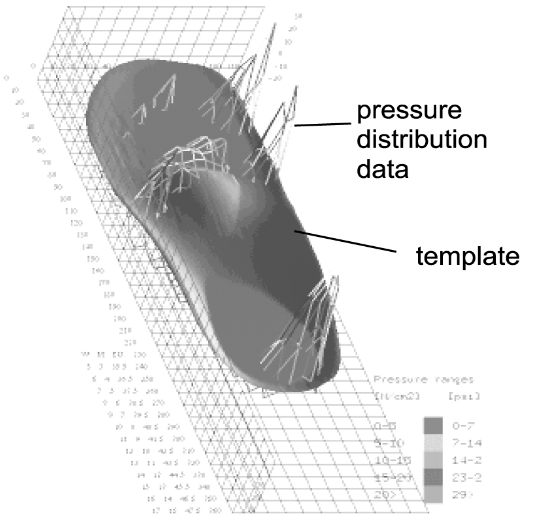

Figure 5. The pressure distribution data mapped over the template

The data from measuring platform and clinical checkup are basis for physician decisions on the shape and magnitude of necessary modifications of the template (standardized type of insole).

Fig. 6. The subroutines and functions in edit mode

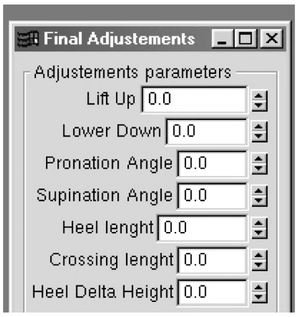

Fig. 7. The subroutines and functions in submodule final adjustment

The next module is module for modifications and adjustments of standardized insoles. It consists of two sub modules: edit mode and final adjustments, figures 6 and 7. Each submodule consists of number of subroutines defining different possibilities for design and modification of insole. The most of the subroutines in edit mode and final adjustments use 3D-bspline function. The parameters enable the user to change the degree of bspline function (curvature) and to change the effective with, i.e. the width of the area connecting affected and unaffected area. The subroutines in the submodule final adjustment are developed for final modification of insoles, like heal design, supination, pronation, lift up of insole or lower down of complete insole, Fig. 7. Depends on the designer (physician or orthotist) selection, the system enables any combination of images to be displayed at the same time, Fig. 8, in order to make the insole design as easier and more efficient.

The postprocessor module converts the data of redesigned insole into the commands for CNC milling machine. The generated code could be checked on the screen, before it is downloaded in the controller of the CNC machine tool, Fig. 9. The postprocessor can generate the code for machining of the insole upper surface, and code for machining the contour. Presently, the generated cutting motions are directed along Y-axis (longitudinal axis of insole), Fig. 9.

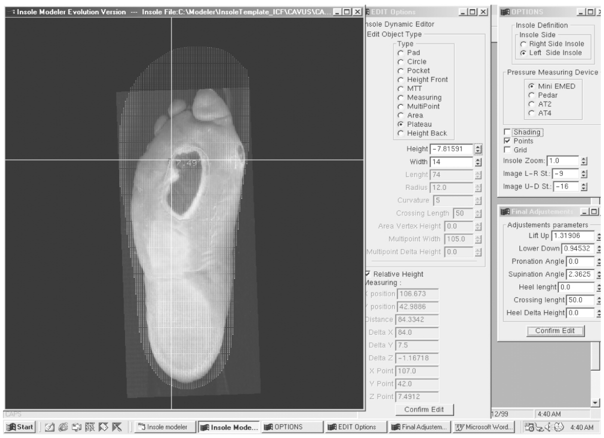

Figure 8. Application of function PLATEAU for designing "valley" bellow the ulcers projection in order to reduce or eliminate the pressure and pain

Finally, as a part of CAD/CAM system there is database module. It is difficult to imagine serious medicine based software without presence of database. In this case database provides to the end user appropriate review of all previously examined patients, both their clinical findings and results of different exams (Rx, pressure data, IR data etc.).

It is possible to add data, erase, seek, update and make a query. In database there is field for storing vectorised graphic files of the designed insoles. Any other module from the Insole modeler can be started, by simple mouse click on appropriate field (e.g. by clicking on pressure data automatically design program is loaded). Database can be viewed as a form or as a table and data may be sorted in different directions. For database programming Visual Basic 6.0 programming language have been used.

The next phase will include the module for processing of foot scan images, what could be used for persons that do not need the physician checkup, i.e. for the production of so called comfortable insoles. The next research project will investigate the possibility for developing a software module that will be able to automatically

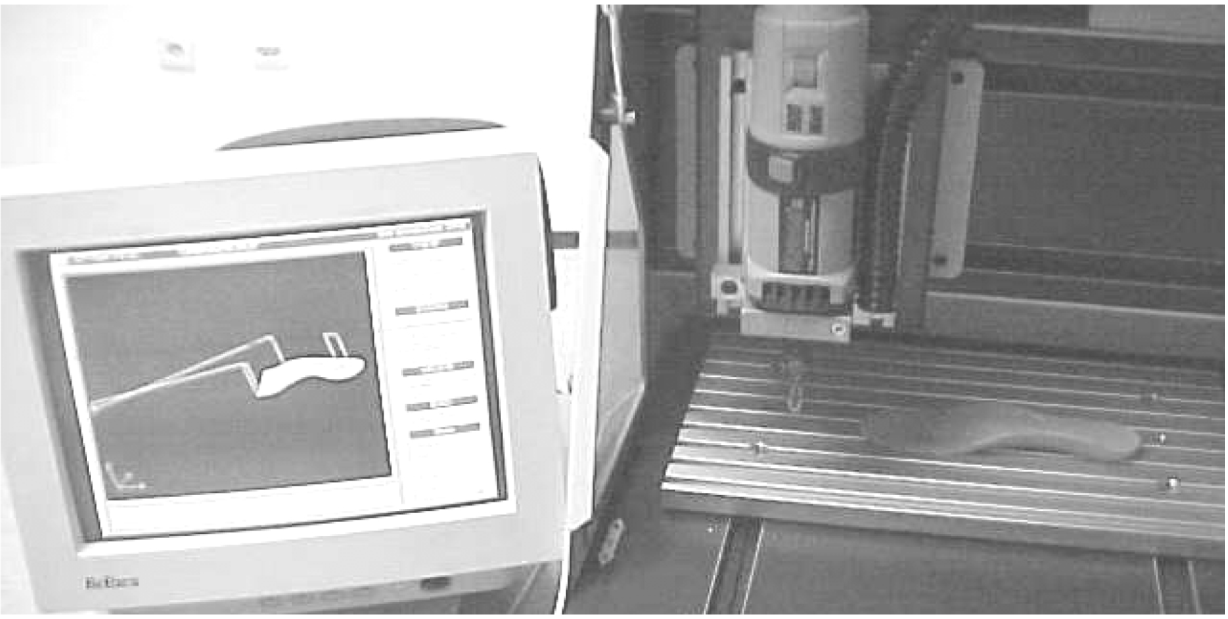

Figure 9. Simulation of cutting tool path generated with postprocessor

recognize a number of foot disease and deformities, and propose the solution. Diagnostic part of module would be based on pattern recognition techniques, while the "healing" part would be an expert system.

4. Conclusion

The application of CAD/CAM in prosthetics and orthotics is relatively new and offers a lot of possibilities and challenges. The advantages, when compared with conventional insole production, are numerous: repeatability, accuracy, easy modification, smaller production time, and possibility to keep a track on insole efficiency. It is predictable that such systems will advance in stress analysis, definition of mathematical and logical connections between foot abnormalities and necessary modifications, same as in the material optimization for the different areas and modifications elements of insole. It is also to expect that new manufacturing technologies as rapid prototyping [9], and new data processing techniques as expert system and artificial intelligence, will contribute to insole production. Although strictly individual, insole production could reach much higher level of efficiency and automatisation.

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TRIBOLOGICKÉ VLASTNOSTI NANÁŠANÝCH VRSTIEV TUHÝCH MAZÍV OVEROVANÉ V ATMOSFÉRE A VO VÁKUU

TRIBOLOGICAL BEHAVIOR OF BONDED SOLID LUBRICANT FILM IN AIR AND IN VACUUM

Trecie testy inorganicky viazaných kompozitných vrstiev tuhých mazív (WS_2, grafit, BN) boli uskutočnené v laboratórnych podmienkach v atmosfére a vo vákuu v rozsahu 10^{-4} Pa.

Stopy opotrebenia a prenos vrstiev boli vyšetrované rastrovacím elektronovým mikroskopom a Augerovou elektronovou spektroskopiou.

Z experimentálnych výsledkov vyplýva, že pre testy uskutočnené v atmosfére v laboratórnych podmienkach si dominantné postavenie zachovávajú vrstvy grafitové. Vo vákuu má rozhodujúci vplyv WS_2 vrstva. Počas zmien z atmosféry na vákuum a opačne, kompozitné vrstvy preukázali lepšie trecie charakteristiky vo vákuu ako v atmosfére.

The friction tests of inorganic bonded composite solid lubricant films (WS_2, graphite, BN) were performed in laboratory air and in 10^{-4} Pa vacuum. The wear traces and transfer films were characterized by scanning electron microscopy (SEM), and Auger electron spectroscopy (AES). Experimental results suggest that when friction tests were conducted in air, graphite plays a governing role, while in vacuum WS_2 plays a governing role. In case of changing atmosphere from air to vacuum or from vacuum to air, the composite film showed better friction behaviors in vacuum than in air.

1. Introduction

Hexagonal boron nitride, graphite, molybdenum disulfide and tungsten disulfide belong to lamella solid lubricants. The crystal structures of these solid lubricants are such that while the atoms lying on the same layer are closely packed and strongly bonded to each other, the layers themselves are relatively far apart and the bond between them, e.g., van der Waals, are weak. When these lamella solid lubricants are present between sliding surfaces, these layers can align themselves parallel to the direction of relative motion and slide over one another with relative ease, thus providing low friction[1]. In addition, strong interatomic bonding and pack in each layer is thought to help reduce wear damage [2 - 4].

Many studies indicate that environment can strongly affect these solid lubricants. For example, graphite and boron nitride were found to lubricate better in humid environments than in dry environments; whereas MoS_2 and WS_2, were found to lubricate better in dry and in vacuum environment [5 - 6]. In recent years some experiments have been conducted to evaluate the synergistic effect of different kinds of lubricants. For example, the composite film of boron nitride and graphite could provide adequate lubrication from room temperature to 800 °C in air. While at low temperature graphite can provide lubrication, BN does so over 500 °C, graphite gets oxidized at high temperature [7].

It was also found that the addition of graphite to bonded MoS_2 film could enhance wear life of such films in air [8]. Moreover there are other composite lubricants comprising of MoS_2 and other synergistic agents, which show lower friction coefficient than those containing MoS_2 alone [9 - 11]. But for various solid lubricants the tribological mechanisms are not clear as detailed.

The major objective of this study is therefore to understand the friction mechanisms of solid lubricant composites in different environments. In this work, the solid lubricant WS_2 which is more stable and has better oxidation resistance than MoS_2 [12 - 13], BN and graphite (1:1:1), which are reported to have synergistic effects [7] were employed having ratios of WS_2: BN: graphite as 1:1:1.

Mica and sodium silicate are used as inorganic binder to avoid reaction between the binder and solid lubricants.

2. Experimental procedures

Friction tests were performed in a ball-on disk configuration. The ball 3 mm in diameter is made of high carbon chromium steel (SUJ-2) and disk 26 mm in diameter is made of stainless steel (SUS304). In order to increase the adherence of solid lubricant films, the surface of disk was abraded with No. 220 alumina sand blast. Then the solid lubricant film was formed with 50 % solid

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lubricant (WS_2, BN, graphite individual and composite with ratio of WS_2: BN: graphite as 1:1:1), 50 % inorganic bonded (mica: $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$, sodium silicate: $Na_2O \cdot 3.1SiO_2 \cdot xH_2O$), dried at 250 °C for 90 minutes in air. After the treatment the thickness of the film was about 15 μm.

