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Research paper

Applying Using Structural-Parametric Geometric Models for Rational Design of Technological Processes in Mechanical Engineering

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Abstract

The article is devoted to some questions of applying the methodology of structural-parametric geometric modeling in modern machine building. Theoretical and practical relevance of the mentioned scientific-applied theme has been substantiated. The main purpose of this publication is to describe the basic provisions of the proposed method of rational computer design of groups of technical objects and the design of technological processes of their production. The corresponding examples of practical use of the considered modeling techniques concerning mechanical parts manufactured by cutting are presented and analyzed. The main advantages of these techniques have been substantiated in comparison with the existing traditional methods of designing technological processes in mechanical engineering. The basic prospective directions of carrying out further scientific researches concerning the outlined subjects have been determined.

Keywords: *designing technological processes, engineering, optimization, structural-parametric geometric models.*

1. Introduction

The issue of further development of the theory and practice of effective design and manufacture of machine-building products is always relevant. This is due to the needs of the mankind in a qualitative, that is, highly productive, economic, reliable, etc., technology.

One of the most progressive directions of successful achievement of the stated goal is the widespread use of modern computer information technologies for designing and manufacturing of various industrial products. The results obtained in this case are largely determined not only by the available capabilities of computer technologies, but also by the software used. In the case under consideration, the quality of the latter depends significantly on the corresponding mathematical models used for the design of industrial products and the technological processes of its production. Particularly important for technical objects are their geometric models. This is due to the fact that both the design of industrial products and their production are closely linked to the formation. Therefore, further improvement of the technical objects used for reproduction and processes of their production of geometric models is an important scientific and applied problem. It should also be noted that the design and production of machine-building products are usually characterized by a large number of possible implementation options and the need for optimization. The above facts must be carefully considered when developing new techniques in the field of computer information technology simulation of various modern technical objects.

2. Literature review and problem statement

Currently, parametric geometric models are widely used for computer design of various technical objects [1-4]. Their main advantage is to provide flexible and productive computer generation of a certain group of similar technical objects by varying the proper parameters of the basic geometric model. The main disadvantage is the limited ability of these models to build objects with another structure, that is, the composition and interconnection of the elements. In order to eliminate these defects and further development of the described area, a methodology of structural-parametric geometric modeling [5-10] was developed. Its general provisions are set out in the publication [5]. This paper gives the basic principles of the methodology (system approach, variability, optimality, openness and development, integrated approach). The main stages of the creation and use of structural and parametric geometric models of technical objects are described (object analysis and the formation of its elements, the definition of relationships between elements, that is, the development of the structure of the object or the simulated process, processing the synthesis options about object, the calculation of its integral parameters and characteristics, the optimal formulation of the object). The implementation of this methodology in the form of a mathematical apparatus of the theory of sets and graphs, which is based on the methods of the theory of curves and surfaces, solid-state computer formulation, parametric and structural optimization, etc. The article [6] substantiates the invariant character of structural-parametric geometric modeling as a component of computer information technologies supporting the life cycle of machine-building products. The obtained scientific results are implemented, in particular, during the sketch design of the aircraft [7], processing group technologies of pressure treatment and assembly operations [8]. Some aspects of combinatorial variation and variational dynamic shaping are described, respectively, in publications [9] and [10].

Thus, the analysis of literary sources proves the perspectives in the theoretical and practical plan for the development of new methods, methods and techniques of computer structural and parametric formulation for modeling of technical objects and processes of mechanical engineering.

3. Purpose and tasks of the research

The purpose of the research is to present, by way of example, the mechanical production of machine-building components by cutting basic provisions of the proposed methodology of rational computer design of groups of technical objects and designing technological processes for their production.

To achieve this goal, the following tasks are defined:

- to analyze the possibility of applying geometric methods for improving the solution of parametric optimization problems in mechanical engineering;
- to illustrate the use of structural-parametric geometric models for rational computer design of groups of details and the design of technological processes for their production;
- to substantiate advantages of the proposed method in comparison with traditional approaches.

4. Geometric modeling as a means of integration and optimization of design and technological preparation of machine-building production

It has been shown in [11] that the general approach to modeling technical objects is to divide the subject or process into several parts, which is easier to define in the formalized form, and then combine properly. Therefore, the analysis consists in the allocation of the necessary elements and relationships between them, and further synthesis - in creating a holistic integral object. It is noted that for full and multifaceted perception of the technical system, it is necessary to apply several of its models in various aspects. As a general basis for such models, it is worth using their common data, which for the technical objects quite often have geometric shape, size, and position parameters.

