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SURFACE-ORIENTED TOOL SET AS A NEW ENVIRONMENT FOR PROCESS PLANNING AND CONCURRENT ENGINEERING

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Abstract. The central element in process planning system is the cutting tool. However, the main attention in the studies has been paid on the process plan itself. From our point of view, such an approach lacks flexibility and cannot give a good overview to take the right decisions. This paper discusses the new principle of tool selection methodology and the role of the tool for process planning and concurrent engineering. The kinematic links between machined surface and cutting tool are taken into account in the elaborated tool selection system. The model of this system is described. The term *form features* is discussed, as well as its meaning in this work. Such an approach enables us to use the system as generic for small and medium size enterprises as well as for the CAPP. This system can be treated as a tool to create of a new environment for process planning and concurrent engineering.

Key words: tool selection, process planning, concurrent engineering.

1. INTRODUCTION

In the near future the main trend is *intelligent engineering*. The term *intelligent engineering* is defined as implementation of heuristic rules in the design, production planning and manufacturing when exact rules are not established. Some examples are given in [1–3]. These authors regard operation selection and sequencing as the core of process planning, generally considered the most difficult part to capture in a computer program. The knowledge of production planning is the supporting environment of process planning. Characteristically, the process planning knowledge is not acquired from an industrial environment but is based on common sense. This knowledge is complex, consisting of a process plan on a current surface, a machine tool, a fixture, etc.

Another significant trend is *concurrent engineering*. Concurrent engineering has the advantage of reducing the throughput time, i.e. the time from an idea to a product, thus decreasing the losses due to optimal solution or close to its technical and technological solutions. Most authors refer to the relation between the form feature or the form element and the production plan on this element as the basic principle. It means that a manufacturing scheme plays the central role, and to adjust the system, several constraints are introduced. In a classical concurrent engineering scheme, a system matches the selected form feature and the process model available in a company. Any mismatching leads to a failure and results in changing the form feature or elaborating a new process. In addition, all the existing process models cannot be optimal in terms of productivity management. Such an approach is too rigid and could be regarded as a particular case.

In the proposed approach, where a cutting tool is the central part, inheritance of the process components is assumed [4]. Once a suitable cutting tool is found, other components of the process can be selected (machine tool, fixtures, etc.). These components determine the manufacturing process. Also, standard elementary processes can be available in the data base.

As a result, *tool selection* can be declared as the main task. This task is characterized by the following features:

- multivariability of solutions;
- large-scale selection criteria;
- presence of subjective criteria for the estimation of solutions;
- noncorrectivity of cutting process models.

Most of the studies in this field are based on the principles of group technology [5, 6]. It means that for the form feature, both the elementary machining process and the cutting tool are selected. A very interesting solution is presented in [6] where the expert system principles are used for tool selection. In fact, the term *form feature* easily facilitates connection of CAM and CAD tasks. A good supporting system for tool selection needs a form feature classification system. These systems will be discussed below.

The starting point here is the link between the surface and the cutting tool forming it. It means that the manufacturing process as a means of giving the tool an appropriate movement to achieve the required form and quality of the surface. Thus we can highlight the following rules:

- the kind of the cutting tool is determined by the kinematic of the cutting process (Fig. 1);
- the type of the cutting tool is determined by the cutting scheme, i.e. how metal is removed (Fig. 2);
- the construction of the cutting tool is determined by the rules of cutting tool design and the designer's experience.

The objectives are:

- to create an environment for the CAPP and for an optimal tool selection when the automated process planning is not reasonable;
- to create a set of possible tools on the relational basis between the surface and the cutting tool;

• to create a tool selection system that could be used for executing various tasks related to the tools (tool management, process planning, and concurrent engineering).

