The problem of applicability of computer-aided design systems in the production of elements of hydraulic units

E N Nesterenko¹, P S Nesterenko¹, Ju L Tchigirinsky¹ and V A Egunov¹

¹Volgograd State Technical University, 28, Lenina ave., Volgograd, 400005, Russia
E-mail: freza851@gmail.com

Abstract: This article is devoted to the problems of organizing digitalized production of elements of hydraulic units, namely, ensuring the applicability of CAPP systems for automated design of technological processes for manufacturing parts of this class. The analysis of the existing CAPP systems used in the design of technological processes, as well as the main problems arising from the use of these systems in the manufacture of elements of hydraulic units. The article considers the technique of applying the theory of graphs to represent the technological process in the form of a structural-temporal table, which considers the process of forming the required quality of a product in the form of a transport network. The article proposes an original method for compiling adjacency tables, which allows to determine the optimal route and processing modes based on information about a specific workpiece and requirements for the final product, which can be used as the basis for the algorithm of the CAPP system functioning.

1. Introduction
The current stage in the development of mechanical engineering is inextricably linked with its digitalization. The basis for organizing digitalized production is the application of the PLM concept, which consists in managing a set of processes in the manufacture of a product throughout its entire life cycle, from design and production to decommissioning [1].

The PLM system includes a number of interconnected modules allowing to increase the transparency and controllability of all processes in the enterprise, at each stage of the life cycle: at the stage of production preparation, at the production stage and at the operational stage. They allow you to determine the real productivity of all departments, calculate the labor intensity of the preparation of production, analysis of the unification of the component parts of the product, the correct assessment of the equipment load, the correct analysis of the needs for tooling and materials, reduce the amount of stocks and work in progress. The first and main stage of the life cycle is preparation of production. This stage of the life cycle is controlled by PDM systems.

However, despite the large number of developed PDM systems, in some cases their individual modules are not applicable in the production of a certain type of product.

2. Materials and methods
The analysis of the applicability of the existing modules of PDM systems in this article was carried out for products that are elements of hydraulic units. Parts of this class, based on their functional purpose,
are made from a limited range of steels of austenitic, austenitic-ferritic and martensitic classes in strict accordance with the recommendations of OST 92-1130-85 "Precise steel parts".

3. Results and discussion
An analysis of the applicability of existing systems in the manufacture of hydraulic elements is given in the table 1.

The analysis shows that the existing systems are mainly applicable in the organization of digitalized production elements of hydraulic units. Difficulties arise when using systems of computer-aided design of technological processes CAPP. As noted in [1], the main problem of using CAPP systems is the absence of criteria for the optimality of technology in a wide range of industries.

| Table 1. The main stages of digital production. |
|------------------------------------------------|
| PLM (product life cycle management) – enterprise lifecycle management system | The possibility of using existing systems in the production of elements of hydraulic units |
| CAD (computer aided design) – design CAD | Applicable |
| CAM (computer aided manufacturing) – system for developing control programs for CNC machines | Applicable |
| PDM (product data management) – summary information on formulations and technology | CAE (computer aided engineering) – engineering calculations system |
| | CAPP (computer aided process planning) – technological design system without CNC |
| | RM (requirements managements) – requirements management module |
| Preparation of production | TDM (time division multiplexing) – technical document management module |
| | Applicable |

In addition, specific technological features of the production of parts for hydraulic units impose their own limitations when applying CAPP systems. There are typical recommendations for processing parts of this class, which are given in OST 92-1130-85. According to OST 92-1130-85, the technological process must, without fail, include preliminary machining, multi-stage heat treatment to ensure the required strength and performance characteristics, as well as a thermostable phase state and final processing with precision accuracy.

The solution to the problem of applicability of CAPP systems consists in clarifying the initial information at each stage of product processing, using mathematical methods to predict the results of multistage machining, taking into account technological heredity.

In the works [2, 3, 4], an original methodology for constructing information support for designing plans for processing elementary surfaces, adapted to the technological capabilities of a particular production, is proposed, based on mathematical methods of the theory of fuzzy sets and mathematical statistics.

The use of graph theory makes it possible to represent the technological process in the form of a structural-temporal table, which considers the process of forming the required product quality in the form of a transport network.

According to this methodology, the information subsystem of routing design is based on an
infological scheme, which shows the main entities and types of connections between them, and the technological processing route itself is presented in the form of an oriented graph, subject to constant "improvement" of the analyzed parameter. Such a route is a graph in which the vertices are processing methods, and the edges are the possibility of making a technological transition.