In our time in engineering, from the organizational point of view there are three types of technologies [12, 13]: single, typical and group. Each of them has its advantages and disadvantages. A promising new modular approach is based on cross-cutting use of the corresponding principle in the design and technological preparation of machine-building production.

In accordance with the above-stated tasks, we first consider the question of applying geometric methods to improve the solution of parametric optimization problems in machine building.

4.1. Geometric modeling as a tool for parametric optimization

We illustrate the proposed methods in the example presented in [11], which relates to the processing time t_k of one part of the turning operation. The corresponding mathematical model has the following form

$$t_k = t_1 + t_2 + t_3, \qquad (1)$$

where t_1 combines components that do not depend on cutting modes;

t_2 is the main time of cutting;

t_3 is the time associated with changing the worn instrument classified as one part.

The value of t_1 consists in the loss of time for the supply of the tool, fastening the part, its control, etc.

The value of the main cutting time is determined by the formula

$$t_2 = \pi DL / (1000VS), \qquad (2)$$

where D is the diameter of parts;

L is the length of cutting.

From Expression (2) we can see that the basic processing time decreases when the cutting speed V and the feed S are increasing.

Time to replace the worn instrument, assigned to one part, is calculated by the following dependence

$$t_3 = T_{in}(t_2 / T - 1/N), \qquad (3)$$

where T_{in} is the time of replacement of one cutting tool;

T is the tool stability;

N is the quantity of parts in the production batch.

The stability of the tool is determined by the formula

$$T = C_V^{1/m} t^{-x/m} S^{-y/m} V^{-1/m}, \qquad (4)$$

where C_V , m, x, y are steel models of cutting process;

t is the cutting depth.

The analysis of the dependences (3) and (4) shows that the time t3 increases with increasing the cutting speed V and the feed S.

Thus, the mathematical model of cutting by the expressions (1) ... (4) can be considered as an object of parametric optimization for determining the rational values of the cutting speed V and the supply S, which minimize the processing time t_k.

Then the optimization problem is formulated as follows: to find such values of the cutting modes V_p and S_p, for which the function (1) reaches its minimum value. This case corresponds to the highest productivity of the investigated process, that is, the production of the maximum number of parts in the least time.

In [1], for S = *const* analytically, by using the equation of the derivative d_{tk} / d_V to zero, this will be

$$V_n = \left[\frac{m}{(1-m)\ T_{in}} \right] \frac{C_V}{t^x S^y}, \qquad (5)$$

which is quite convenient for practical application.

According to the dependence (5), the processing of steel 60X with a T15K6 carbide plate was performed at S = 0.3 *mm / rev*; T_{in} = 2 *min*; t = 3,5 *mm*; C_V = 300; m = 0.27; x = 0.12; y = 0.325, and the value V_p = 242 *m / min* is obtained.

In the given work it is noted that in determining the optimal cutting modes, only velocity V and filing S are taken into account, since the influence of the cutting depth t on the treatment is insignificant. However, in this case, the question about the action of V_p of the variable value S remains open. Note that in order to find the point in which both modes are rational, it is advisable to apply numerical optimization methods and three-dimensional geometric models in the form of corresponding graphs that allow simplifing substantially ongoing research on optimization and enhance their visibility.

In support of this, Figure 1 shows the dependence

$$F(S,V) = \frac{1 + T_{in} t^{x/m} S^{y/m} V^{1/m} / C_V^{1/m}}{SV}, \qquad (6)$$

which is obtained from the formula (1) by leaving only the quantities influencing V_p and S_p.

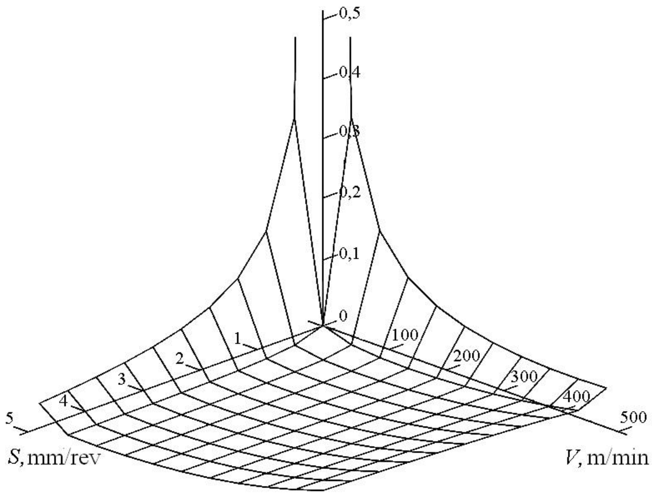


Fig. 1: Three-dimensional geometric dependency $F(S,V)$ model: S – innings, V – cutting speed.