The apparatus used in this investigation is shown schematically in Fig. 1. The evacuating system is consisted of an oil-sealed rotary pump and turbo pump. Three steel balls were buried in the tip of the slider and rotated co-axially on the disk. The disk was mounted on gimbals so that the balls could be rotated with the same load and set into the same orbit. The diameter of rotation was 20 mm, and the speed of rotation was controlled to 9 mm/sec. The load was 1.8 N (0.6 N each ball). The friction force was measured by strain gauge attached to the leaf spring. For wear life test in air as well as in vacuum, the apparatus was set up in such a way that as soon as friction abrupt increased the test was terminated. This condition signaled metal-to-metal (between the substrate of disk and the ball) contact due to solid lubricant film breakdown.

In case of friction test in vacuum, the chamber was subjected to vacuum to 10^{-4} Pa for six hours before the actual start of the experiment. For composite film the tests were conducted in alternate sequence (vacuum/air or air/vacuum) of 500 cycles for each environment with a maximum of 4 changes(4 hours). The relative humidity of the environment was approximately 60 - 75 % in air.

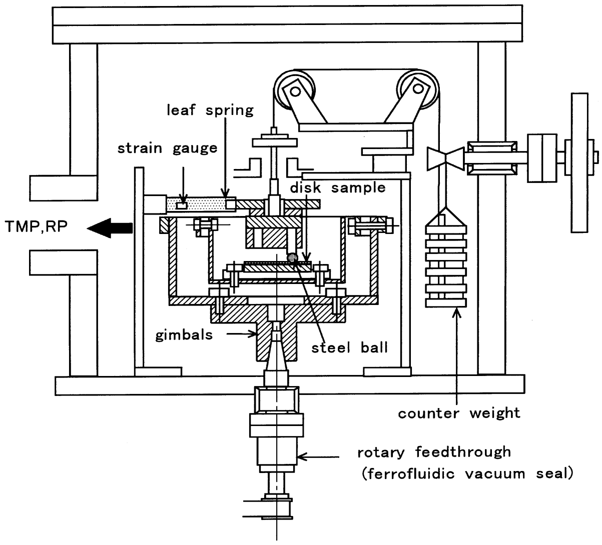

Fig. 1

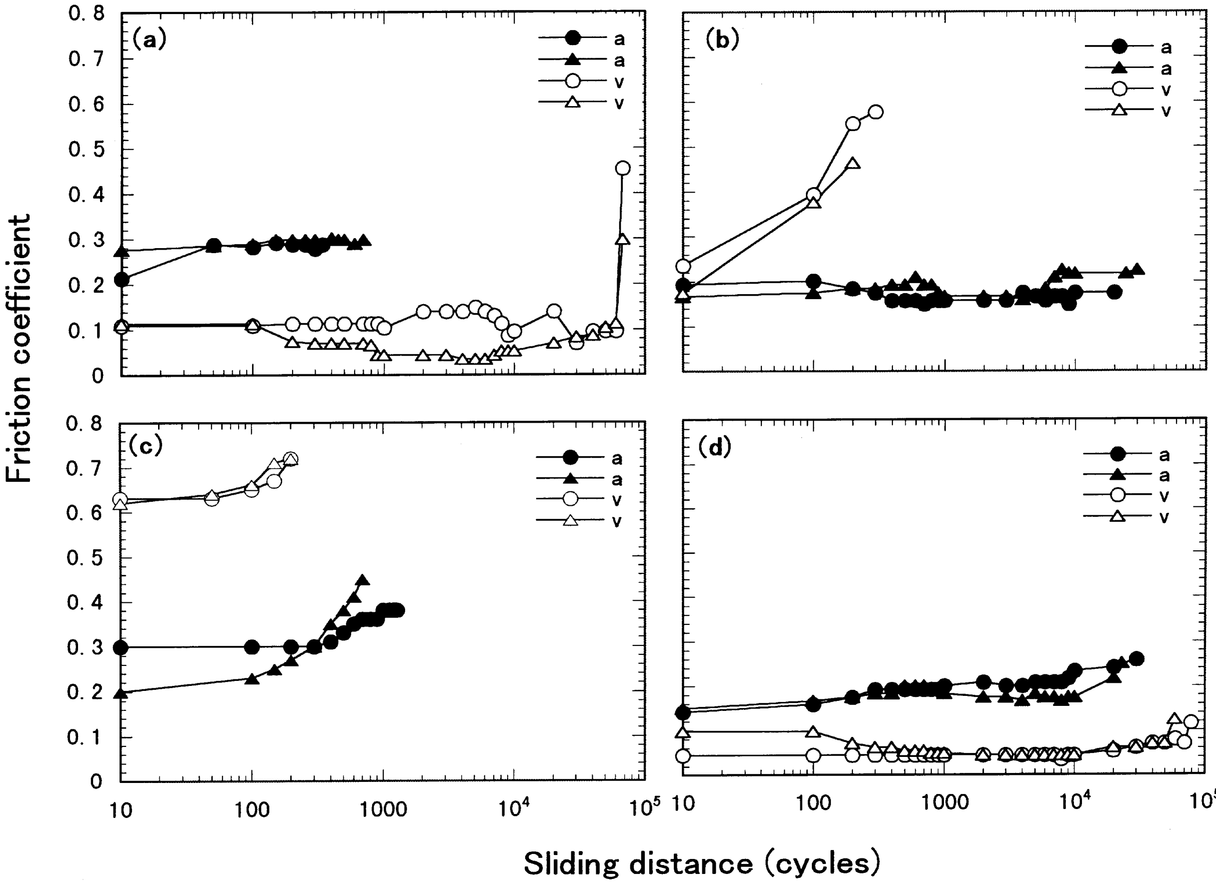

Fig. 2

3. Experimental results

Figure 2 shows the sliding distance versus friction coefficient in air and in vacuum for individual or composite films. In each case, at least two measurements were made. It can be seen that: (a) The friction coefficient for WS_2 film was about 0.1 in vacuum and about 0.3 in air. The endurance life is also affected by environment and though the film lasts for 68000 cycles in vacuum, it was less than 750 cycles in air. (b) Graphite film shows low friction coefficient about 0.2 in air with an endurance life of 25000-30000 cycles. In vacuum, however, the friction coefficient increased at quite an early stage from 0.2 to 0.6 and the endurance life was less than 250 cycles. (c) For BN film, the friction coefficient was 0.6 in vacuum and 0.2-0.3 in air, but in both environments the endurance life were less than 1000cycles. (d) For composite film, the friction coefficient was 0.06 in vacuum and 0.2 in air, the endurance life reached 59000-70000 cycles in vacuum and 23000-37000 cycles in air. Thus the composite films showed nearly the same friction behaviors as graphite in air, and WS_2 in vacuum.

4. Effects of environment on friction coefficient of composite film

Figures 3 and 4 shows the friction coefficient and surface component of wear traces for disk sample obtained by the friction test of composite films. As shown in Figure 3 (a), from a friction coefficient about 0.08 in vacuum, it increased to about 0.19 in air. Then it decreased to about 0.13 on the successive test in vacuum. This value of 0.13 in vacuum, however, is a little higher than that one obtained in vacuum only. And then it again increased to about 0.19 in the following test in air.