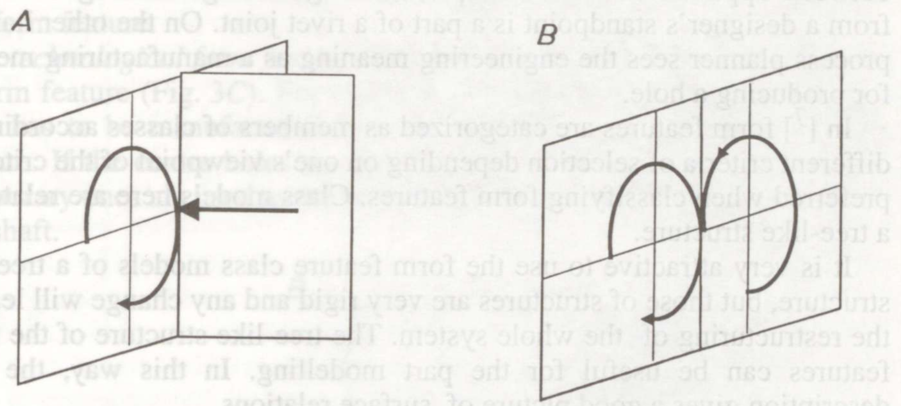


Fig. 1. Examples of cutting kinematic: *A* – scheme of machining with turning tool, core drill, etc., *B* – scheme of machining with mills the rotating parts, with rotating broach the rotating parts, etc.

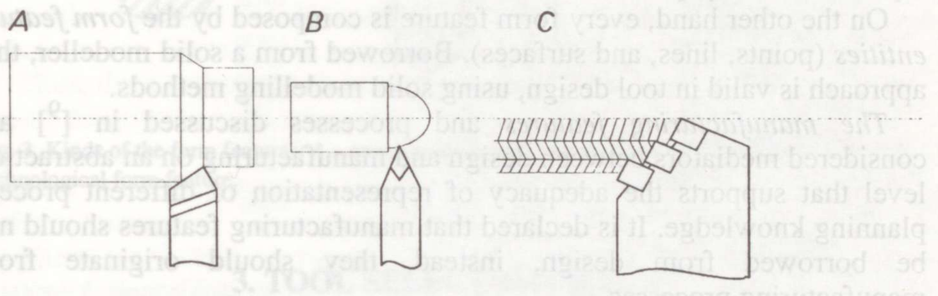


Fig. 2. Forming the types of cutting tools: *A* – longitudinal turning, *B* – form turning, *C* – turning with allowance dividing.

2. FORM FEATURES

The term *constructive peculiarities* was used in the early 1970s. But then it carried only the meaning of the part classification constraint. In the late 1970s, the term *form feature* was taken into use, denoting part modelling and later process planning. However, inconsistencies are observed in different treatments of this term. Since a form feature is the main part of a tool selection system, the meaning of the term used in this study is discussed here.

A wide coverage of the problem is given in [7]. The author defines the form feature as follows: *A form feature is a generic shape which carries some engineering meaning*. However, generic shape refers to some type of general description, a pattern which uniquely defines the type of a shape.

Engineering meaning can vary from one form feature to another and between applications. For example, the engineering meaning of a hole from a designer's standpoint is a part of a rivet joint. On the other hand, a process planner sees the engineering meaning as a manufacturing method for producing a hole.

In [7] form features are categorized as members of classes according to different criteria of selection depending on one's viewpoint of the criterion preferred when classifying form features. Class models here are related in a tree-like structure.

It is very attractive to use the form feature class models of a tree-like structure, but those of structures are very rigid and any change will lead to the restructuring of the whole system. The tree-like structure of the form features can be useful for the part modelling. In this way, the part description gives a good picture of surface relations.

On the abstractional level, the form feature must be described in a network like a structure, facilitating description of the form features from each particular user's point of view [8]. On this level, we have a template description of the shape. But a detailed discussion of this problem is the topic of another paper.

On the other hand, every form feature is composed by the *form feature entities* (points, lines, and surfaces). Borrowed from a solid modeller, this approach is valid in tool design, using solid modelling methods.

The manufacturing features and processes discussed in [9] are considered mediators between design and manufacturing on an abstraction level that supports the adequacy of representation of different process planning knowledge. It is declared that manufacturing features should not be borrowed from design, instead, they should originate from manufacturing processes.

Based on the analysis of different studies, the following assumptions can be highlighted:

- A form feature is a geometrical element used in the part model with a desired exploitation target.
- When renamed, the form feature remains unchanged.
- Abundance of the form feature names is explained by different targets of the features.
- A process is a means of facilitating surface formation, using a required tool.

In the following part, *the form features* will be discussed. A form feature is object oriented, which derives from the engineering meaning of a form feature. Thus, *constructional form features*, *functional form features*, and *technological form features* are in use.

Constructional form features are used in the part design (Fig. 3*A*). In [7] the term *part form feature* is used as an exceptional case to describe the part configuration for the classifying purposes. Their shapes are represented by a full object or by a simpler shape, but it has to be an object which can exist by itself.