In the image above, the values of T_{in}, t, CV, m, x, y are the same as in the preceding example.

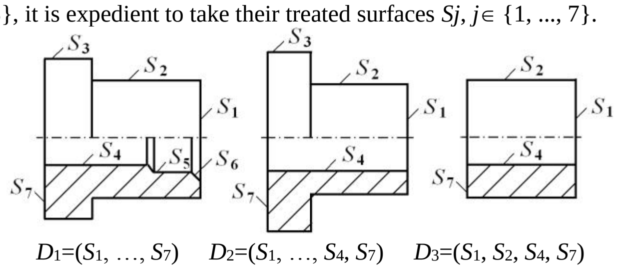
The application for the case S = 0.3 mm is about the optimization procedures from well-known software packages Mathcad and Microsoft Office Excel yields a result that coincides with the analyzed value V_n = 242 m/min. The variation in these systems, in addition to the value S (two-dimensional search), shows that the optimum cutting speed V_p with increasing supply S decreases. The most advantageous value of S_p corresponds to the maximum allowable value of S. These facts are confirmed by the graph of Figure 1.

Thus, the advantage of computational methods of optimization, in comparison with analytical ones, is their simplicity and versatility. The ideal results obtained are explained by a sufficiently smooth nature of the target function (6). Similar data were obtained using the approaches proposed in [14], which is devoted to structural-parametric methods of approximation as means of solving optimization problems. The approach proposed in it allows us to find not only local extrema, but also global in the case of complex target functions.

4.2. Use of structural-parametric geometric models for rational computer design of groups of details and designing technological processes of their production.

Let us consider the key stages of the proposed methodology of integrated computer design and technological processing of machine building products, based on the three typical parts and operational routes for their production, presented in [11], see. respectively Figure 2 and Table 1.

In this case, for the characteristic features of the parts Di, $i\in$ {1, 2, 3}, it is expedient to take their treated surfaces Sj, $j\in$ {1, ..., 7}.



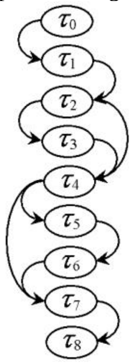
$D_1=(S_1, \ldots, S_7)$ $D_2=(S_1, \ldots, S_4, S_7)$ $D_3=(S_1, S_2, S_4, S_7)$

Fig. 2: Group of parts $D_1 \ldots D_3$: $S_1 \ldots S$ – we treated surfaces.

Table 1: Technological routes for manufacturing parts

Operations		Surfaces									Parts		
Des.	Name	-	S_1	S_2	S_3	S_4	S_5	S_6	S_7	-	P_1	P_2	P_3
τ_0	Preparatory	x									x	x	x
τ_1	Trimming		x								x	x	x
τ_2	Turning			x							x	x	x
τ_3	Turning				x						x	x	
τ_4	Drilling					x					x	x	x
τ_5	Drilling						x				x		
τ_6	Boring							x			x		
τ_7	Cuting								x		x	x	x
τ_8	Control									x	x	x	x

If for instance of a typical detail Di there are variants of their manufacturing $N_{Di}\in$N, then the creation of *individual technology* for each of them will be inefficient. It is more effective to use *typical technological processes* in accordance with the routes shown in Table 1. The application of the *group approach* can be considered even more progressive. In order to do this, as an *integrated part* covering all the elements (surfaces) of the treatment, it is necessary to take D_1. The corresponding *network model* is depicted in Figure 3.



τ	τ_0	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7	τ_8
τ_0	0	1	0	0	0	0	0	0	0
τ_1	0	0	1	0	0	0	0	0	0
τ_2	0	0	0	l_{23}	l_{24}	0	0	0	0
τ_3	0	0	0	0	1	0	0	0	0
τ_4	0	0	0	0	0	l_{45}	0	l_{47}	0
τ_5	0	0	0	0	0	0	1	0	0
τ_6	0	0	0	0	0	0	0	1	0
τ_7	0	0	0	0	0	0	0	0	1
τ_8	0	0	0	0	0	0	0	0	0

a *b*

Fig. 3: Group technology model: *a* is the structure and parameters graph, *b* is the adjacency matrix of elements; $\tau_0 \ldots \tau_8$ are technological operations, 0 is falsity, 1 is the truth; l_{23}, l_{24}, l_{45}, l_{47} are logical expressions.