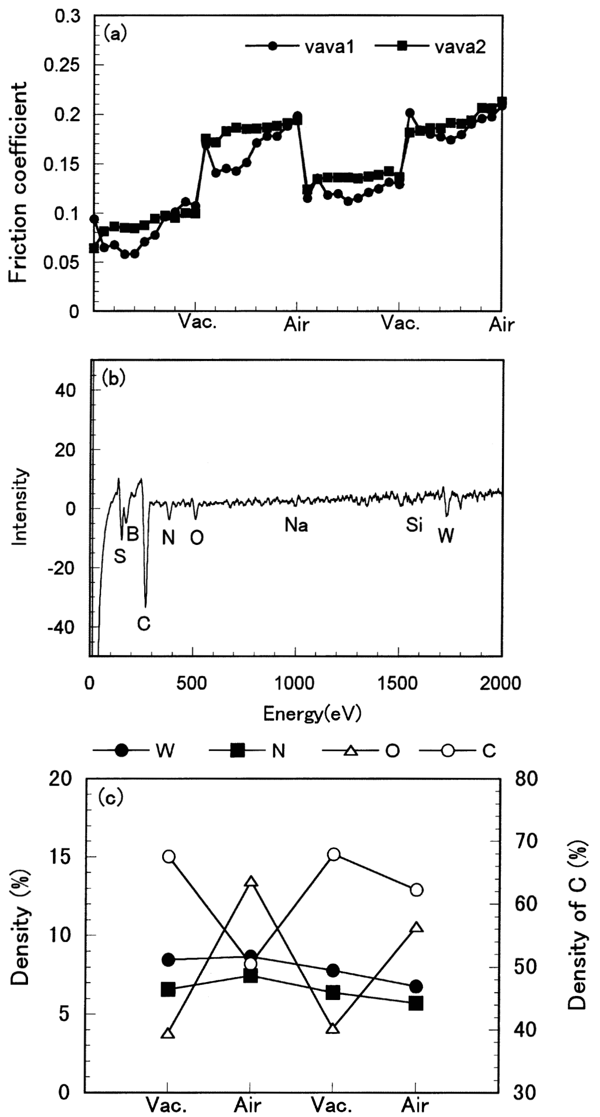

Fig. 3

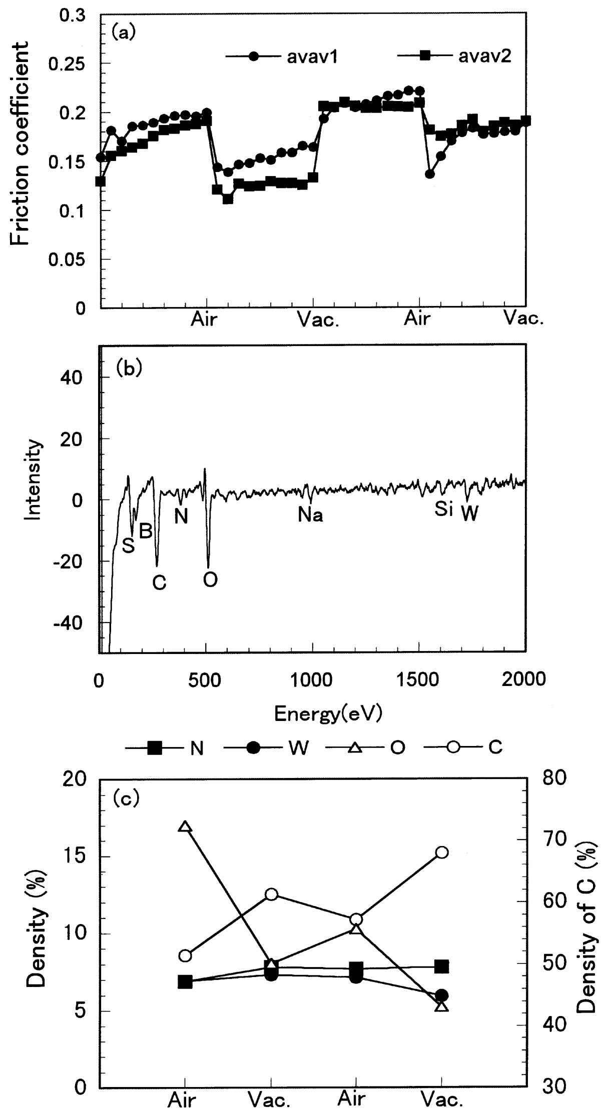

Fig. 4

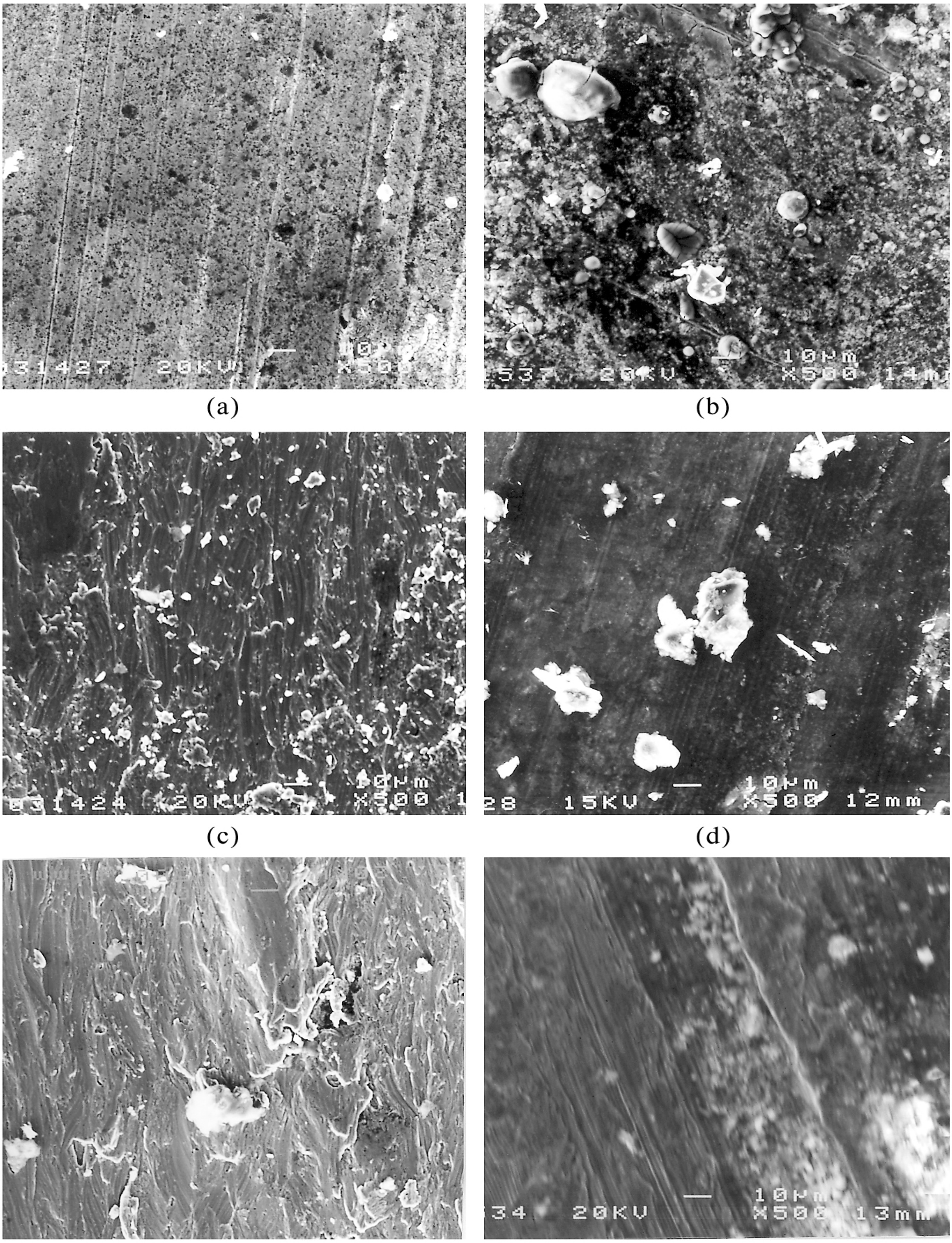

Fig. 5

Figure 3 (b), (c) shows the AES spectra and the results of quantitative analysis with relative inverse sensitivity for wear trace on various environments. Because the signals Na and Si are fuzzy like background, and the interference between the signals of S and B makes the amounts of these atoms unclear, the signals of N, C, and W show that all kinds of lubricants BN, graphite and WS_2. The density of oxygen and carbon were affected strongly by environment and it is interesting that the density of carbon was higher on the sliding surface tested in vacuum than that tested in air.

Figure 4 shows the results obtained by the friction test beginning in air. The changing tendency of friction coefficient and the density of oxygen and carbon on the wear trace are similar to that shown in Figure 3. The friction coefficient in vacuum also increases after the test in air, and the density of carbon increases after friction test in vacuum.

5. Sliding surface of composite films

Figure 5 shows typical topographic features of wear traces, which were taken from the individual film after friction test shown in Figure 2 (a), (b), (c). Only wear traces for WS_2 sliding in vacuum and graphite sliding in air formed tenacious films as shown in Figure 5 (a), (d), which prevent gross metal contact and provide long endurance life. The wear trace for WS_2 sliding in air is patch and has some cracks as shown in Figure 5 (b). The wear traces for graphite sliding in vacuum and BN in both environments are very rough as shown in Figure 5 (c), (e), (f), which present the metal to metal contact due to partial or complete removal of lubricant film.

Figure 6 shows typical topographic features of wear traces, which were taken from the composite films after the friction tests

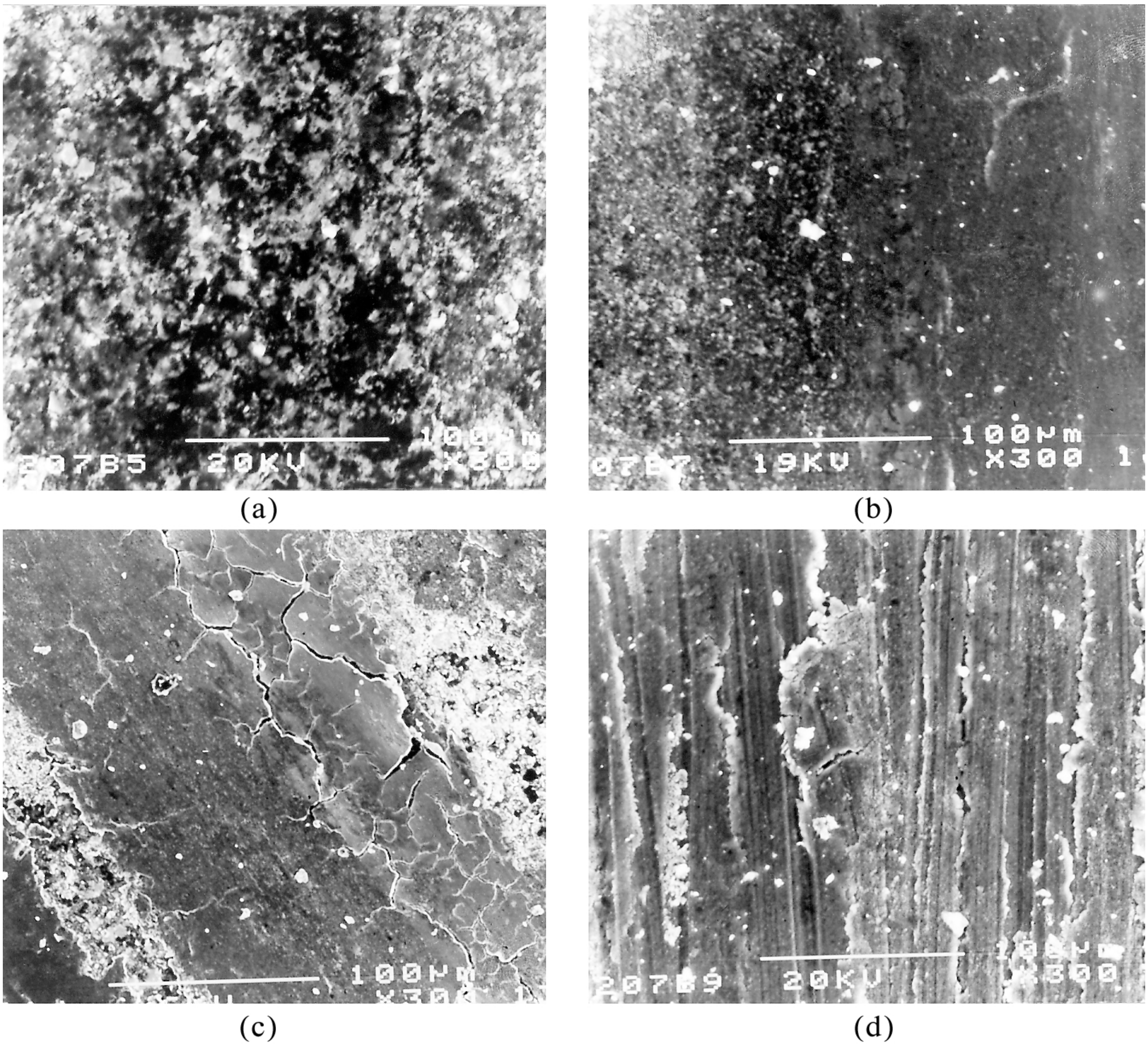

Fig. 6

shown in Figure 3, 4. Figure 6 (a) shows the wear trace of composite film after testing in vacuum only. This sliding surface is rough and looks like it's made from the cluster of powder. Figure 6 (b) shows the wear trace, which has undergone friction test in vacuum, air, vacuum, air. Though the friction coefficient of this film was higher than that of the film tested only in vacuum, the sliding surface is quite smooth. This result means that the surface roughness of wear trace is not directly related with its friction coefficient. Figure 6 (c) shows the wear trace of composite film after testing only in air. Though some cracks can be seen on the sliding surface, the greater part of sliding area is smoother than the one sliding only in vacuum. Figure 6 (d) shows the wear trace, which has undergone friction test in air, vacuum, air, vacuum. The sliding surface is smooth in comparison with the wear trace obtained by test in vacuum only. But it is rougher than the sliding surface obtained by the friction in air, while the friction coefficient is high.

6. Sliding surface of steel balls

Figure 7 shows the AES spectra for adhesive films on steel ball after sliding in air and in vacuum. It can be seen that tungsten disulphide, boron nitride and graphite adhere to the surface of steel balls both in vacuum and air atmosphere, which can prevent metal contact and get low friction coefficient and long endurance life for composite film. The high intensity of W atom means that the WS2 film mainly transferred on the surface of steel ball in vacuum as shown in Figure 7 (a). Comparing with Figure 7 (a), the intensity of Fe increased and W decreased as shown in Figure 7 (b). The high intensity of Fe means that the thickness of lubricant film transferred on the sliding surface of ball is thin. The low intensity of W means that does not only WS_2 plays an important role in air.

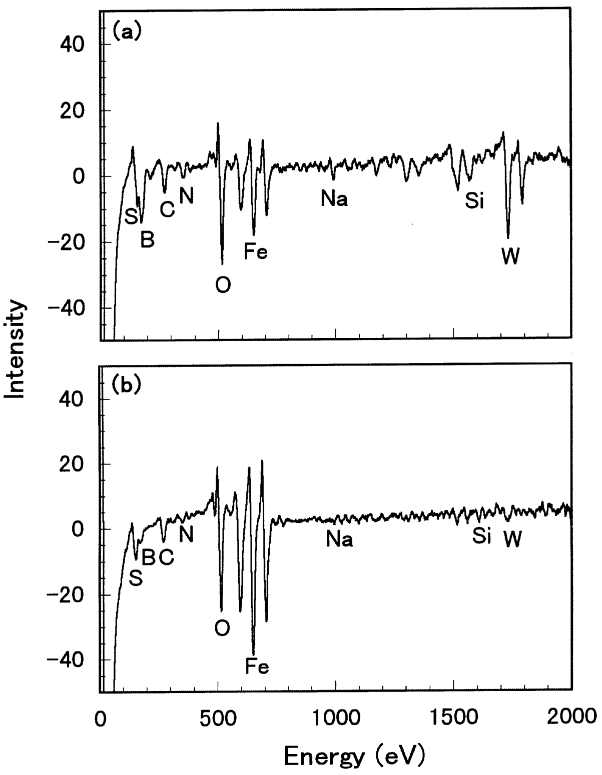

Fig. 7

7. Discussion

It is widely accepted that a good lubricant must have two important characteristics, shearing and adhering. Shearing can provide low friction, which is often explained by the basal-slip on intrinsic cleavage mechanism for lamella solid lubricants. For graphite and BN the adsorbed gases are responsible for the low friction, because the basal face of graphite has a low surface energy, the edges are highly active and react with gases and water in air, which decrease the surface energy of edges allowing sliding on basal face [13 - 18]. On the other hand, MoS_2 and WS_2 provide low friction in vacuum, and dry environment, because in humid environments the MoS_2 or WS_2 react with the oxygen or water and promote corrosion of metals by forming layers of oxysulphide according to following reaction [19]:

$$2WS_2 + 7O_2 + 2H_2O \rightarrow 2WO_2 \cdot SO_2 + 2H_2SO_4$$

$$2WS_2 + 7O_2 \rightarrow 2WO_3 + 4SO_2$$

In vacuum graphite exhibits a relatively high friction coefficient, in air the friction coefficient drops to 0.2, however, in contrast to graphite, the friction characteristics of WS_2 improve in vacuum as shown in Figure 2.

