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SYSTEM-STRUCTURAL MODELING OF TECHNOLOGICAL PROCESSES FOR MANUFACTURING «COVER»-TYPE PARTS

СИСТЕМНО-СТРУКТУРНЕ МОДЕЛЮВАННЯ ТЕХНОЛОГІЧНИХ ПРОЦЕСІВ ВИГОТОВЛЕННЯ ДЕТАЛЕЙ ТИПУ «КРИШКА»

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Abstract. *This paper discusses the methodology of system-structural modeling of technological processes and systems using the example of a «cover»-type part. The principles of the systems approach were applied in the analysis of mechanical assembly production. The structure of a technological operation is described. It is shown that the emergence of the most significant types of technological processes depends on the types of machines, tools, and technological equipment. The functional, temporal, and spatial structures of the technological process and its components are analyzed.*

Keywords: *technological system, technological process, technological operation, system-structural modeling, structure, machine, tool, fixture, cover.*

Introduction.

System-structural modeling of technological processes and systems makes it possible, based on fundamental knowledge of manufacturing engineering, to carry out process design through the development of effective models of complex objects. This also encourages the application and further development of system-structural modeling methodology in industrial practice as a scientifically grounded method for improving technological processes.

The essence and principles of the systems approach in the design of complex systems are discussed in [1, 2]. The systems approach as the most advanced methodology of scientific research is analyzed in [3, 4]. Studies [4, 5] present system modeling methods, systems thinking, and system analysis of advanced technical objects. The mathematical foundations and mathematical tools for modeling systems are presented in [6, 7]. Research into technological systems − specifically their modeling, design, and optimization − is covered in [8, 9]. Works [10, 11] explore the design of technological processes and structural transformations in mechanical engineering. The design issues in manufacturing and assembly, as well as system-structural modeling methods of technological processes, are presented in [12, 13, 14]. Study [15] reveals the capabilities of model-based systems engineering (MBSE) in modeling.

Thus, it can be concluded that modern science perceives the world as an infinite and continuously developing hierarchy of systems. The systemic nature of our thinking stems from the systemic nature of the world, and therefore, further research in the field of system-structural modeling of complex objects and processes is a relevant and urgent task today.

Main Text.

At the current stage of development, manufacturing technology is a science about the regularities of production processes, the selection of optimal process parameters, and rational ways of managing them. This science is increasingly becoming a direct productive force, with manufacturing processes evolving under its influence and becoming its technological application. The practical goal of manufacturing technology is to ensure the most cost-effective production of high-quality products with high productivity.

The structure of a technological operation in mechanical assembly production depends on the following factors:

− the required number of setups, transitions, passes, and actions;

− the number of workpieces processed simultaneously (single-position or multi-position machining);

− the number of tools used in the operation (single-tool or multi-tool machining);

− the number of spindles or supports involved and machining positions (single-position or multi-position machining).

Practice has shown that solving the problem of optimal structural configurations of technological processes should be based not on empirical methods but on theoretically grounded approaches. Research shows that structural relationships at the level of elementary links directly determine the production capabilities of both individual technological operations and entire processes. It should be noted that even the elementary components of technological operations, such as machines, tools, and fixtures, are complex systems themselves. Therefore, theoretical foundations for the effective use of work equipment have been developed, along with methods for optimizing the structure of technological processes.

The study of the stochastic nature of technological processes allows the following conclusions:

1) The emergence of major types of technological processes depends primarily on the types of equipment, tools, and technological fixtures. These variants arise as a result of using products that differ in structure and design;

2) Comparing different variants means comparing the results of applying different work equipment systems to the same workpiece.

It should be noted that every technological process includes functional, temporal, and spatial links between its structural elements. Each type of link corresponds to its own structure. Therefore, we can speak of functional, temporal, and spatial structures of the technological process and its components.

Let us consider an example of developing a functional-structural model of a technological process for manufacturing a «cover»-type part. First, we analyze the functional structure of the technological process, which defines a partially ordered sequence of transitions from the initial workpiece state O_0 to the final state O_k (finished part according to its working drawing). Each machining operation (turning, milling, etc.) corresponds to a specific transformation φ. The formula of the *functional structure* of the technological process is as follows:

$$S_\varphi(O,F) = O_0\varphi_1O_1\varphi_2O_2\varphi_3O_3\varphi_4O_4\varphi_5O_5\varphi_6O_6\varphi_7O_7\varphi_8O_8\varphi_9O_9$$

The corresponding graph of the functional structure is shown in Figure 1.

