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**Вінницький національний
аграрний університет****УДК 631.312****DOI: 10.37128/2306-8744-2023-2-5****INNOVATIVE METHODS OF
MONITORING THE MECHANICAL
PROCESSING PROCESS**

The problem of ensuring the necessary quality and exploitation of the properties of machine parts is becoming more and more important in mechanical engineering. The main idea of the work consists in the development of a fundamentally new approach to the monitoring of a machine tool complex of mechanical processing, the essence of which is the organization of the method of controlling the mechanical processing process on the basis of a single integrated information environment adapted to the universal complex of computer modeling Matlab/Stateflow and Matlab/Simulink, with structural representations of all components of the mechanical processing process and modeling as a problem-solving tool that expands the functionality of machine tool complexes. However, until now, generalized theoretical relationships between surface quality parameters, processing accuracy, operational properties of parts and parameters of mechanical processing processes, which allow solving the problem of technological support of given operational properties of parts.

Management of the process of forming a surface with the necessary properties is carried out mainly by using partial experimental dependencies and tables of processing modes. The complexity of the problem lies in the fact that when processing parts, it is necessary to establish such processing conditions that would provide a set of requirements for tool wear, processing accuracy, surface quality characteristics, productivity, etc. The areas of the most effective use of production systems are primarily determined by the technological equipment that is a component of the system, the nomenclature of processed parts and the automated control system, which allow to solve the problem of technological provision of given operational properties of parts.

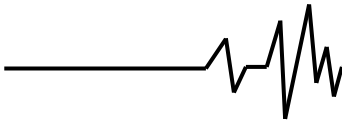
Keywords: machine complex, functionality, monitoring, equipment calibration, machining process, information, material and energy flows, multi-purpose and multi-coordinate machines, machines with parallel kinematics.

Analysis of recent research and publications. Complex automation of technological processes has long been one of the most important areas of development of complex technological systems. The last decades are characterized by significant progress in the automation of mass and multi-series production of machines, assembly units and parts in various industries.

In recent years, significant technical and organizational changes have taken place in the field of mechanical engineering, which are associated with the emergence of new means of technological influence, the creation of new types of flexible production systems (FMS) with labor-saving ("unmanned technology"), wide and increasingly increasing introduction into the field production of

software-controlled equipment and computing equipment. This is especially relevant for flexible automated productions, the functioning of which is impossible without a significant increase in the reliability and efficiency of complex precision equipment, and primarily metal cutting machines. On the one hand, these are highly efficient machines in which many achievements of science and technology have been implemented. From the second, there are machines that are designed for the manufacture and processing of parts of other machines.

Main part. The development of a system for monitoring the mechanical processing mode should begin with the definition of the optimization criterion based on technical and economic analysis [1-10]. In practice, performance and cost criteria are most often



used, which include the dependence of tool stability on cutting parameters. As a result of optimization according to these criteria, there are conditions that ensure the maximum (in the first case) and minimum (in the second case) values of these criteria in certain situations. In many situations, certain values of the stability of the tool act as such conditions. However in production, the task of finding the maximum possible productivity or the minimum possible cost of mechanical processing at given stability values is often set.

In recent years, attempts have been made to develop other dependences of wear or tool stability on cutting parameters. However, it is more convenient to perform the calculations of the optimal cutting modes using the optimization objective function, which is the basis of the standards by which machining modes are determined in almost all branches of mechanical engineering. Therefore, further calculations will be made using the formula

$$\Pi_v = \frac{bhs}{1 + \tau_{cm} (h^{x_v} \frac{318c_v k_v D^{q_v-1}}{z^{u_v} y_v b^{r_v}} s^{y_v} n^{1-y_v})^{1/m}}$$

where $\frac{318c_v k_v D^{q_v-1}}{z^{u_v} y_v b^{r_v}} = A_{1.}$, c_u is a constant value for a certain group of processed materials; k_u is a coefficient that depends on the properties of the processed material, the cutting part of the tool and the type of lubricating-cooling liquid; D is the diameter of the milling cutter or workpiece; n — rotation frequency, rpm; $sz = s/(nz)$ — feed, mm/rev., mm/tooth; z — the number of cutter teeth; h and b — cutting depth and width, mm; $x_u, y_u, r_u, q_u, u_u, m$ are measurement indicators that depend on the properties of the tool and cutting conditions (the values of these indicators and coefficients c_u and k_u are contained in the relevant reference books).