A functional form feature gives a particular part its functional meaning (Fig. 3*B*). For example, providing a disc shape part with teeth, a gear is achieved; and by having a thread in the hole, some elements can be fixed. The selected tool and the order of manufacturing depend on the function of the form feature.

A technological form feature facilitates formation of the main shape of a form feature (Fig. 3*C*). For example, to manufacture an inner thread, a hole has to be manufactured first. So, the hole is a technological form feature. If the centre holes on the shaft are not planned by the designer, temporary ones are used as the technological form features to manufacture the shaft.

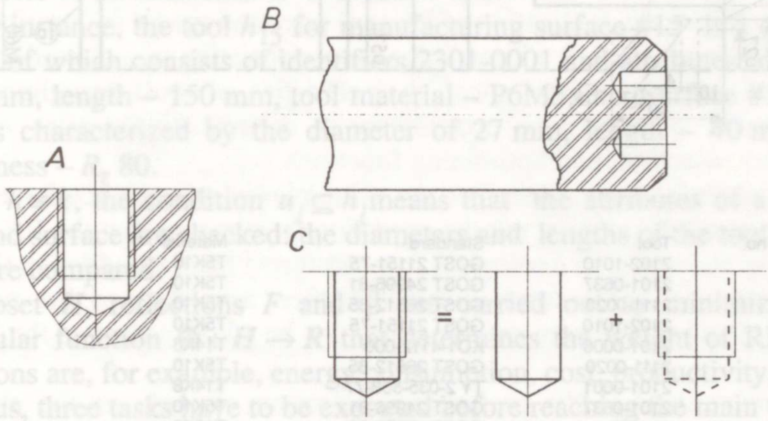


Fig. 3. Kinds of the form features: *A* – constructional form feature, *B* – functional form feature, *C* – technological form feature.

3. TOOL SELECTION MODEL

The model elaborated is based on the following presumptions:

- a part consists of the constructional, functional and technological form features;
- there is a finite-dimensioned set of available tools (realizing elements) to machine each form feature;
- there is a number of objective functions characterizing the accepted decision.

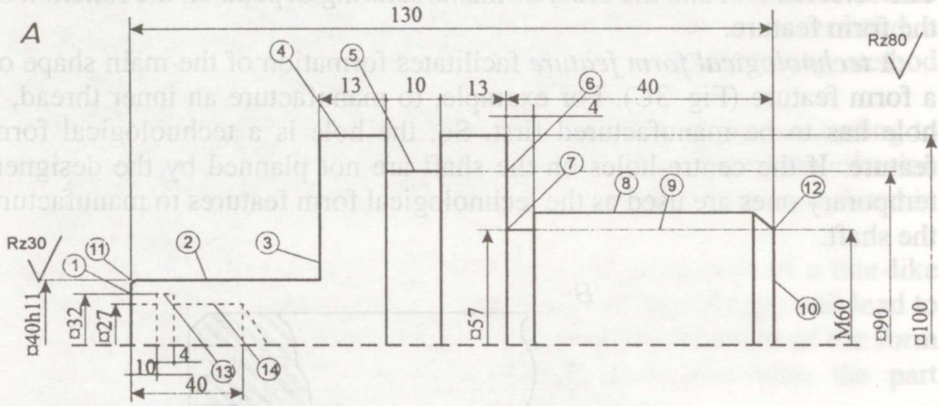
To solve the task, the following initial data are necessary:

- a partly sorted set U of the form features (kinds of holes, slots, etc.);
- a set of realizing elements (RE) K;
- conditions specifying RE as belonging to a certain set.

In terms of the part manufacturing, the RE K are all possible tools – conventional (cutting tools) as well as nonconventional (based on different physical, chemical and electrical processes) to form a current surface.

A reflection $F(U)$ is given in order to describe the part by means of subsets of the form features. In Fig. 4, for the part $F(U)$ is the sequence of numbered surfaces from 1 to 15 (here, the centre hole is the technological form feature and is not shown in the figure).