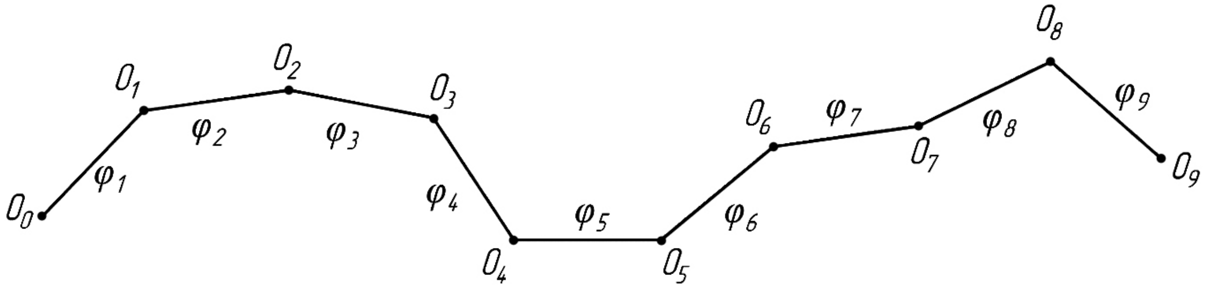


Figure 1 - Graph of the functional structure of the technological process

Author's illustration

The *temporal structure* formula of the technological process under standard sequential execution (without time shift − ρ) is as follows:

$$S_{\text{в}}(F, \Omega) = \varphi_1 \rho \varphi_2 \rho \varphi_3 \rho \varphi_4 \rho \varphi_5 \rho \varphi_6 \rho \varphi_7 \rho \varphi_8 \rho \varphi_9$$

The corresponding graph of the temporal structure is shown in Figure 2.

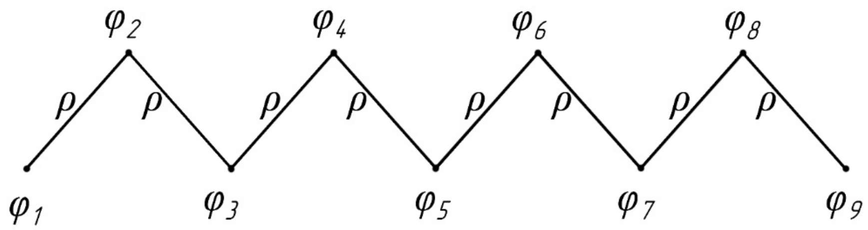
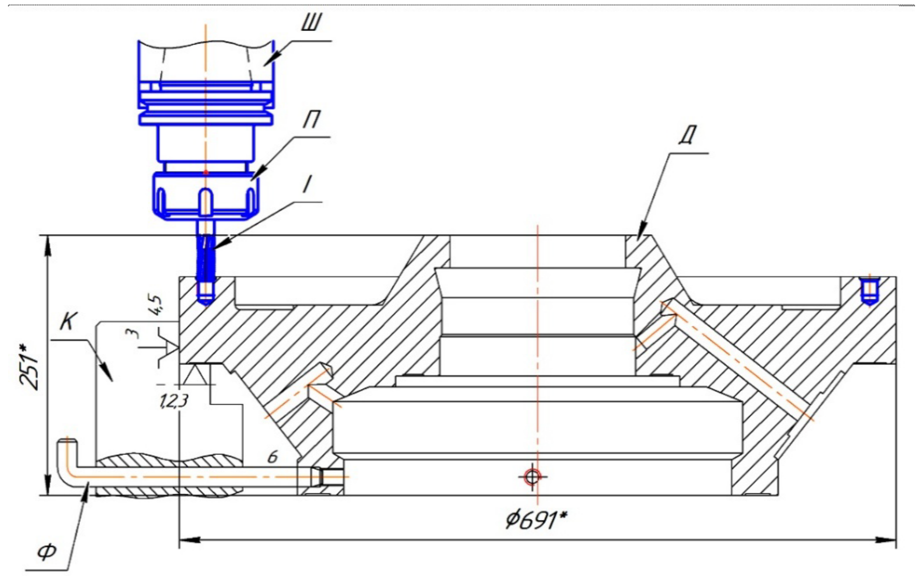


Figure 2 - Graph of the temporal structure of the technological process

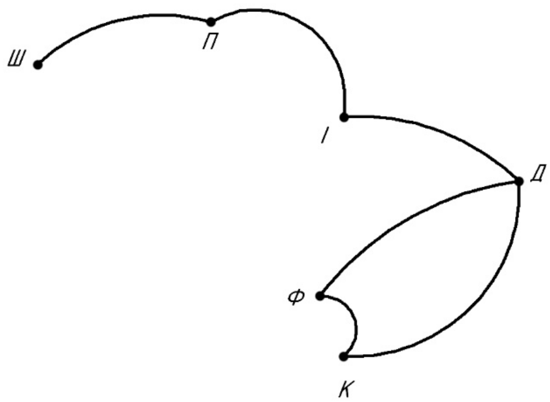
Author's illustration

Figure 3 presents a setup sketch for a milling operation (a) and the graph of the spatial structure of the technological operation (b).

For functional-structural analysis of individual operations and the entire technological process, a special table is used, as shown in Figure 4.



a)



b)

Figure 3 - Setup sketch of the milling operation (a) and spatial structure graph of the milling operation (b)

Author's illustration

This table shows the sets of machines, tools, and fixtures used in each operation. Each operation's structural model is defined. The degree of process coverage by different operation types (three-element, two-element, one-element, and zero-element) is calculated. The shares of manual, mechanized, and automated labor in the total labor intensity of part manufacturing are determined. The share of the technological process covered by manual, mechanized, and automated operations is also calculated. Based on the analysis, conclusions are drawn about the structural efficiency of the examined process (high level).