Adhering can provide long endurance life, because effective lubrication of metal surfaces depends on the existence of a layer lubricant, which prevents gross metal contact [20]. For this reason, BN is not a good lubricant either in vacuum or in air. Its adherence to the surface of steel ball to be lubricated is poor.

It is suggested that bonded with sodium silicate the lubricant powders were dispersed in composite film. Under the effect of perpendicular and shear forces, mica deformed and oriented nearly parallel to the surface of friction and lubricants were sheared [21]. In case of vacuum, WS_2 easy shear and easy form transfer film on the steel ball. WS_2 layer will attain low friction coefficient and low wear rate. Graphite and BN may be considered as unoriented polycrystalline mass for which the face-edge interaction is important [22]. Furthermore graphite debris piled up in front of steel ball. With the sliding the piled up graphite debris were pressured onto the wear trace of composite film. For this reason the wear trace of disk looks like a cluster of powder (Figure 6 (a)) and remains a lager of C (Figure 3 (c)). It is possible that graphite and BN powder decreased the real contact area where WS_2 is lubricating in vacuum. This may be the reason why composite film showed lower friction coefficient than WS_2 film only. By contrast, because WS_2 and graphite have nearly the same friction coefficients in air, both WS_2 and graphite shear in friction test. But WS_2 easily reacts with moisture and oxygen in surrounding environment to form WO_3 and sulphur compounds. The adherence to the steel ball is not good as in vacuum. With the increasing of friction force, the shearing not only takes place in the surface layer of graphite and WS_2, but also conduct mica to deform and let sodium silicate fracture. For this reason, the wear trace of disk looks smoothly and some cracks can be seen on wear trace of disk in air. Because WS_2 covered only the real contact area and the other area of graphite powder was laid uncovered, the concentration of C on wear trace was lower than that tested in vacuum where only WS_2 sheared.

Where the test was carried out in vacuum after in air, the friction coefficient was a little higher than the obtained by the test in vacuum only as shown in Figure 3 (a). In this case as graphite, WS_2, and BN shear together, and high forces of shearing let sodium silicate break down. The sodium silicate debris may become obstacle of the shearing of WS_2.

The endurance life of the composite film was similar to WS_2 film in vacuum and to graphite film in air. This is also explained as the friction of composite film was governed by the shearing of WS_2 in vacuum and by the shearing of graphite in air.

8. Conclusions

1. It is observed that the graphite, WS_2 and BN composite film showed the friction behavior, which resembles WS_2 and graphite in vacuum or in air respectively.
2. In changing from air to vacuum or from vacuum to air conditions, the composite film showed better friction behavior in vacuum than in air.

9. Acknowledgments

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METODOLÓGIA VÝVOJA APLIKÁCIÍ STEP/EXPRESS PRE OBLASŤ NAVRHOVANIA TECHNOLOGICKÝCH POSTUPOV

METHODOLOGY FOR THE DEVELOPMENT OF STEP/EXPRESS APPLICATIONS IN THE AREA OF PROCESS PLANNING

Článok sa zaoberá výskumom týkajúcim sa vývoja generickej metodológie, ktorá umožňuje interakciu modelov založených na STEP/EXPRESS a nástrojov na špecifické aplikácie navrhovania technologických postupov.

The paper deals with the research related to the development of a generic methodology which enables the interaction of STEP/EXPRESS based models, and tools for specific applications in the area of process planning.

1. Introduction

In order to develop a CAPP application, the main problem is to develop a system for extracting CAD information that can be used by the process planning application. At present, the current CAD systems are AutoCad, PRO//Engineer, and CATIA that run on different hardware systems such as PC and graphical workstations. There are many widely used methods for extracting information from solid models. Two of the most commonly used techinques are *C*onstructive *S*olid *G*eometry *(CSG)* and *B*oundary *Rep*resentation *(B-Rep)* modelling. These representations are complete and unambiguous, and represent an object in 3D space. However, solid modellers do not link low level geometric and topological entities with the tehnological information necessary to CAPP systems. Some of the currently available CAPP systems that use solid modelling techniques require extra information to be added manually.

Research has been focused on the aspects of feature modelling, feature extraction and feature refinement, using solid modelling as a basis to create/extract the feature data and knowledge.

Since the creation of the *ST*andard for the *E*xchange of *P*roduct Model Data (STEP, ISO 10303), a new methodology for the development of CAPP systems could be approached. ISO 10303 is an international standard to provide an unambiguous representation and exchange mechanism of computer-interpretable product information throughout the life cycle of a product [1]. The standard aims at being generic and it is a framework for representing information, and knowledge, and exchanging/sharing this information. Also, it is an ***Open Data Standard*** that gives the user back the control of his data. The first released version of STEP has been operational since 1994.

2. Overview of STEP and EXPRESS

STEP can be defined as a neutral product model data exchange mechanism that is capable of representing product, and it is intended to be informationally complete for all engineering applications. STEP is organized by three layers: application, logical and physical [1].

The *application layer* develops some models specific to applications.

The *logical layer* uses *EXPRESS, EXPRESS-G* (the graphical subset of the EXPRESS) and *EXPRESS-X,* which are data descriptive languages developed in order to define entities and their relationships and to describe the models physically implemented by a schema.

The *physical layer* provides data structures to meet data sharing and communication needs.

2.1. STEP - Fundamental Concepts

- Application protocols:
  The specification of an application context and the data constructs that are required for product data exchange. Therefore, an application protocol is the specification of the product-

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related data constructs, which are supported according to the implementation methods.

- Integrated resources:
  The application-context-independent data constructs which constitute the minimal set of entities that are used by all application protocols.

- Description methods:
  Common mechanism for the specification of data constructs of ISO 10303.

- Implementation methods:
  Standard implementation techniques for the information structures defined in the application protocols.

Step Components Table 1.

Part 1	Overview and fundamental principles
Part 11	Description methods: EXPRESS language
Part 21	Implementation methods: clear text encoding of the exchange structure
Part 31	Conformance testing: general concept
Part 41	Integrated generic resources: fundamentals of product structure configuration
Part 42	Integrated generic resources: geometric and topological representation
Part 43	Integrated generic resources: representation structure
Part 44	Integrated generic resources: product structure configuration
Part 46	Integrated generic resources: visual presentation
Part 101	Integrated application resources: draughting
Part 201	Application protocol: explicit draughting
Part 203	Application protocol: configuration controlled design

- Abstract test suites:
  Provide data used to test the conformance of a given implementation of ISO 10303.

2.2. STEP - General Organization and generic product models

According to the fundamental concepts, the current version of the standard is formed by the components presented within table 1.

Based on the fundamental concepts the generic product model has been developed as it is described in detail within reference [1]. The model has been designed and implemented using the integrated resources of STEP.

It consists of generic entities which are well defined by the EXPRESS language in STEP [1]. Generally, a product model called also a generic product model (GPM) can be adapted for any applications. Furthermore, GPM provides a complete product description according to STEP. The product models can be used to integrate different software systems.

2.3. Some Aspects regarding EXPRESS Language

The development of STEP required a method of modelling the information relationships that should facilitate the task of data transfer and storage. The EXPRESS information modelling language has been developed and it is used throughout the STEP standard.

EXPRESS is a complex language when taken as a whole. However, a lot of it is quite simple and once the fundamentals have been mastered, the difficult parts fall into place. The fundamentals are as follows:
- SCHEMA represents a wrapper for collections of related information;
- ENTITY is the logical definition of an object which represents a real world object;
- ATTRIBUTE defines the property of an object;
- TYPE is the representation of value domains;
- RULE defines handling of full and partial constraints.

Other aspects of EXPRESS include:
CONSTANT FUNCTION
PROCEDURE executable
STATEMENT

Programming in EXPRESS language is based on the definition of SCHEMA and all the declarations must occur within a schema. EXPRESS-G allows a graphical representation of schema.

EXPRESS-X specifies the conversion of information from one structure to another. The conversion is defined as mapping.

The EXPRESS language can be used outside the STEP standard.

3. Development of STEP/EXPRESS Applications

The research regarding the definition of a unified methodology for the development of applications in the area of process planning is directed to investigate the following aspects:
- Complex structures defined within the EXPRESS environment are very difficult to understand unless deep knowledge of the structure has been achieved. Application programming using STEP/EXPRESS tools is, therefore, a specialized task. The problems are: *how to extract, manipulate and use the information included in the physical files used to transfer the product information.*

- The main direction could be the creating of specific programs to interact with the information using probably one of the many EXPRESS tools available on the market (National Institute of Standards and Technology and/or PDES/STEP Tools Inc.'s) Using these tools, the EXPRESS schema for the Application model is converted into an appropriate language which should be used to manipulate the Physical File information.

- EXPRESS language is a relatively Object-oriented language, and the schemas could be translated into C++, CLOS, Smalltalk. Depending on the toolkit the information is either stored interactively within the computer or uses an object-oriented language.

- In some situations the software developer should need to know what information structures and entities are defined within the EXPRESS schema. This problem is then doubled if a further schema is also required to be accessed within the application. It is envisaged that some form of generic tool should be required to query the physical files allowing non-EXPRESS users to develop applications that utilize the physical file information. This tool would be built upon one of the available EXPRESS toolkits employing an Object-Oriented programming language and using an X-based graphics toolkit for extra data input/output. The tool would be graphically and icon driven using a pseudo EXPRESS-G structure to allow non-EXPRESS users to visualize and access various physical file information constructs. Also, the tool would allow mathematical manipulation of information, checking of the physical files to make sure that required entities for the application are present, development of windows for input and output of relevant data, the creation of new physical files for use in other applications and allow for queries of more than one physical file at any time.

- Due to the way the NIST toolkit has been written, it is essential to know which schemas will be required within a certain application. Once the schema libraries have been written, the compilation of the EXPRESS-G Query Program can go ahead. This will allow the access to the schema structures as required as well as access to the physical files of the schemas.

- The application program itself should be a combination of C++ standard functions with the NIST toolkit functions.

- The STEP standard only defines the data required for Product Data. Several applications such as Process Planning require Manufacturing Data. A provision has been made within the STEP standard but it is limited to passing the title of the operation as well as a text description of the process.The Manufacturing data that is required is purely based on the resources available within most factories: for example machines, both computer controlled and manual, robots, flexible manufacturing cells, assembly processes, for example welding, gluing etc, as well as people. Each of these resources has various limitations. In the case of machines, some of the limitations are: size of raw material, component that can be machined safely, surface finish capability (related for both tool type and the speeds and feeds of machining) and machining tolerances (for example parallelism, cylindricity, perpendicularity, etc.) It is, therefore, envisaged that the EXPRESS-data modelling language to be used in order to develop a manufacturing resource model for including costs, possible tolerance limitations, features which can be manufactured, etc., which would enhance the functionality of the STEP environment.

- Assuming some forms of STEP data in the required form is available, how to use the Application program created in conjunction with the CAD system to allow an integrated CAD/CAPP/CAM system to be developed. Using a CAD system that uses features as a basis for developing solid models initially, it will be necessary to convert the data stored into STEP data conforming to the required parts of the standard.

- Some form of STEP data in the required form is available. Application program created in conjunction with the CAD system allows developing an integrated CAD/CAPP/CAM system. Using a CAD system that uses features as a basis for developing solid models initially, it will be necessary to convert the data stored into STEP data conforming to the required parts of the standard.

- Exchange product knowledge between different hardware/software systems in order to create a distributed process planning system which could use the Internet environment to communicate.

- Within the STEP standard the dynamic data exchange could be defined. However, a real progress in dynamic data exchange and communication has been made by VRML (Virtual Reality Modelling Language) that creates the background for the development of collaborative engineering systems

4. Conclusions

Several STEP/EXPRESS applications are still under research, and in the development phase.

Some projects supervised by the National Institute of Standards and Technolgy are presented at http://www.mel.nist.gov/div826/msid/sima/projectmap.html.