With its orderly sequence

$$\tau = (\tau_0, \tau_1, \ \ldots \ , \tau_8) = (\tau_k)_1^{N_\tau}, \tag{7}$$

where Nτ=9, the required set of technological operations.

In Figure 3, *b* of the adjacency matrix, except 0 (false) and 1 (true), logical expressions l_{mn}, where $m\in 1 \ldots N_\tau$, $j\in 1 \ldots N_\tau$, are used.

In this case

$$\begin{aligned} &l_{23} = \{S_3 \in D_i\};\ l_{24} = \{S_3 \notin D_i\}; \\ &l_{45} = \{S_5 \in D_i\};\ l_{47} = \{S_5 \notin D_i\};\ i \in \{1,2,3\}. \end{aligned} \tag{8}$$

In the general case of dependence (8) have a more complex form. The analysis of the constructed network model shows that with its help, in particular, the parts $D_4=(S_1, S_2, S_4, \ldots, S_7)$ are made. To exclude such a fact, it is necessary to make corrections in (8)

$l_{45} = \{(S_5 \in D_i) \wedge (S_3 \in D_i)\}$

In accordance with the above scheme, you can create and *rebuild models* that provide the generation of structural and parametric design options that differ not only in the composition, but also in the order of its elements. We only need to consider these models as a set of network components based on sequences of the type (7). From the given material, it is clear that geometrical parameters are widely used for monitoring mechanical engineering products. During parametric design, the shape, size, and position of technical objects are determined by means of certain variables, dependencies between them, certain constraints, etc. This allows for an effective automation to rebuild the existing geometry in a way that is appropriate. These techniques are similar to the use of typical technological processes, but are used in the field of computer design. More promising is the structural-parametric methodology of geometric modeling, which is an analogy of the group approach to production in mechanical engineering.

Let's consider the parametric computer geometric solid-state model of the complex part D_1, which is made of cylindrical billets (Figure 4). The last is indicated by a dashed line.

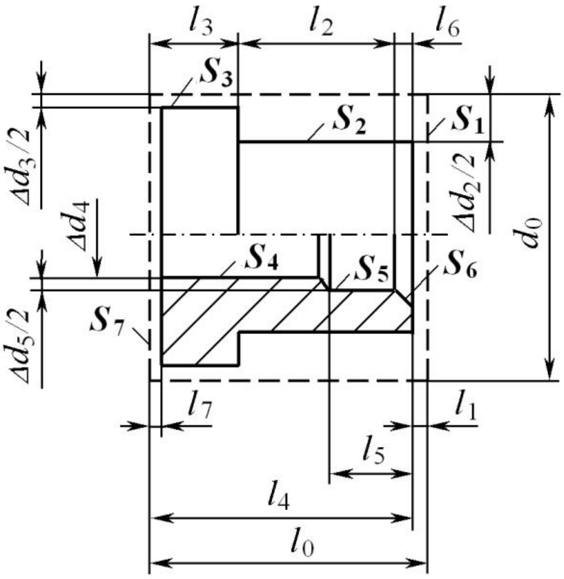


Fig. 4: Parametric Model of Complex Detail D_1: S_1 ... S_7 – treated surface, Δd_j and l_j is the change in the diameter of the surface during its treatment and the length of the cutting, d_0 and l_0 are the diameter and length of the initial direct circular cylinder.

The given parametric geometric figure is the main executing form generoting element for the integral group model shown in Figure 3. As parameters for the surfaces S_j, $j \in \{1, \dots, 7\}$, the parameters Δd_j and l_j are used that contain the values corresponding to the change in the diameter of the surface under its processing time and cutting length. Zero values Δd_j are not shown. The functioning of the analyzed complex part D_1 as a part of the integral group model considered above, by applying Boolean subtraction operations to the original body, is evident.

With the increase in the size of batches in parts, in particular D_1 and D_2, other than cylindrical types of billets are rational, for example, in the form of stamping, which in shape and size are closer to the finished products. These and similar aspects can also be taken into account by the given methods. Consequently, we outline the basic moments of the proposed method of using computer structural and parametric geometric models for integrated design of mechanical engineering objects and the design of technological processes for their production.

Let us consider now some issues of optimization of machine-building products.