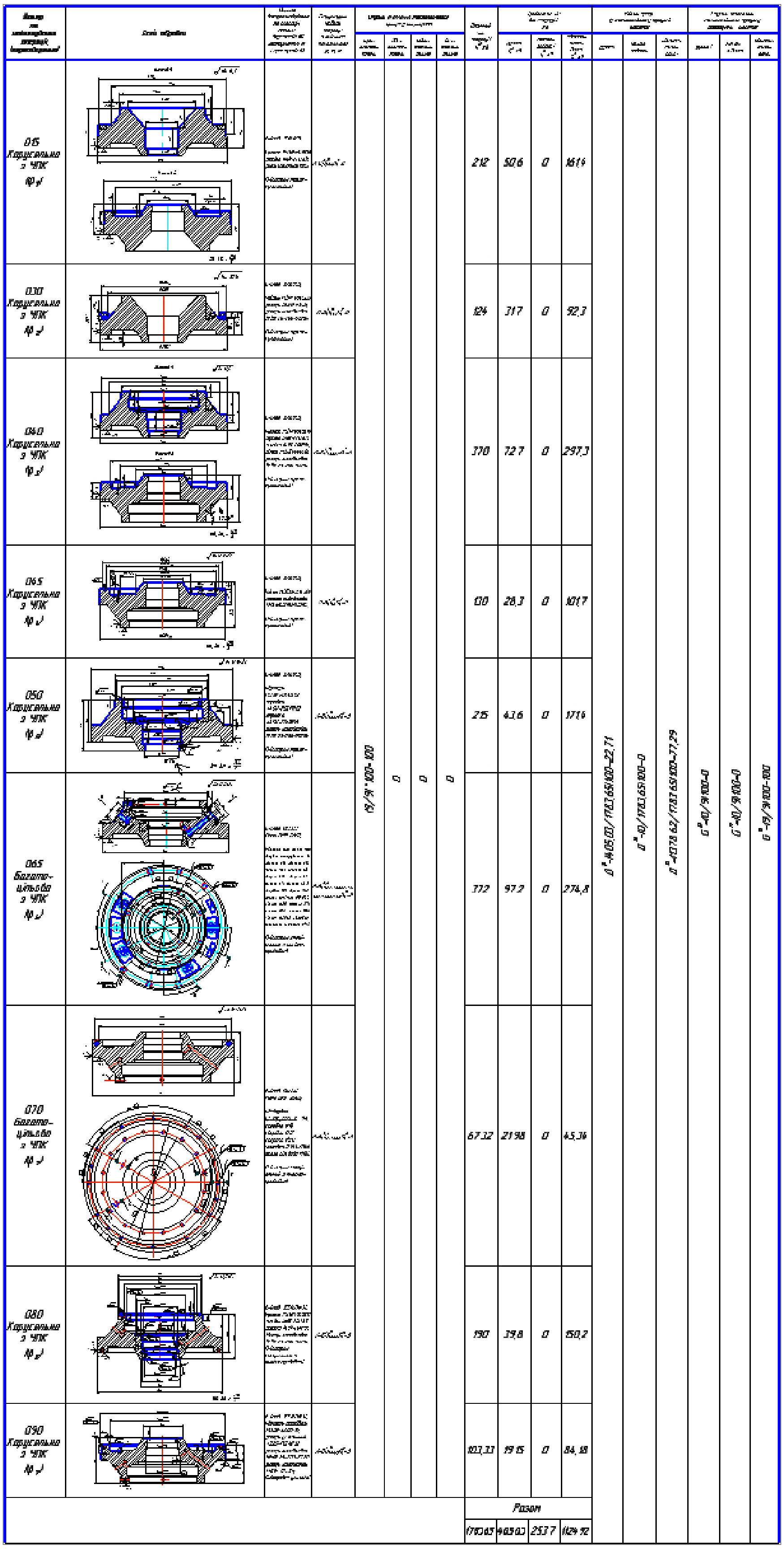


Figure 4 - Functional-structural analysis of operations and the entire process for manufacturing the «cover» part

Author's illustration

Conclusions.

The application of system-structural modeling methods enables the improvement of technological processes for manufacturing parts. The use of set-theoretic principles for classifying elements of the technological system makes it possible to identify technological regularities in the synthesis of machining routes. The proposed principles for building functional-structural models of operations and processes are important for identifying internal reserves of technological systems and for assessing the advancement level of both existing and newly designed technologies.

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Анотація. *В роботі розглянуто методику системно-структурного моделювання технологічних процесів і систем на прикладі деталі типу «Кришка». Для цього використано принципи системного підходу при аналізі механоскладального виробництва. Дано опис структури технологічної операції. Показано, що поява найбільш істотних різновидів технологічних процесів залежить від різновидів верстатів, інструментів і технологічного оснащення. Проаналізовано функціональну, часову та просторову структури технологічного процесу і його частин.*

Ключові слова: *технологічна система, технологічний процес, технологічна операція, системно-структурне моделювання, структура, верстат, інструмент, пристрій, кришка.*

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