A



B

Surface no.	Tool	Standard	Material
1	2102-1010	GOST 21151-75	T5K10
2	2101-0637	GOST 24996-81	T5K10
3	2111-0020	GOST 26612-85	T5K10
4	2102-1010	GOST 21151-75	T5K10
5	2101-0000	KO1-4112-000	T14K8
6	2111-0020	GOST 26612-85	T5K10
7	2101-0001	TY 2-035-558-77	T14K8
8	2101-0637	GOST 24996-81	T5K10
9	no tool	GOST 18885-73	T15K6
10	2102-1010	GOST 21151-75	T5K10
11	2102-1010	GOST 21151-75	T5K10
12	2102-1010	GOST 21151-75	T5K10
13	2190-3878	TY 2-035-558-77	T14K8
14	center drill	OST 2 120-5-80	P6M5
15	2301-0001	GOST 10903-77	P6M5

Fig. 4. Example of tool selection: *A* – part, prepared for the tool selection process, *B* – selected tools.

As a rule, the set of realizing elements is given in the form of subsets. This is done by: $\beta : \boldsymbol{K} \rightarrow \{\boldsymbol{K}\}$. In fact, different classification systems are used for this purpose. The most common one classifies the tools according to their operations. So, $\{\boldsymbol{K}\}$ can be turning tools, cutting tools, drills, mills, etc. This principle is not quite correct, but it enables us to simplify the solution of production planning tasks.

Ordinarily, operation β is carried out during the preparation of initial data in the form of tables (catalogues of tool manufacturers) or data base files. So, if no special classifying conditions are imposed during the solution of the main task, then the operation can be omitted.

Operation π is used to determine the correct correlation between the set of form features forming the part and the realizing elements

$$\pi : F(U) \to \beta(H). \quad (1)$$

The task is to find such subset $\boldsymbol{H}$ and reflections $\boldsymbol{F}$ and β that satisfy condition (1), where $\boldsymbol{H} \subseteq \boldsymbol{K}$. Here, the subset $\boldsymbol{H}$ consists of the tools needed to form all surfaces of the part. Again, as shown in Fig. 4, subset $\boldsymbol{H}$ is the second column.

It should be mentioned that the elements of the sets $\boldsymbol{U}$ and $\boldsymbol{K}$ themselves are, at the same time, the sets of attributes of the form features and the realizing elements of the form features. Therefore, it is important to check the condition $u_i \subseteq h_i$.

The elements of $\boldsymbol{U}$ and $\boldsymbol{K}$ $u \in \boldsymbol{U}$ and $k \in \boldsymbol{K}$ are characterized by data, the so-called information model, the essential parts of which are the identifiers of the elements $u^i \in \boldsymbol{U}$ and $k^i \in \boldsymbol{K}$.

For instance, the tool h_{15} for manufacturing surface #15 is a drill, the model of which consists of identifiers 2301-0001 and attributes: diameter – 27 mm, length – 150 mm, tool material – P6M5, etc. Surface #15, hole u_{15}, is characterized by the diameter of 27 mm, length – 40 mm, and roughness – R_z 80.

As $h \equiv k$, the condition $u_i \subseteq h_i$ means that the attributes of a current tool and surface are checked: the diameters and lengths of the tool and the hole are compared.

Subset $\boldsymbol{H}$, reflections F and β are carried out to minimize some particular function $\Phi : \boldsymbol{H} \to \boldsymbol{R}$ that determines the weight of RE. Such functions are, for example, energy consumption, cost, productivity, etc.

Thus, three tasks have to be executed before reaching the main task:

- part description by the form features;
- transformation of set $\boldsymbol{K}$;
- check of correspondence between the sets of realizing elements and the form features.

There can be one or many RE types for machining the form feature in tool selection. If X_i is the vector of attributes, characterizing the form feature, then set $\boldsymbol{U}$ can be formed as a set containing elements (u_i^i, X_i).

If the operation of RE selection is denoted by

$$\alpha : (u_i^i, X_i) \to (k_i^i, X_i), \quad (2)$$

it means that the relevant tool attributes and the form feature are matched, then the tasks of RE selection are determined as

$$\pi : (\alpha F)(U) \to \beta(H). \quad (3)$$

The solution of the problem is a set of RE (kind of tools) for selection. It is appropriate to mention that this level of solution is virtual due to its generic character. The type and construction of RE $k \in \boldsymbol{K}$ corresponding to $(\alpha F)(\boldsymbol{U})$, is the physical RE.

