Structure of a products flow in multi-nomenclature rotary lines with regard to tool change times

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Abstract. Flexible manufacturing systems are widely used for reducing the volume of products production and increasing the variety of their forms. However, there are large numbers of products that differ in minor elements and have a similar manufacturing technology - fasteners, furniture fittings, etc. The use of flexible manufacturing systems for their manufacture is inefficient due to the availability of cheaper and more productive, re-adjustable and onenomenclature equipment. In turn, the use of this high-performance equipment also becomes ineffective, because large quantities of goods are difficult to be sold, and small batches do not pay off the costs of changing equipment. We propose to use multi-nomenclature rotary lines for solving this problem. The ability of creation of flexible production systems which are based on multi-nomenclature rotary lines is considered in this article. Augmented classification of a products flow in multi-nomenclature rotary lines allows to determine the structure of the products flow and to identify their structural feature - the impact of the time for the tool change on the structure of multi-nomenclature rotary machines. The number of sizes of manufactured products and the number of group tool blocks should be selected on the basis of the possibility of their replacement.

1. Introduction
There is a tendency to reduce the output of products and increase the variety of produced products forms and sizes [1]. Flexible production systems based on CNC machines are widely used in modern engineering to meet these requirements [2]. However, there are a large number of products that differ in minor elements and have a close manufacturing technology - fasteners, furniture fittings, etc. The use of flexible production systems for their manufacture is inefficient due to the availability of cheaper and more productive, re-adjustable and single-nomenclature equipment. In turn, using of this high-performance equipment also becomes inefficient because large quantities of goods are difficult to be sold and small batches do not pay off the cost of changing the equipment [3]. The solution to this problem can be the creation of flexible manufactures based on multi-nomenclature rotary lines [4] which allows combining a group of serial productions into a multi-nomenclature mass one. It should be noted that the proposed lines do not allow producing different types of products with different production programs without line reconfiguration [5]. Therefore, further improvement of multi-nomenclature rotary machines and lines in order to increase their flexibility is an urgent task.

The purpose of this article is to study the structure of the products flow in multi-nomenclature rotary machines and lines to identify and solve problems that reduce their flexibility.
To achieve this goal it is necessary to identify the features of the products flow structure in multi-nomenclature rotary lines, to determine the most rational products flow structure for the implementation of flexible production, to analyze the selected flow structure from the point of view of its implementation on multi-nomenclature rotary lines.

2. Selecting the products flow structure

The current classification of the products flow structure in multi-nomenclature rotary lines [3] does not take into account the peculiarities of automatic lines processing in relation to the organization of the products loading into the line. The developed classification of product flows in a multi-nomenclature rotary line takes into account these features and is shown in figure 1.

![Figure 1](image)

*Figure 1.* Classification of products flows in a multi-nomenclature rotary line in terms of logistics.
This classification is based on the classification of product flows which is used to solve logistics problems [6]. By the degree of continuity flows are diverted into continuous flows, - a certain number of products move at the time of the flow, and discrete flows, - products move at intervals at each moment of time. By the degree of regularity deterministic flows (which are characterized by definite parameters) and stochastic flows (characterized by a random character of the parameters) are distinguished. By the degree of stability the flows are divided into stable flows which are characterized by constant values of the parameters for a certain period of time, and unstable flows which are characterized by a change in the flow parameters. By the degree of variability, stationary flows (typical for a steady-state process, their intensity is constant) and non-stationary flows (typical for an unsteady process, their intensity varies during a certain period of time) are distinguished. By the nature of the products movement the flows are uniform (characterized by a constant speed of objects movement and equal intervals of the beginning and completion of objects movement) and uneven flows (characterized by a change in the speed of movement, the possibility of acceleration, deceleration, and stopovers). By the degree of periodicity, periodic flows are distinguished with constant parameters or the constancy of the nature of their variation through a certain period and non-periodic flows with the absence of regularity in the variation of the flow parameters. By the degree of controllability the flows are divided into manageable (adequately responsive to the control action on the part of the control system) and uncontrollable (not responsive to the control action).

The total number of possible variants of the products flow patterns is determined by the movement of different products along the structural elements of rotary machines [5] (figure 2). It is selected when looking at the variants of the morphological matrix:

\[
M = \begin{pmatrix}
    p_1^1 & p_1^2 & p_1^3 \\
    p_2^1 & p_2^2 & p_2^3 \\
    p_3^1 & p_3^2 & p_3^3 \\
    p_4^1 & p_4^2 & p_4^3 \\
    p_5^1 & p_5^2 & p_5^3
\end{pmatrix}
\]

(1)

where M is the morphological matrix;

\(p_1^1, ..., p_5^3\) are morphological features.