Other useful Internet addresses are as follows:
http://ts.nist.gov/ts/htdocs/210/216/216.htm
http://www.prostep.darmstadt.gmd.de
http://www.steptools.com
http://www.epmtech.jotne.com/learn/index.html
http://bbbsr1.bau.tu- dresden.de/sphinx/anonymous/card/STEP
http: //wwwcib.bau.tu-dresden.de/~rainer

Based on the development and research directions presented in the paper it is possible to use STEP/EXPRESS within a practical framework such as a process planning application. However, a unified and generic methodology for STEP/EXPRESS applications is still under research and there are a lot of tools commercially available in order to build applications. Further research will approach in detail the development and the implementation of STEP/EXPRESS process planning applications based on the methodology outlined this paper.

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PROBLÉMY VÝMENY INFORMÁCIÍ MEDZI MODULMI NA 3D MODELOVANIE A NAVRHOVANIE TECHNOLOGICKÝCH POSTUPOV

INFORMATION EXCHANGE PROBLEMS BETWEEN 3D MODELLING AND PROCESS PLANNING MODULES

Cieľom tohto projektu je vyvinúť nástroj komunikácie medzi 3D CAD a navrhovaním technologických postupov. Sú prezentované doterajšie výsledky: (i) Prenos CAD dátového modelu a iných informácií o výrobku z 3D CAD systému (Solid Edge) do databázového modulu, (ii) modul na klasifikovanie prvkov a súčiastky. Tento prístup je založený na STEP technológii s cieľom definovania počítačom podporovaných nástrojov na štruktúrovanie dát a menežovanie vedomostí o výrobku implementovaných v relačných databázach. Problémy opisu prvkov a súčiastky predstavujú kritickú časť. Prvkové modelovanie pre 3D návrhové činnosti patrí k najefektívnejším prístupom. Pre rozličné oblasti použitia sú predstavené rôzne prvky (konštrukčné, technologické, nástrojové prvky a pod.). V tejto oblasti nebola dosiahnutá dohoda a používané termíny často nie sú jasné pre užívateľov. V článku je podaný preto krátky úvod riešenia horeuvedených problémov.

The objective of this project is to develop a tool for communication between 3D CAD and process planning. Our accomplishments so far have been: (i) Transfer of the CAD data model and other product information from the 3D CAD system (Solid Edge) to a database module, (ii) the part/detail and feature classification module. The approach is based on STEP technology to define computer-aided tools for data structuring and management of product knowledge implemented on the relational database. Problems of part and form feature description play a crucial role in this framework. In 3D modelling Form Feature (FF) based design activities are the most effective approach. A number of FF definitions have been introduced for different implementations (design features, manufacturing features, tool features etc). However, the consensus in the field has not been reached and often the terms used are not clear for the users. In the present paper a short introduction is given to solve the afore described problems.

1. Introduction

Manufacturing of tomorrow will be digital information driven. Effective utilisation of manufacturing information and knowledge will be a key issue for manufacturers of all kinds of products. There is a strong need in the industry to have a standard for the digital representation of manufacturing systems and the integrated design and manufacturing environment as well. Such a standard will enable sharing data from different vendors of components to be integrated into a consistent model of the product or the manufacturing system being designed (Fig.1).

2. Background

Most industrial companies today use a large number of computer applications in their product realisation processes. A large amount of data/information about the product is created and used individually by different engineering applications during the product lifecycle (Fig. 2). Much of this information is common for all applications and could be shared but it is not shareable today. As a consequence, the creation and support of this data/information is currently time and cost consuming.

Process planning and production planning for manufacturing processes are still most times two distinct sequential off-line activities. Process plans are ordered sequences of tasks able to transform raw material to a final part or product. Tasks are chosen taking into account available or potential production means. Production planners receive process plans as their input and a task is to schedule the tasks on the machines while respecting the precedence relations given in the process plans. However, decisions made at the process planning stage, e.g., selection of machines, selection of task sequence, constrain the available choices for optimisation on the subsequent production-planning phase. On the other hand, process planning and scheduling may have contra dictionary objectives, such as required technology versus resource usage. As such, process planning forms the link between design and manufacturing. The tools and processes available in a given shop greatly influence the way in which designers and manufacturers view a part and the way in which they decompose it into machinable volumes, or features. By

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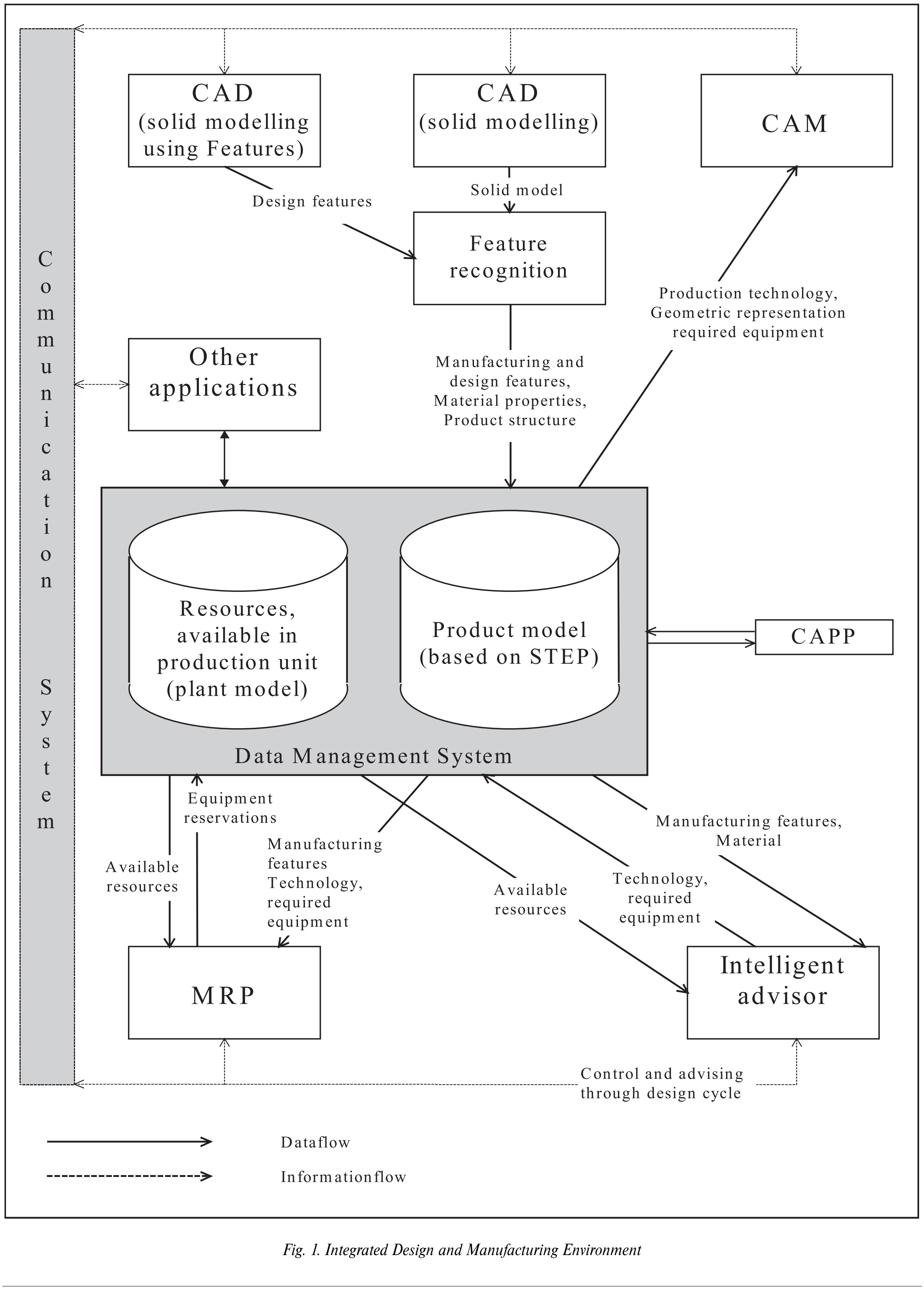

Fig. 1. Integrated Design and Manufacturing Environment

introducing features as primitive for representing product lifecycle aspects, the efficiency of modelling product database can be improved considerably.

3. Product information modelling

Most up-to-date CAD tools are developed for representing the geometry of components. However, information about geometrical component (feature) e.g. holes, pockets etc. and their relationships, tolerances, surface finish, etc. is missing in the geometric data models. This information is essential for manufacturing planning process, and therefore, the representation of features at the design stage is significant for the integration of CAX system. A Feature information in CAM includes most of the design data stored in the CAD system. Therefore most of the feature data in design system can be directly transferred to the manufacturing data model. The other problem is feature classification. There is no consensus by now in the field, so different variations of feature definition exist.

One of the most significant approach today in product modelling is the development of ISO 10303 [ISO 10303-1] standard called STEP (Standard for Exchange of product model data) which defines models, database access and neutral data file format for representation and exchange of product data (Julian Fowler). One task of the entire project is to ascertain the efficiency of STEP standard (AP203, AP244) for describing features. For this task, now well known data modelling language EXPRESS has been used. In the later phase for data exchange between applications two methods could be used, via neutral file (*.stp) or via the STEP database interface SDAI (Simple Database Access Interface) using commercial tool from Steptools Products - ST-ORACLE (Goh. 1994).

4. Implementation

Manufacturing planning systems need to extract feature-based component information from CAD systems both accurately and efficiently. Currently, there are two main approaches to obtain feature information automatically from CAD systems, i.e. feature recognition and design by features (Mäntylä, 1994), (Salomons, 1993), (Gao, 1991), (Joshi, 1988). With the first approach, features are recognised from a Boundary Representation (Brep) or a Set-Theoretic model of a component via a processor or feature recogniser. Technological information about the features (the manufacturing implications for example) has to be added after the recognition process. The problem with this approach is that the recogniser can become very complicated as more complex features are to be identified, and there may be some features which cannot be recognised. With the second approach, features