The group model depicted in Figure 3 is a multigraph, and the components of its adjacency matrix are multidimensional arrays in terms of programming, that is, the sets of various elements. The arcs connecting the vertices are subjected to certain parametric dependencies, which describe the operations of design and the technological process of making the object. The multigraph allows you to have a comprehensive description of the system being analyzed, in a broader sense, for example, taking into account operational, marketing requirements, etc. The optimal variants correspond to the extreme paths in the network model. For their definition, the method of indexing the vertices is used. The question of using structural-parametric methods for the effective management of production systems is discussed in the publication [6].

It concerns defining the best variants of technological processes for reducing the cost of production, increasing its quality, optimal use of available equipment, equipment, tools, productivity growth, etc. Also, the tasks of implementing rational modifications of existing technological systems have been analyzed with respect to their changes in the direction of increasing the efficiency of practical functioning. It has been shown that the use of structural-parametric geometric models can serve as a methodological basis for organizing the optimal support of the life cycle of diverse products in mechanical engineering in the environment of modern computer information technologies.

4.3. Justifying the advantages of the proposed methodology for designing technological processes in mechanical engineering

The main scientific and applied result of the proposed methodology for the design of technological processes in mechanical engineering is the development of a group of new effective methods of computer simulation. The considered approach is the further development of the methodology of structural-parametric form-formation. The presented materials make it possible to obtain rational engineering solutions in production.

Compared with the traditional methods of designing machine-building technological processes, the presented methodology is aimed at more closely integrated automation of the stages of construction and industrial products manufacturing. An important and practically useful feature of the proposed design techniques is to ensure the productive implementation of variational changes both in the products construction, and in the technology of their production. This moment allows flexibly and successfully adapting to the changing market conditions of the modern economy. In this case, the possibility of structurally-parametric optimization of both created technical objects and technological processes of their manufacture is realized.

The practical significance of the methods using geometric models described in this publication for solving the problems of parametric optimization of mechanical engineering objects is in the process of obtaining results that contribute to improving the visibility of the processes under development and to increase the efficiency of computational procedures in determining not only local but also global extremes of target functions.

We also would like to note that the above-mentioned structural and parametric geometric models and analyzed optimization tools allow visualizing, dynamically and realistically simulating the shaping of many types of mechanical engineering products at the level of technological transitions and their components. This is the basis for conducting successful computer experiments instead of more expensive and long-term field studies, which significantly contributes not only to lowering the cost of industrial products, but also to improving their quality.

Consequently, the main advantages of the methodology of the use of computer structural and parametric geometric models for the rational design of mechanical engineering products and technological processes of their production are described in this article are the system approach to the objects being processed, the flexibility and productivity of the proposed modeling techniques, their universality, the obtaining of integrated rational solutions of the set engineering tasks, visibility of their solutions, etc.

5. Conclusions

Creation of modern high-quality equipment, with minimal expenses for this of all sorts of resources, requires intensive development of various scientific areas and their fruitful introduction into practice. In this article it is shown that one of such means is structural-parametric geometric modeling.

It is noted that technological processes form the basis of production in mechanical engineering. The effectiveness of the latter in many cases determines not only the quality of industrial products, but also their cost, timing, of production etc. Modern advances in computer technology and the related achievements of mathematical and software support the development of many technical objects at a fundamentally new level, for which different computer models are widely used. An effective way to reduce the cost of software development is to unify the methodological and information support of the applicable automated design systems. As a productive way of solving these problems, this publication proposes the use of structural-parametric geometric models.

It has been shown that the creation of perfect mathematical and computer models and their productive application in practice contributes to increasing the efficiency of many processes in mechanical engineering. This applies both to the design of industrial products and to the technological processes of their production.

Perspective directions of further research in relation to the subject discussed in this article can be considered further through-all integration of all stages of the life cycle of complex technical products (ie design, production and operation) with a view to its complex optimization. The last her term we refer to multi-criteria optimization simultaneously in the aspect of several technical disciplines, such as design, strength, technology, exploitation, er-integrity, environmental friendliness, etc.

One more interesting direction of further studies is the use of structural-parametric geometric models for rational design of technological processes in mechanical engineering can be considered as ensuring their real-time playback dynamically. Some aspects of the above-mentioned tasks are analyzed and approaches to their solution in the publication [10] are described. On the example of the wing of an aircraft this article covers such stages of its life cycle as sketch design and manufacturing with the help of assembly technical operations in the form of riveting. In [15], in the dynamical key, the processes of milling of details are investigated using structural-parametric geometric models. Thus, the works [10, 15] together with this article testify to the versatility and perspectives of using in the mechanical engineering of the methodology of structural-parametric geometric modeling.

The prospective directions of conducting further scientific researches, analyzed above, require their comprehensive theoretical and practical elaboration.

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