Morphological features here are the possible variants of flow structures according to different classification criteria:

\([p_1^1, p_2^1, p_3^1]\) - by the ratio of the number of product sizes (Zo) and the number of multi-nomenclature working positions (Up) (Zo < Up, Zo = Up and Zo > Up);

\([p_2^1, p_2^2, p_2^3]\) - by the number of simultaneously processed products: group processing, unit processing and mixed processing;

\([p_3^1, p_3^2, p_3^3]\) - by the nature of readjustment of multi-nomenclature rotary machines: with sequential processing, with simultaneous machining of products and with mixed processing;

\([p_4^1, p_4^2, p_4^3]\) - by thread: with parallel flow, with sequential flow and mixed flow;

\([p_5^1, p_5^2, p_5^3]\) - by the identity of the flow characteristics: with the same characteristics for all multi-nomenclature working positions, with different characteristics for each position and with mixed flows.

The total number of possible variants of flow structures that can be generated by the proposed morphological matrix is determined by the expression:
\[ N = 3^k = 3^3 = 243 \]  \hspace{1cm} (2)

where \( N \) is the number of possible variants of the products flow structure; 
\( k \) is the number of classification characteristics.

Thus, 243 variants of products flow structure are possible.

Taking into account the presented classification, the total number of possible variants of the flow structure \( N \) can be determined by the formula:

\[ N = 243 \cdot 2^7 = 31104 \]  \hspace{1cm} (3)

For implementation of flexible automated production on the basis of multi-nomenclature rotary machines it is necessary to ensure the possibility of launching products into production without changing the automatic line. The flow must be continuous as a whole along a line and discrete for individual product sizes. Other characteristics of the flow are determinism and stability, steady-state and uniformity. To ensure the necessary flexibility, the outflow of products must be periodic and controlled.

Figure 2 shows the scheme of a multi-nomenclature rotary machine (MRM), on which the described products flow can be realized. The scheme shows group tool blocks (GTB), which allows processing of different products. During the process of work, the products enter the multi-nomenclature rotary machine in the loading zone 1 in loading stream V. During the transportation with the speed \( ST \), the products are processed and unloaded from the machine after processing in the unloading zone 2 along the output stream W. To process a product of other size, tool change in zone 3 occurs. It should be noted that in this case the number of tools in the GTB should be equal to the number of standard sizes of the machined products. This will allow processing in each GTB all sizes of products. In addition, the tool changers must provide the ability to change the tool (turning the tool store 180 degrees when rotating in 2 sides or 360 degrees when rotating in one direction). The number of GTB and the number of instruments in the GTB have to be picked up so that to provide a possibility of this condition performance. In other words, the following condition must be satisfied:

\[ t_s \geq t_i \]  \hspace{1cm} (4)
where $t_3$ is the time to change the instrument, i.e. the time of finding a multi-nomenclature instrument cluster in zone 3 (see figure 3);

$te$ is the response time of the tool changers in the block.

![Figure 3. Scheme of a multi-nomenclature rotary machine.](image)

The time of the block change in zone 3 at the stage of preliminary calculations can be taken as $\frac{1}{4}$ of the time of the kinematic cycle [3] of the multi-nomenclature rotary machine. Thus, expression 4 takes the form:

$$
t_3 = \frac{1}{4} Tk = \frac{1}{4} \frac{Up}{Pc} \geq t_e
$$

(5)

where $Tk$ is the time of the kinematic cycle (full revolution) of the multi-nomenclature rotary machine;

$Up$ is the number of group tool blocks;

$Pc$ is the cyclic productivity of the machine.

For the convenience of calculations, we assume that the machine processes $Zo$ of different sizes of products, and that the machine provides the production of each size with a capacity $QA$, i.e. $Pc = Zo \cdot QA$. Thus, expression 5 takes the form:

$$
t_3 = \frac{1}{4} Tk = \frac{1}{4} \frac{Up}{Zo \cdot QA} \geq t_e
$$

(6)

where $Zo$ is the number of product sizes processed in each GTB (number of tools in the GTB)

$QA$ - machine performance when machining a product of one size.

In figure 4 is a graph of the time dependence of the block being in the tool change area on the number of product sizes processed in one block and the number of group tool blocks. The graph is plotted from the dependence 6 for $QA = 100$ pcs / min.

From the diagram in figure 4 it is clear that for certain values of $Up$ and $Zo$, condition 6 will not be satisfied, i.e. with such designs of multi-nomenclature rotary machines it is not possible to implement flexible production on the basis of multi-nomenclature rotary machines. This is due to the fact that in order to ensure the required high productivity, it is necessary to increase the rotational speed of multi-
nomenclature rotary machines and to reduce the time of finding group tool blocks in the tool change area.

3. Conclusion
When it is necessary to reduce the volume of products output and increase their diversity the grouping of serial productions into a multi-item mass production will allow the creation of new flexible production systems based on flexible multi-nomenclature rotary lines. The supplemented classification of products flow structures in multi-nomenclature rotary lines made it possible to determine the structure of the products flow in flexible multi-nomenclature rotary lines and to reveal the peculiarity of their structure. The influence of the time of tool change on the structure of multi-nomenclature rotary machines is revealed. The carried out researches allowed to find out that the number of sizes of manufactured products and the number of group tool blocks should be chosen with considering of possibility of their change for realization of flexible manufacture on the basis of multi-nomenclature rotary machines.

4. References
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