For different types of processing, the values of c_u, k_u and indicators of variable measures are different. In addition, indicators x_u, y_u, r_u, q_u, u_u are not used in all types of mechanical processing.

The input data of the model is the electronic image of the part, which includes geometric and structural parameters. As an example in fig. 1 shows the implementation of the electronic model of the product (hydraulic distributor housing) using CAD software AutoDESK Inventor [1,10].



Fig. 1. Electronic image of the part a) - 3D model of the distributor housing; b) - fragment of a text file, c) - parametric model of the corpus; containing a description of the geometry and elements of the part

The created system describes all the above-mentioned flows and displays the following actions: decomposition of the electronic image and its transformation into a process of mechanical processing, which the system displays; obtaining an optimized process of mechanical processing (by modeling); selection depending on the current state of the processing route system; assembling a model of the production processing system from subsystems; decomposition of the geometric image of the part obtained from the automated design system; decoding of the control program for the numerical software control system obtained from the adaptive control system; selection and assignment of the tool; monitoring of the state of the machining process on the machine, etc.

Optimization of the processing technology of the part on the machine is carried out according to the classical method based on the criterion of maximum processing productivity. In the machines of traditional

schematic solutions, relatively simple graphic objects are specified and measured: lines, planes, cylinders, which correspond to simple movements, while parallel kinematics machines have complex elementary movements whose control is difficult. Therefore, an event-oriented state graph of the processing process was developed, which is implemented using the Stateflow complex [1]. Optimization of the process of processing the part on the machine is carried out according to the methodology based on the criterion of maximum processing productivity. Design and technological limitations are the lowest possible rotation frequency of the milling cutter n_{dmin} , at which the conditions for obtaining chips deteriorate and growth appears, the highest possible rotation frequency of the milling cutter n_{dmax} , which is determined by the structurally specified upper limit of the range and the value $n_{\theta max}$, when exceeding which rapid wear and destruction of the tool occurs due to its heating, the largest feed per tooth sz_{1max} ,



limited by the permissible processing cleanliness and tool strength, the largest and smallest feeds $s_{min} \leq s \leq s_{max}$ of change in the rotation frequency of the feed drive. The permissible moment on the tool is $M \leq \min(M1d, M2d)$, which is determined by the strength of the tool and machine mechanisms (Fig. 2). A feature of the optimization of the machining process on a parallel kinematics machine is that the feed Sz is carried out by simultaneous movements of several kinematic links. Therefore, the optimization of the

processing process has to be carried out in two stages. At the first, determine the necessary technological indicators of the processing process (sz , h and b , nd). At the second stage, based on the determined value of sz , determine the optimal distribution of movements of each kinematic chain necessary to implement the determined sz . The objective function is the minimum amount of work performed on each movement.

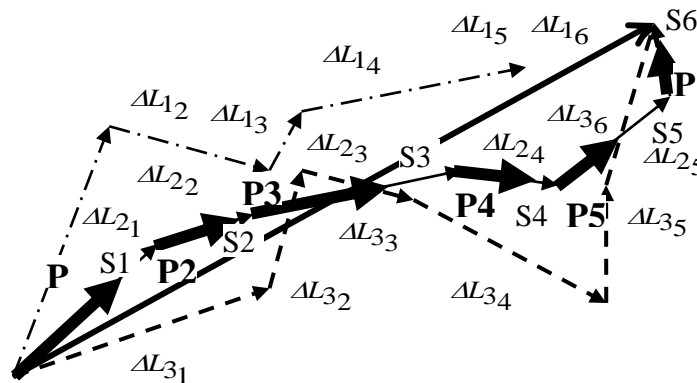


Fig. 2. Trajectories of coordinate movements of machine tool drives

The geometric characteristics of the working space of the machine tool (the ability of the drive to provide the necessary value of movement at a given angle), the error of approximation of the movement trajectory (which is determined by the minimum discreteness of the movements of the drives) and the maximum permissible forces developed by the movement drives [1,3, 5]. The spatial system of the parallel kinematics machine is a statically indeterminate system. To determine the loads arising in the machine's feed drives, it is necessary to create and implement its mathematical model. Simulation of the movement of the parallel kinematics machine platform is carried out using the Simulink package of the Matlab mathematical system. The calculation is carried out using the extension blocks of the SimMechanics package. The SimMechanics extension package of the Simulink system is intended for physical modeling. Its purpose is technical design and modeling of mechanical systems (within the limits of the laws of theoretical mechanics). The model of the mechanism is created based on the setting of the inertial parameters of its moving parts. In fig. 3-5 show