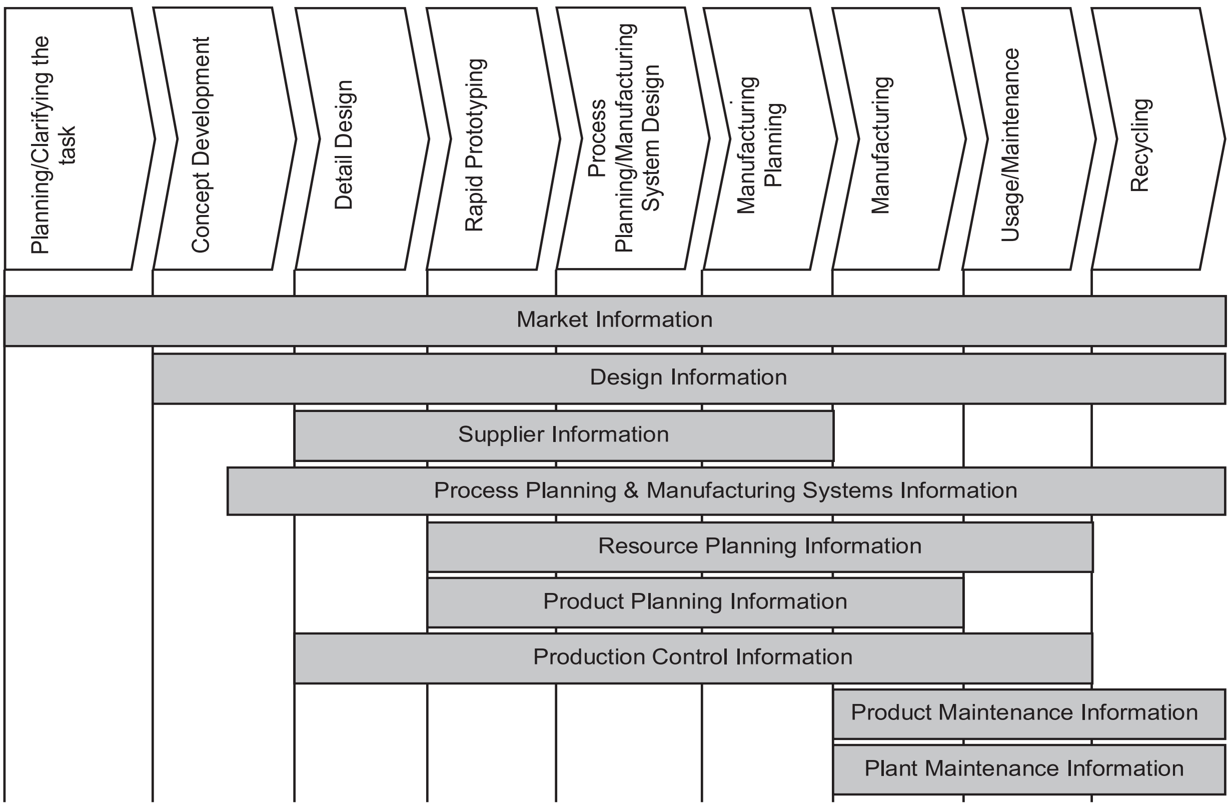

Fig. 2 Information needed during the product life cycle

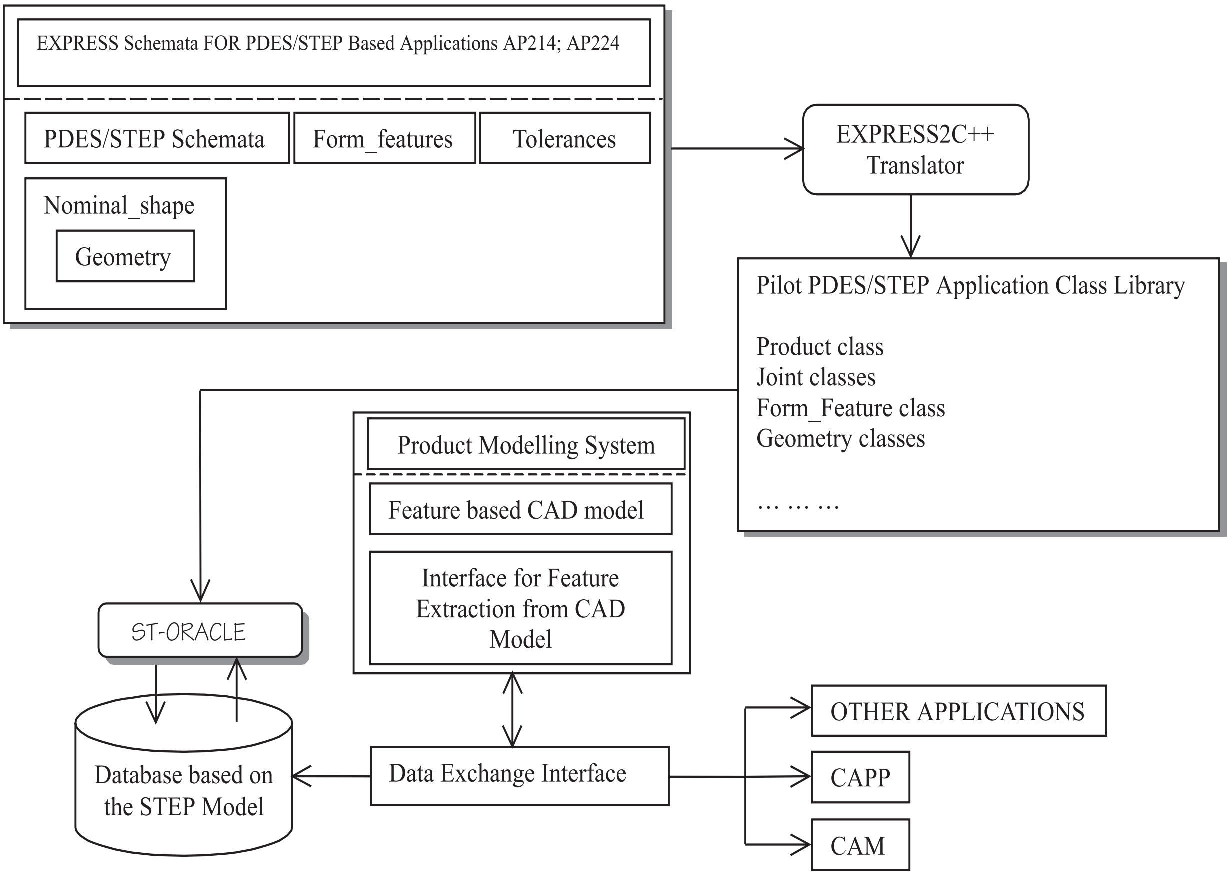

Fig. 3. Communications bus between 3D modelling and process planning

can be recognised directly from the model in a runtime mode. In our work we are using the second approach. After the recognition process the extracted data will be stored in to the database using a data exchange interface. Our prototype runs under MS Windows and uses a standard computer.

To manage the data we use relational database ORACLE V7 (Fig. 3). As mentioned before for converting EXPRESS entities in to relational database we use commercial tool - ST-ORACLE.

4 How to consider features on the planning stage

Briefly about our consideration related to form features. FFs are mainly considered as pure geometrical forms.

Actually, more information is needed for engineering activities. So, the FF-specific attributes are needed. According to J. Shah four requirements the feature should at least fulfil, are:

- It has to be a physical constituent of a part;
- It ought to be mappable to a generic shape;
- It should have engineering significance;
- It must have predictable properties.

Hence FF is defined as:

$$FF: = FF(X_f(I), \Delta_f(I), Q(I)), \quad (1)$$

where $X_f(I)$ is dimensions of the FF, $\Delta_f(I)$ is tolerances of FF, and $Q(I)$ is quality data of FF.

The set of FFs on the part has to be defined by their mutual location, hence the FFs interface has to be defined.

$$FF - interface: = FF(x(i), \Delta(i), R(i)) \quad (2),$$

where $x(i)$ - dimensions, $\Delta(i)$ - tolerances, $R(i)$ - rules to complete the part.

FF can be simple or complex. To complete the complex FF the interface is needed as well as to define location of it on the part. Beside this, *temporary FFs* are used, for instance, centre holes for machining if the designer has not foreseen these and they would be excluded from the ready part.

How to gain the part condition defined by the designer depends on the skills of the process planner and manufacturer. If FF (in the sense of design feature) for particular part is defined quite clearly, then the manufacturing feature can have multiple contents. Different experience of a process planner, different tools and machine tools to be used etc.

The difference between design features and process planning features has been indicated and it can be considered as multiple view problems (principle of the FF forming). But sometimes the difference is caused by different consideration of the feature meaning (manufacturing feature - geometrical form with production information). As an example, a tool-feature, set-up-feature and a machine-feature are introduced by (Deneux 95). Such approach is not convenient from the point of view of heuristic planning.

No manufacturing specific information is explicitly present in the form feature description. The manufacturing information will be retrieved from the geometrical representation of component alone taking into account constraints in the form of FF attributes. So, actually we can speak about the *design features and activity oriented computational features* during the product life cycle. The main objective of the manufacturing process is to gain the product in its different stages with predicted quality in a very wide sense. There is a lot of ways for this depending on the process planner's experience, knowledge, manufacturing environment etc. Predefined terms with different meaning are the main source of problems by data exchange between different modules. As consequence, the intermediate stages of parts and FFs as derivations from design FF have been used in our activities.

So, the initial blank's form and dimensions will be defined by "backward chaining" - from the finishing tool with needed set-off to roughing tool. As rule, the result depends on lot size and possible tool set for the present FF, as well as on the planner's experience.

During the activities toward the manufacturing, FF has to be considered as a physical constituent of a part. To machine the hole in a shaft one possible set of tools is possible, but the same hole in the body can be machined by another set of tools. This underlines the fact that pure tool-feature is not quite clear from the point of view of manufacturing planning activities.

Instead of using the term "quality feature" the specific bill of rules for the quality definition of a particular part is needed. Information for the quality control activities will be extracted from the design FF's semantics in the form and content as needed.

From our point of view such an approach enables to eliminate diversity of terms and create an opportunity to derive the needed information for particular application

5. Conclusion

By letting the computer applications have a common description of the manufacturing resources, in an information model described in computer interpretable format, we can minimise the time and money spent on data exchange problems. Such a problem solving support strongly the virtual manufacturing as well.

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KOMUNIKÁCIE COMMUNICATIONS

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THE ROCK ISLAND LINE JE POZORUHODNE PEKNOU TRAŤOU

THE ROCK ISLAND LINE IS A MIGHTY FINE LINE

Výskum informačných a komunikačných technológií má tendenciu byť ovládaný perspektívami technologického determinizmu a teóriami sociálneho formovania. Bola vyvinutá teória sietí založená na požiadavkách účastníkov, ako alternatívny prístup pre pochopenie a interpretáciu sociálno-technických zmien. Bola použitá pri veľkom množstve technológií a zvykla sa používať na preskúmanie, ako technológia konštruuje a je konštruovaná rozličnými tretími nezúčastnenými skupinami a ako spoločnosti podporujú svoje záujmy publikovaním textov a riadiace orgány „zmocnením sa kontroly" nad technologickým pokrokom (Bowker, 1992). Tento článok využíva účastnícko-sieťovú teóriu, aby sa preskúmalo, ako sa vplyvní činitelia v procese sociálnej zmeny pokúšajú stabilizovať sily vo svoj vlastný prospech. Spôsobom analógie s rapídnym vývojom globálnej komunikačnej infraštruktúry pre káblové, telefónne, PC, TV služby a podobne, sa článok zameriava na najvýznamnejší vývoj komunikačnej infraštruktúry počas 19. storočia - železnice, a to hlavne na úlohu tejto technológie v otváraní amerického západu.

Research into information and communication technologies tends to be dominated by the perspectives of technological determinism and theories of social shaping. Actor-network theory has emerged as an alternative approach for understanding and interpreting sociotechnical change. It has been applied to a wide variety of technologies and been used to explore how technology both constructs and is constructed by different stakeholder groups and how companies promote their interests through published texts and the courts to "seize control" of technological developments (Bowker, 1992). This article borrows from actor-network theory in order to explore how influential actors in the process of social change attempt to stabilise forces to their own advantage. By way of analogy with the rapid development of a global communication infrastructure for cable, telephone, PC, TV services etc., the article focuses on the most significant development in the communication infrastructure during the nineteenth century - railways, and in particular on the role of this technology in the opening up of the American West.

Actor-network theory (ANT) rejects the deterministic notion that technology is the cause of social change. It prefers instead a view that sees "technology, the social world, and the course of history as rather messy contingencies". (Bijker & Law, 1992, p. 8) Technological development needs to be understood in the context of developing patterns or networks of a complex set of heterogeneous elements, which conventionally we conceive of as separate, such as the technical, the social and the "natural". From this standpoint, a question that might be asked is how it happens that technologies are able to achieve some kind of stability at particular times and "why it is that they take the form they do, rather than some other shape". (Bijker and Law, 1992, p.8)

Recent work into the development of the cable industry in Scotland has used actor-network theory in order to identify critical events that have influenced the construction of the UK market for Household Information Systems (Somerville, 1997). Such an approach recognises a range of stakeholders and actors (e.g. companies, government departments, published texts such as annual reports, social groups, consumer organisations, stock dealings, standardisation bodies, regulators, on-line systems and software). A crucial objective of this study has been to show how various actors attempt to create stability amidst turbulence and uncertainty.

I propose to tell a narrative about a parallel communication and information network that emerged in the last century - the railway. More specifically, I would like to offer some thoughts on how it ever came to pass in the United States that that there developed such a configuration of rail tracks as could be conceived of as a "system". From a deterministic perspective, the railroads were part of an inevitable process that would "develop" and "civilise" the American hinterland and establish coherence and order across the United States from East to West. According to this version of history a communication network would unfold as if with a pre-programmed utilitarian purpose. See, for example, Smith and Marx's discussion (1994, pp. 9-11) of how the railroads were represented as part of an iconography of progress. Thus, it would appear that technology was bound up intrinsically with manifest destiny and had the power to tame deserts and wildernesses and to convert savages: "wherever the iron horse travels, he will carry, not only the rich production of our soil, but our laws, our liberty, and our religion". (Meinig, 1993, p. 348) From another point of view, the nineteenth century texts that aggrandised the numerous railroad projects with their rhetoric of progress, expansionism, prosperity and advance of the nation were another element of a complex set of actor-network relationships. Through their propaganda, their advertising, their descriptions in the press and the speeches made about them, the railroads came to be what they

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were. In other words, they were constructed by the hacks, the PR men and scribblers hired by railroad companies and newspapers as much as by the navvies who physically laid the tracks.