The mathematical representation of such a route is described in the form of an incidence matrix, which can be used to show the presence and direction ("1", "-1") or the absence of "0" connections between the vertices (Fig. 1).

![Figure 1. Adjacency matrix (a) and undirected graph (b).](image)

It should be noted that the use of the incidence matrix is not a rational solution, due to the need for significant computing resources to find a path in it. Sorting processing methods according to the analyzed technological indicator (from the maximum value to the minimum) value will allow the initial data to be presented in the form of an adjacency matrix.

Multiplying the resulting incidence matrix or adjacency matrix by the weight characteristic of the corresponding graph arc makes it possible to use the algorithm for finding the shortest path in the graph (finding the optimal route) and full recursive enumeration of all routes in the graph (finding alternative routes). An economic, technological, or probabilistic objective function can be used as a weight characteristic of an arc. In the case of the simultaneous assessment of several indicators characterizing the accuracy and quality of the surface, it is necessary to compile an aggregate adjacency matrix. As an example, Table 2 presents a fragment of the compiled adjacency matrix for methods of machining flat surfaces, given in work [2]. The values presented above the main diagonal reflect the change in the complex indicator of accuracy and processing quality, below the main diagonal - the confidence probability of this improvement. The overall assessment of the reliability of the processing method (confidence level) is determined in accordance with the following expression (1):

\[ \alpha = \alpha_{Ra} \cdot \alpha_{IT} \]  

(1)

| N | Previous technological method | The next technological method |
|---|------------------------------|-----------------------------|
|   |                              | 0  | 1  | 2  | 3  | 4  | 5  |
| 0 | Rough milling                | 1  | 1  | 0  | 0  | 0  |   |
| 1 | Finishing milling            | 100,0 | 0  | 1  | 1  | 0  |   |
| 2 | Semi-finish grinding         | 100,0 | 76,77 | 1  | 1  | 1  |   |
| 3 | Thin milling                 | 100,0 | 100,0 | 99,99 | 0  | 0  |   |
| 4 | Finishing grinding           | 100,0 | 100,0 | 99,84 | 81,81 | 1  |   |
| 5 | Thin grinding                | 100,0 | 100,0 | 100,0 | 100,0 | 100,0 |   |

Table 2. Fragment of the adjacency matrix according to the parameter number of the accuracy grade (IT) and roughness (Ra) of the machined surface.
This method has found practical application in works [3, 4]. On the basis of this method, in the
works, programs are proposed that implement a discrete-event model of the multi-junction machining
process. The use of the developed software modules made it possible to analyze the existing
technological processes, as well as to correct them, relying on the calculation for a more optimal
processing route. However, these software modules do not allow taking into account the effect of heat
treatment on the technological heredity of the part. Therefore, in order to obscure the applicability of
this method of constructing technological processes for the manufacture of hydraulic elements, the
operation of heat treatment should be added as one of the factors. As an example, the adjacency matrix
is given in general form for the case of manufacturing a part of accuracy class 1 from steel
X102CrMo17 table [3].

| N  | Previous technological method        | The next technological method |
|----|--------------------------------------|------------------------------|
| 0  | Rough turning                        | 0                            |
| 1  | Coarse grinding                      | 1                            |
| 2  | Heat treatment by mode I             | 2                            |
| 3  | Finishing turning                    | 3                            |
| 4  | Heat treatment by mode II            | 4                            |
| 5  | Precision turning (solid turning)    | 5                            |
| 6  | Grinding                             | 6                            |
| 7  | Heat treatment by mode II            | 7                            |
| 8  | Lapping                              | 8                            |
| 9  | Stabilizing heat treatment by mode II| 9                            |

4. Conclusion
The introduction of the heat treatment operation in its various variations as a factor under
consideration made it possible to ensure the applicability of this methodology for determining the
optimal route both for the elements of hydraulic units, and to expand the scope of its application in the
construction of CAPP systems, which led to a better understanding of the relationship between the
conditions and processing results.

The proposed approach makes it possible to reliably determine the values of increasing the
accuracy and quality of processing, which can be considered as criteria for the formalized design of
technological processes.

References
[1] Product Lifecycle Management (Volume 3): The Executive Summary, John Stark. 2018. 137p
[2] Tchigirinsky Ju L 2010 Formalized approaches in technological design Russian Engineering
Research 30 (3) 305-307
[3] Tchigirinsky Ju L and Polyanchikov Yu N 2012 Refining the permissible parameter ranges in
formalizing path design Russian Engineering Research 32(2) 189-191
[4] Tchigirinsky Ju L and Polyanchikov Yu N 2012 Refining the permissible parameter ranges in
formalizing path design Russian Engineering Research 32(2) 189-191