Based on the denotation, this task can be solved as a sequence:

• selection of the kind of the tool

$$\pi : (\alpha F)(U) \rightarrow \beta(H);$$

• selection of the type of the tool

$$\gamma : H \rightarrow \{H^T\};$$

• selection of the construction of the tool

$$\gamma_1 : H^T \rightarrow (k_i^i, X_i).$$

4. IMPLEMENTATION MODEL

In the following, realization of the tool selection model is described. On the virtual level, there is a knowledge base, consisting of a classifier of the form features, the technological characteristics of tools (roughness and precision of a machining process for a definite tool), rules of tool parameter selection, and optimizing functions.

It is essential to mention that the principles of precedence have to be considered while carrying out the operation α. It means that the RE on the preceding elements (technological form features) must be added to the RE. For instance, if the reamer is selected, then according to the rules of process planning, the bore and the drill must be added as one of the RE set variants.

The next stage is the preliminary selection of tools on the physical level. It means that the existence of the tools, as well as the existence of a suitable machine tool must be checked in a particular enterprise. Also, in this stage the tool material is selected for all possible tool combinations, as the tool construction depends on the tool material [10].

The criteria for tool selection have to be calculated in the next stage. The criteria for tool selection are determined by the enterprise itself. Then the information goes to the optimization block in order to select the final tool variants. For this purpose, the Π_τ – space optimization method is used [11].

Thus, the tool selection system does not need a new system, but according to the particular conditions, it can be fitted into the existing one on the virtual level.

5. MODEL REALIZATION

As the idea is relatively new, we can only discuss its realizability and applicability. In terms of realizability, the scheme is quite logical. The pair *surface-tool* has been existing throughout the history of the part manufacturing. However, implemented in the context of the process plan, new opportunities of tool application were hidden. So, the development of new technologies and machine tools with the desired parameters was hindered.

An example of a prototype of an expert system tool selection is described in [8]. As a result, a tool set is achieved on a given part (Fig. 4). Figure 5 shows the interrelations of the manufacturing environment where the tool is the central part, and the required process plan is available. This is a topic for further discussions, though, the main idea of this figure will be explained briefly here.

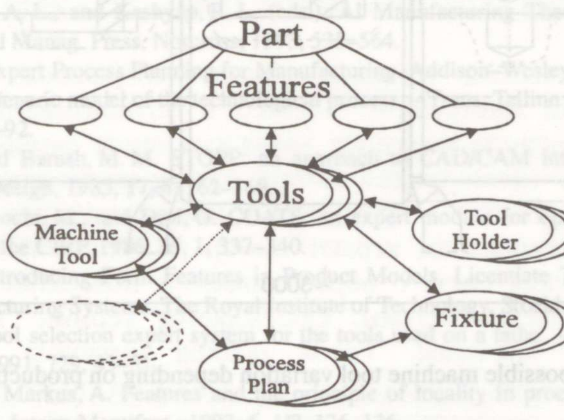


Fig. 5. Engineering environment's interrelations in the surface specific conception.

Conventional manufacturing planning is based on the priority of relations between the part and the manufacturing plan. Once the manufacturing plan is finished, the machine tool, fixtures, and tools are searched. The new ideas of typical technology (pattern technology) of parts, group technology and their modifications are achieved in order to shorten the lead time, but the priority of the tool is not admitted.

At the same time, new good performance tools and a new conception of the machine tools have been elaborated. A new trend in manufacturing engineering – the intelligent manufacturing engineering, based on the principles of artifical intelligence, is under development.

Once we have the tool set variants for manufacturing a part, a new opportunity to select a suitable machine tool is evident. It creates a good environment for synthesizing a production plan. The criterion for machine tool selection is not a production plan but a tool set. Thus, we are concerned with a conceptual production plan design rather than an applied one.

The authors in [12] describe a new method for process planning, based on the use of genetic algorithms. It could be interesting to use the selected tools for the path generation to perform the part machining. In terms of genetic algorithms, the tool set variants are the new populations of chromosomes [13] and fitness evaluation is needed, using different constraints to select the best one.

This is illustrated in Fig. 6, where all the tools needed are shown except for the grinding wheel. During many years, the classical scheme of manufacturing various machine tools has been used. In this case, the lead time was about two weeks for the shaft of the dimensions $L = 3000$ mm and $D = 500$ mm. Thereafter a new machine tool, a machining centre, was designed on the basis of the same tool set and, as a result, the lead time shortened to three days.