Before pursuing this, though, something more might be said to justify the claim that railroad history offers an insightful analogy for thinking about contemporary developments in communication and information technologies. "The pace of change", "globalisation", "space/time compression" - all are part of the rhetoric used to describe contemporary life and warn of a future in which information technologies will revolutionise society beyond recognition. It is a happy coincidence that at the time of writing BBC Radio 4 is running a serial about the impact of the telegraph in the nineteenth century, entitled "The Victorian Internet". A salutary lesson to be learnt is that there is nothing especially original about many of the afflictions that we ascribe to current use of the internet. When the telegraph was introduced into the USA there were problems of access, ownership and monopoly, security, and conflicts between the needs of business and domestic consumers (Duboff, 1983). The telegraph opened up new possibilities for espionage and warfare; so significant was it in the field of journalism that it inspired newspaper titles. There were online romances and there is even a record of an online marriage in 1876 (Standage, 1999).

In the mid-nineteenth century the interdependent industries of the telegraph, railroads and the press provided the infrastructure needed for the emergence of major corporations and the development of revolutionary new managerial systems (Duboff, 1982). In their own era they were implicated in change on a scale that was unimaginable only a few decades earlier. With news able to travel in seconds rather than weeks there was a form of globalisation and space/time compression, or "annihilation of space by time", as Marx called it (Marx, 1858, p.524). Standage (1999) describes the process whereby we imagine that our own generation is "poised on the very cusp of history" as "chronocentricity": "today we are repeatedly told that we are in the midst of a communications revolution but... if any generation has the right to claim that it bore the full bewildering, world-shrinking brunt of such a revolution, it is not us - it is our nineteenth-century forebears (pp. 199-200).

Actor-network theory would contend that there is no grand narrative by which the history of the US railroads can be told: "ANT cannot be told. Cannot be told as a single narrative. As an overall story about the growth of a centred network with its successes and reverses. And instead imagine that it can only - and best - be represented as a set of little stories, stories that are held together (if they are) by ambivalences and oscillations" (Law, 1997, p. 12). So there are numerous potential plots, themes, characters and materials that can be interwoven. There are visionaries and manipulators, entrepreneurs and robber barons, publicity campaigns and grand rhetoric, newspapers of mass communication and telegraph wires, politicians and lobbyists, stock-market dealings and dealers, legal adversaries, imported labourers, steel, coal, inhospitable landscapes, geographical and geological obstacles and so on. Meinig (1993) describes railroads as, "a machine ensemble in which roadway and vehicle were technically conjoined; a new geographic phenomenon. Learning to handle such things under the pressure of investors and competitors was intensive practice for a truly national - continental - scale of life in the modern world" (p. 347). The second sentence here implies a level at which technical objects and humans were "conjoined".

With the advantage of hindsight we can attempt to make sense out of transportation history, construct cause and effect relationships and say confidently that it was inevitable that the technology of the railroad would supersede that of the waterways. It was not, though, a simple matter of one technological system replacing another. Sometimes railroads were integrated with waterways; at other times they were intended to provide a faster and rival method of transportation (Meinig 1993). On occasions the army assisted private companies with surveying and track laying but such partnerships were fairly random and certainly not part of any coherent or centralised plan (Meinig, 1993, p. 235). When the first railroads were built, during the 1830s, around the Eastern seaport towns, it was still the era of the steamboat. It was not until about 1845 that the railroads began to look like they would emerge as a superior form of overland transportation. Even then, though, it would seem that the demise of water transportation was exacerbated by a period of drought (Meinig, 1993, p. 337). Rapid as the development was at this time, the most significant growth occurred in later decades with the emergence of some kind of infrastructure in the hinterland regions. By 1860, 30,626 miles of track had been laid. This increased to 52,922 by 1870 and to 93,267 by 1880 (Meinig, 1993). A key feature of the early period was the relative restriction of building to coastal regions and a separation between north and south created by the absence of bridging across the Potomac and Ohio rivers at Washington, Cincinnati, Louisville and Cairo, as well as the fact that there was no single company operating across this geographical boundary.

Three stages of development can be traced: firstly, railroads that developed supplementary to water transport; secondly, networks that developed between East Coast cities and established ports; thirdly, a general movement westwards towards the Appalachians. The westward routes rapidly developed their own momentum driven by "the relentless need to extend further so as to capture western produce before it ever reached a river landing or before it was diverted by a competitive rail line to a river port"(Meinig, 1993, p. 326). However, this was not a case of technology being exploited in any planned or coherent way. Individual states had their own aspirations and promoted specific projects and disrupted others. Thus, they were significant actors who attempted to "shape a network to serve their own interests" (Meinig, 1993, p. 338) but, at the same time, there were federal plans for a centralised system, driven to some extent by military aspirations. Burrell (1997), citing Hoskin and MacVe (1986), explains how "the US railway system in the nineteenth century acted as a transmitter of West Point's military forms of thinking into the very heart of the USA" (Burrell, 1997, p. 31). However, centralisation was never likely to win support in a new country where forces militated against the idea of any single metropolis being at the centre of a network. "In France all roads radiated from Paris; in the United States there was a determined effort to not have them radiate from Washington“ (Meinig, 1993, p. 350). The most powerful shapers of a network were not government or military planners but rather the “metropolitan capitalists who had access to the best information, credit sources, mercantile and manufacturing connections, and engineers - as well as political influence“ (p. 338).

The pattern of railroad development, then, reflects the particular circumstances of North America so that if there ever was a “system“ as such, it was quite different from that in Great Britain. In actor-network terms, the technology itself “starts to play different roles - but also to imply different roles for the actors round about it“ (Law, 1997). Moving westwards there was an apparently unlimited potential for expansion but it was not the case, as it was elsewhere, of providing an updated communication infrastructure for some pre-existing order of settlement; the settlements themselves had to be constructed and were a sine qua non for westward development: “the overall pattern of early railroad building in the West was rather a muddle, in part because of narrow interstate programs and in part because so much of the region was still in such a malleable formative stage that there were few obvious points upon which to anchor larger strategies“ (Meinig, 1993, pp 326-7).

Even by 1860 westward routes came to a halt at, or just beyond the Mississippi. The significant lines at this time cut a swathe from the north east, extending into Canada, down to the area of the Great Lakes, linking up Boston, New York, Philadelphia, Baltimore, Cincinnati, St Louis, Chicago, Detroit and Buffalo. To the south there were more fragmented links around the coastal towns of Richmond down to Wilmington, Charleston, Savannah and extending westward to Atlanta, Chatanooga, Memphis, Vicksburg and New Orleans. This was a “patchwork“ of lines rather than a system or network and there were crucial obstacles that stood in the way of integration: “the many companies, patchwork of construction, different gauges, and lack of bridges across major rivers and even of connections within major cities greatly affected the movement of passengers and freight“ (Meinig, 1993, p. 328). At this point, I would like to isolate one of these obstacles or actors - water - and consider its role in the actor-network relationship.

In 1856, the Chicago and Rock Island Railroad (C.R.I.) constructed a bridge across the Mississippi at Rock Island. This was important, strategically, for two main reasons. Firstly, it overcame a significant obstacle that stood in the way of a much more ambitious project - the creation of a northern transcontinental link to the Pacific (for which there would be generous financial rewards from government and by this time a few key players, from north and south, were jostling for advantage in the race to the Pacific). Secondly, it undermined the economic power of the South further by diverting transported goods away from a river route down the Mississippi to a new West-East railroad system, which would increase the power of Chicago and the Eastern seaports. Such a fundamental challenge to the interests of people whose livelihoods depended on water transportation was not to go unchallenged and the Rock Island Bridge project was a crucial site of struggle between key actors whose interests were interwoven in the struggle for power between North and South.

The C.R.I. chose Rock Island as a crossing point because the island in the middle of the river - Rock Island - made the task of building a bridge across to Davenport, on the west bank, significantly easier and cheaper. A problem for the C.R.I. was how to justify such an ambitious project if it appeared merely to link up two towns whose commercial interests were tied up in river transportation. The solution was to locate the project within a grander scenario, which could be shown to override parochial interests and serve the “national interest“. The town of Council Bluffs, further west on the river Missouri, was rapidly developed so that the bridge building project could be presented as a way of linking up with this new and “vital“ town (Brown, 1977). This enabled the aspirations of the C.R.I. to be located within a wider discourse of western development and expansion in the national interest. Such capital intensive projects requiring the construction of settlements and shifting of populations were, of course, highly risky.

The bridge became a kind of test case in a power struggle between a complicated nexus of actors and the struggle itself was enacted partly through a series of court cases, which located the struggle between economic adversaries within a legal discourse, in which the conflicts would be framed in terms of justice and democratic rights. While it was still in its planning stage, steamboat owners from St Louis objected that the bridge was “unconstitutional, an obstruction to navigation, dangerous, and it was the duty of every western state, river city, and town to take immediate action to prevent the erection of such a structure“ (Brown, 1977, p. 7). Such objections from Southern interests firmed up as soon as actual building started in 1854. At this time the Secretary of War was Jefferson Davis, soon to become President of the seceding Confederate States during the Civil War and a powerful broker on behalf of Southern interests. He ruled that Rock Island could not be a legitimate crossing point because of its former use as a military reservation. This move was rapidly followed by a federal injunction, taken out by the steamboat interests, which charged the bridge builders with trespass, destruction of government property and obstruction of steamboat navigation (Brown, 1997). In July of 1855 the judge ruled in favour of the Railroad Bridge Company (an offshoot of the C.R.I.). This set an important precedent for it was now officially declared and recorded that “railroads had become highways in something the same sense as rivers; neither could be suffered to become a permanent obstruction to the other, but each must yield something to the other according to the demands of the public convenience and necessities of commerce“ (Zobrist, 1965, p.164). In legal terms, then, railroads were now on an equal footing with the rival technology that they were rapidly undermining and they had “translated“ a key part of the state apparatus to reflect their interests.

When the bridge was completed in 1856 the Philadelphia Bulletin reflected a sense of Eastern triumph in its editorial: “now that civilisation has got safely over the Mississippi by steam, we see no reason why we may not live to see her take a first class ticket in a lightning train for the shores of the Pacific“ (Brown, 1997, p.9). However, the East-West axis was not going to be developed uncontested. On May 6th 1856, just a few days after the bridge had been opened, a packet boat named the Effie Afton, which was steaming well away from its usual route between New Orleans and Louisville, collided with the bridge and set it on fire. This calamity was much appreciated by local river transporters, some of whom had already prepared a banner in advance for just such an eventuality, which read: “Mississippi bridge destroyed. Let all rejoice“ (Brown, 1977, p.9). The rivermen pressed home their advantage and were strongly supported by the St Louis Chamber of Commerce, which resolved to “assist vigorously in the prosecution of the case against the bridge company“ (Beveridge, 1928, p. 599). The front man for the Southern interests was the owner of the Effie Afton who sued the bridge company for damages, claiming that the bridge structure was an impediment to safe river transport. The bridge company hired Abraham Lincoln as their defence lawyer. Thus, the bridge fiasco intensified as a legal battle and embroiled on opposite sides two men, Abraham Lincoln and Jefferson Davis, who would play out the North-South struggle on a national and devastating scale five years later in military combat.

While the battle was being fought in the courts, the conflict was extended to the public domain by the newspapers of Chicago and St Louis (just at the time when newspapers were exploiting the new parallel technologies of telegraph and railroad to develop their own business interests). The Chicago papers accused St Louis of being the real plaintiff in the case, while making their own allegiances clear: “facts...do not warrant the incessant clamour kept up by those who insist that the magnificent structure shall be torn down...We trust that...the outcries of the St Louis and river press may be silenced (Chicago Tribune editorial, April 17, 1857, cited in Beveridge, 1928, p. 599). Meanwhile the St Louis papers made their own case: “The Railroad Bridge at Rock Island is an intolerable nuisance...It is utterly impossible for any man not an idiot to note the disasters at Rock Island and honestly ascribe them to any other cause than the huge obstruction to navigation which the Bridge Company have built there and insist shall remain, even though lives by the score and property by the million are destroyed every year...We have rarely seen such illustration of supercilious insolence, as have been presented by the bridge“ (Beveridge, 1928, p. 600).