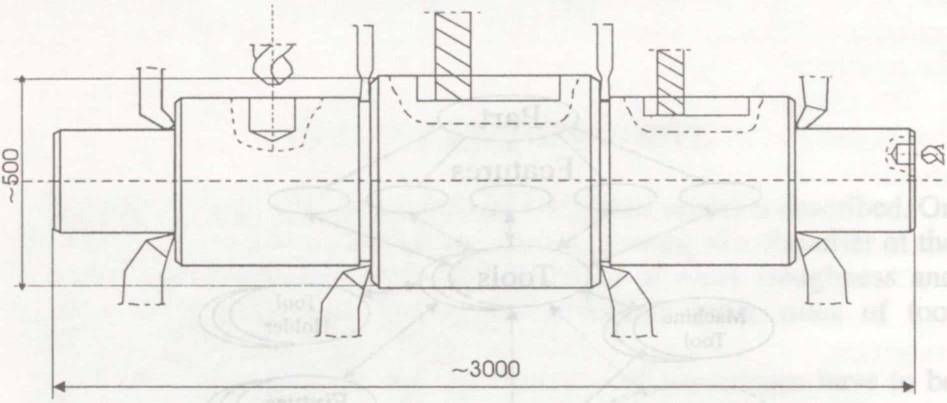


Fig. 6. Example of possible machine tool variation depending on production conditions.

6. CONCLUSIONS

Main advantages of the proposed methodology are:

- direct dependence of the constructional form feature on the forming tool, providing for tool selection from among the existing ones or designing a new one;
- reduction of the number of tools;
- selecting the manufacturing plan for the most suitable tool as a set of manufacturing plan elements inherited to the selected tool;
- existence of cutting tool sets for machining the part, facilitating variations in machine tools depending on production conditions;
- existence of intermediate cutting tools to ensure normal cutting conditions for the finishing tool to determine the suitable form and dimensions of technological form features;
- independence of particular technology;
- possibility to group the cutting tools, for example, the selection of a suitable special machine tool, as well as a machining centre;
- possibility to use principles of concurrent engineering at an early stage of process planning.

Thus, the selected tool set exists as a particular environment for process planning and concurrent engineering.

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DETAILI PINDADEGA MÄÄRATUD INSTRUMENTIDE HULK KUI TEHNOLOOGIA JA TOOTE INTEGREERITUD PROJEKTEERIMISE KESKKOND

Jüri PAPSTEL

Töötlemistehnoloogia projekteerimise keskne element on tööriist. Sellegipoolest on senistes käsitlustes peatähelepanu kontsentreeritud protsessile enesele. Niisugune lähenemisviis on autori arvates vähepaindlik. Artiklis on esitatud lõikeriistade valiku uued põhimõtted ning diskuteeritud instrumendi osa üle tehnoloogia projekteerimisel ja integreeritud projekteerimisel. Väljapakutud tööriistade valiku süsteemis on lähtutud kinemaatilisest seosest töödeldava pinna ja riista vahel. On kirjeldatud süsteemi mudelit. Lähemalt on avatud termini *pinnakuju*

iseärasused. Pakutud süsteemi võib kasutada kui üldist rakendamiseks konkreetses ettevõttes kas iseseisvalt või automatiseeritud projekteerimissüsteemi osana. Süsteem võib olla ka projekteerimiskeskkonna loomise vahend nii tehnoloogia projekteerimisel kui ka integreeritud projekteerimisel.

ПОВЕРХНОСТЯМИ ДЕТАЛИ ОПРЕДЕЛЕННОЕ МНОЖЕСТВО ИНСТРУМЕНТОВ КАК НОВАЯ СРЕДА ПРОЕКТИРОВАНИЯ

Юри ПАПСТЕЛ

В технологическом проектировании центральным элементом служит режущий инструмент. Однако в опубликованных до сих пор работах основное внимание уделялось лишь самому процессу. Такой подход, с точки зрения автора, сужает возможности гибкого проектирования. В статье предлагается новый принцип – основную роль при проектировании играют выбор режущего инструмента и его кинематическая связь с обрабатываемой поверхностью детали. Описывается модель системы. Обсуждается термин "особенность формы" и его значение. Такой подход позволил разработать обобщенную систему, пригодную для любого конкретного случая. Систему можно рассматривать как инструментарий для создания среды проектирования.