Lincoln’s defence was built around two arguments, offering simultaneously a micro and a macro perspective on the incident. Firstly, he invoked the by now familiar discourse of manifest destiny in an attempt to persuade the jury that the expansion of railroads, and the crossing of rivers, was bound up with inevitable progress: “there is a travel from east to west whose demands are not less than that of those of the river. It is growing larger and larger, building up new countries with a rapidity never before seen in the history of the world. This current of travel has its rights as well as that of north and south“ (Starr, 1927, p. 108). Secondly, he scrutinised the internal “facts of the case“ with vigorous detail and produced empirical evidence, based on observations and measurements of the river currents, to prove that the Effie Afton’s starboard wheel was not operating at the time of the accident: “the latter (Lincoln) was devoted to complicated matters: the river currents, their velocity, the position of the piers, engineering problems of river navigation, and the like, all being handled with mathematical precision“ (Starr, 1927, p.107). Thus, the jury was asked to reach a verdict on the basis of detailed evidence, as though there were no wider economic and political agenda and yet, ironically, that agenda is implied through references to the rights of “currents of travel“ made as a backdrop to the whole case.

When the jury failed to reach a verdict the moral victory was with the railroad, though there were a few more skirmishes to come. Now effectively in retreat, the Southerners attempted to rally by pressing, in 1858, for a congressional law forbidding bridges over navigable rivers. Although this failed, they won a pyrrhic victory later that year when a judge in an Iowa court declared the bridge to be “a common and public nuisance“ (Zobrist, 1965, p. 170) and ordered the part of the bridge that lay within the state of Iowa to be dismantled. The dispute was played out, then, at state and federal levels of the legislature. The C.R.I. duly appealed and the matter was finally settled when the Supreme Court of the United States ruled in their favour in 1862. A report on the final verdict describes the case as being: “valuable as marking the evolution of the Lincoln doctrine that a man has as good a right to go across a river as another has to go up or down the river, that the two rights are mutual, that the existence of a bridge which does not prevent or unreasonably obstruct navigation is not inconsistent with the navigable character of the stream“ (Starr, 1927, p.115). The economic interests of one alliance of actors (railroad owners, financial backers, politicians etc.) are expressed in terms of mutual rights and masked by the transformation of Lincoln, the bit part actor, into “the author of the American doctrine of bridges (Starr, 1927, p.116).

Thus, the geographical constraint of water implied one script for human settlement and economic activity, while bridges implied another. Railroad bridges became a powerful iconographic representation of a technology that could simply override the apparent constraints of the “natural“ landscape. Acts of sabotage against them were not uncommon. The events that took place in the aftermath of the Rock Island case reveal much about the skulduggery of railroad magnates in manipulating so-called “market forces“ and manoeuvring to establish strategic advantage in the race to complete the first transcontinental link. However, the story is a little too complicated to be continued here (see Agnew, 1950 & 1953; Brown, 1977; Donovan, 1962). In its muddled way this was a critical incident in railroad expansion and the development of a transcontinental “system“. It brought together a wide array of forces operating in the pre-civil war decade and illustrates how railroads used the courts to legitimise technological development.

Reviewed by: J. Bujňák

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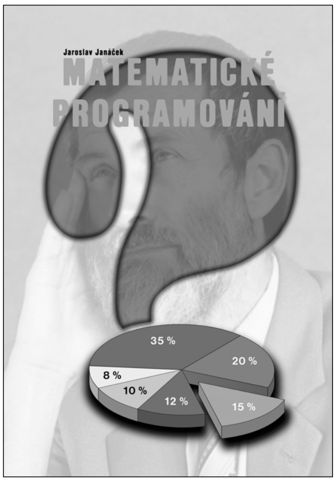

Matematické programovanie

Nedávno sa dostala na pulty našich predajní vysokoškolská učebnica ***Matematické programování od prof. RNDr. Jaroslava Janáčka, CSc.*** *Učebnica je určená na štúdium predmetu matematické programovanie v rozsahu ako je táto problematika prednášaná na viacerých fakultách Žilinskej univerzity. Pre pochopenie obsahu učebnice postačujú základné vedomosti z diferenciálneho počtu, lineárnej algebry a teórie grafov. Učebnica je členená na tieto kapitoly:*

1. *Modely úloh matematického programovania*
2. *Lineárne programovanie a teória duality*
3. *Diskrétne lineárne programovanie*
4. *Separované a kvadratické programovanie*
5. *Diskrétne dynamické programovanie*

Prvá kapitola je venovaná klasifikácii a tvorbe základných modelov matematického programovania. Tejto kapitole je venovaných až 32 strán textu, čo len podčiarkuje význam, ktorý autor kladie správnej formulácii úlohy.

Druhá kapitola zoznamuje čitateľov so základnými pojmami a tvrdeniami lineárneho programovania a teórie duality. Sú vyložené algoritmy základnej, revidovanej, lexikografickej aj duálnej lexikografickej simplexovej metódy. Princípy primárnej a duálnej metódy, ktoré využívajú špeciálnu štruktúru úloh, sú ukázané pri riešení priraďovacej a dopravnej úlohy.

Tretia kapitola je venovaná úlohám a základným metódam diskrétneho lineárneho programovania. Metóda rezných nadrovín a konštrukcia normálnych rezov sú vysvetlené na prvom Gomoryho algoritme pre riešenie úlohy úplného celočíselného programovania. Je podaný originálny dôkaz konečnosti prvého Gomoriho algoritmu. Výklad princípu a dvoch implementácií metódy vetvenia a hraníc je demonštrovaný na úlohe výroby lupienkov a hranolčekov s nedeliteľnosťami a Kolesárovom algoritme pre úlohu o batohu. Pozornosť je venovaná aj základným primárnym a duálnym heuristickým metódam. Záverečná časť kapitoly sa zaoberá jednou z možností zlepšenia dolného odhadu pomocou subgradientnej metódy založenej na Lagrangeovej relaxácii.

Štvrtá kapitola je venovaná úlohám kvadratického a separovaného programovania. Najskôr sú analyzované základné pojmy a potom nutné a postačujúce podmienky pre kvadratické programovanie, na ktorých je založená Wolfeova metóda. Výklad končí metódou linearizácie separovaných úloh matematického programovania.

Záverečná piata kapitola objasňuje Bellmanov princíp optimality v úlohách dynamického programovania. Pre typy úloh s pevnými aj voľnými začiatkami a koncami sú formulované príslušné Bellmanove funkcie. Riešenie kombinatorických úloh pomocou dynamického programovania je ilustrované aj na známej úlohe obchodného cestujúceho.

Predložený text učebnice (225 strán) podáva náročnú problematiku zrozumiteľne aj vďaka množstvu citlivo zvolených ilustračných príkladov, na ktorých sú demonštrované vysvetľované pojmy a postupy. Je však zarážajúce, že kniha bola vydaná v minimálnom náklade 250 výtlačkov. Očakávam, že si učebnica rýchlo nájde svojich čitateľov najmä medzi študentmi technických a ekonomických vysokých škôl.

RNDr. Štefan Peško, CSc.

Dizertačná práca: Priame momentové riadenie asynchrónneho motora s predikčným filtrom
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Školiteľ: prof. Ing. Branislav Dobrucký, PhD.


ŽILINSKÁ UNIVERZITA V ŽILINE
Elektrotechnická fakulta

PRIAME MOMENTOVÉ RIADENIE ASYNCHRÓNNEHO MOTORA S PREDIKČNÝM FILTROM
Dizertačná práca

Autor: Ing. Ľubomír JOZEFÁK
Školiteľ: Prof. Ing. Branislav DOBRUCKÝ, PhD.

Žilina 1999

Resumé:

Doktorandská dizertačná práca sa zaoberá skúmaním algoritmu priameho momentového riadenia (PMR) pohonu s asynchrónnym motorom. Je v nej zahrnutý teoretický rozbor algoritmu priameho momentového riadenia s hexagonálnou dráhou vektora toku statora (PMR-H) a s kruhovou dráhou vektora toku statora (PMR-K). Práca ďalej obsahuje teoretický rozbor niektorých problematických režimov činnosti algoritmu PMR, napr. pri veľmi nízkych otáčkach motora, pri zmene hodnoty odporu vinutia statora, odporu rotora a pod . Je zaradená nová metóda, nazvaná „PMR-K s oneskoreným prepínaním vektora napätia", ktorá modifikuje algoritmus PMR-K takým spôsobom, aby bolo možné meniť dráhu vektora toku z kruhovej na hexagonálnu a späť" v závislosti od stanovenej podmienky (napr. od veľkosti otáčok). Práca obsahuje tiež vysvetlenie základov teórie Kalmanovho filtra a možnosti jej aplikácie predovšetkým v elektrických pohonoch s asynchrónnym motorom. Predikčný Kalmanov filter vykonáva odhad prúdu rotora, toku rotora a otáčok motora. Pre odhad odporu motora je použitý tzv. Rozšírený Kalmanov filter. Väčšina teoretických úvah je podoprená výsledkami počítačových simulačných experimentov. Okrem toho práca obsahuje výsledky meraní, vykonaných na laboratórnom modeli pohonu s asynchrónnym motorom. Praktické experimenty sú venované činnosti algoritmu PMR-K a jeho modifikácii - „PMR-K s oneskoreným prepínaním vektora napätia". Stručne je spomenutá tiež problematika rušenia okolitého prostredia, ktoré vzniká v dôsledku použitia frekvenčného meniča.

Dizertačná práca: Riadiaci a informačný systém vo vojenskej automobilovej doprave
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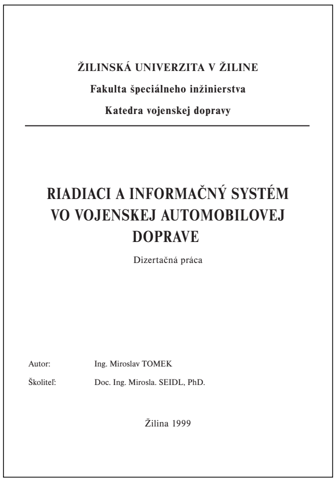
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Fakulta špeciálneho inžinierstva
Katedra vojenskej dopravy

RIADIACI A INFORMAČNÝ SYSTÉM VO VOJENSKEJ AUTOMOBILOVEJ DOPRAVE
Dizertačná práca

Autor: Ing. Miroslav TOMEK
Školiteľ: Doc. Ing. Mirosla. SEIDL, PhD.

Žilina 1999

Resumé:

Dizertačná práca je zameraná na riešenie riadiaceho a informačného systému vo vojenskej automobilovej doprave. Základnou úlohou bolo analyzovať rozhodujúce problémy riadenia na stupni dopravná základňa za brannej pohotovosti štátu. Práca obsahuje 114 strán textu a 79 strán príloh. Je metodicky rozdelená do ôsmich kapitol.

Práca predstavuje ucelený súbor poznatkov, analýz a autorských záverov vo vzťahu k systému riadenia dopravnej základne. Nadväzuje na celý rad štúdií a vedeckých úloh, ktoré boli na tematiku velenia a zabezpečenia vojenskej automobilovej dopravy v minulosti zamerané. Tvorivým prístupom bola vykonaná aplikácia všeobecných zásad velenia na konkrétne organizačné štruktúry, funkcionárov a efektívny rozhodovací proces v zložitých podmienkach. Dizertačná práca sa podrobne zaoberá všetkými funkciami systému velenia cez plánovanie, organizovanie, operatívne riadenie až po kontrolnú činnosť, a to vo všetkých fázach dopravnej zásobovacej činnosti.

S využitím metód sieťovej analýzy boli zostavené možné metodiky činnosti veliteľa, hlavných funkcionárov a štábu dopravnej základne v procese plánovania úloh postupnou a súbežnou metódou.

Prínosom dizertačnej práce je, že okrem nových teoretických poznatkov v oblasti vojenskej vedy, sú niektoré výsledky okamžite použité v praxi. Rovnako praktické využitie majú návrhy týkajúce sa miest velenia dopravnej základne a bojových dokumentov.

Celkové závery pre vojenskú prax a ďalší rozvoj vedného odboru sú zhrnuté v závere práce.

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