the procedures for calculating the kinematic and power parameters of the parallel kinematics machine and the geometric model of the mechanism. The model provides two main types of loading - processing with axial tools (drills, countersinks, reamers) and milling cutters (end, groove, mushroom). Modeling of the movement of the platform is carried out according to the principle of inverse dynamics. The geometric characteristics of the movement are determined on the basis of an accurate geometric model. And then a correction is made to the calculated coordinates, which takes into account dynamic phenomena, arising during movement as a result of the inertial properties of the platform itself and drive links. On the basis of the calculation of the parameters of the movement of the drive rod of the platform, the angles of inclination of the rod, the reaction in the hinges and the drives of the movement of the rods of the mechanism are determined. Models using SimMechanics package function blocks are universal and allow you to create models of new mechanisms simply by replacing some modules.

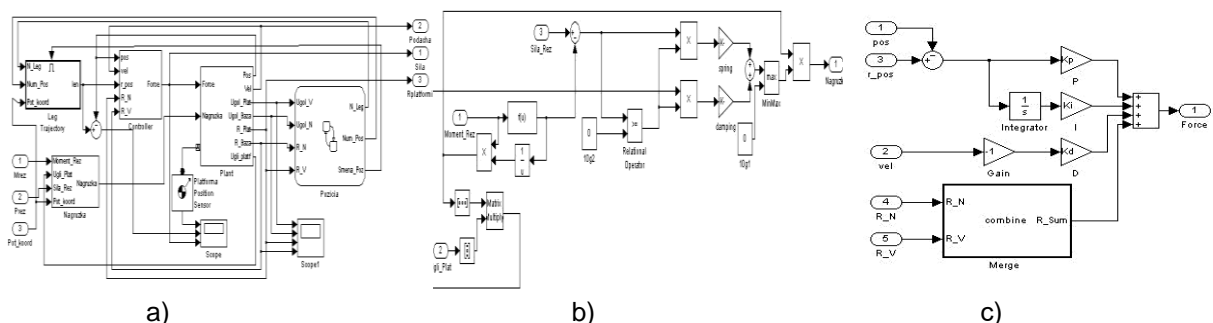


Fig. 3. Mathematical model for calculating machine parameters: a) - the main module of the procedure; b) - module for setting the platform load; c) - the module for determining the load in the rod linear movement drive

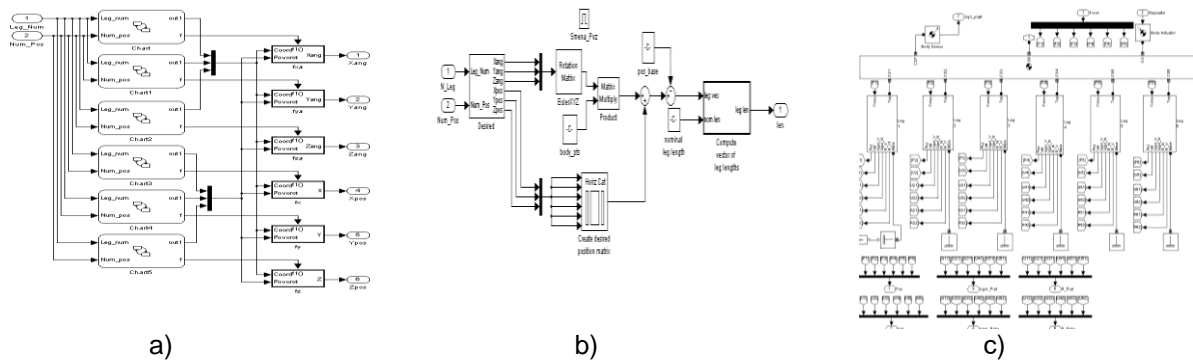


Fig. 4. Mathematical models for calculating the coordinates of the trajectory of the platform movement: a) - task module; b) - calculation module; c) - modeling module

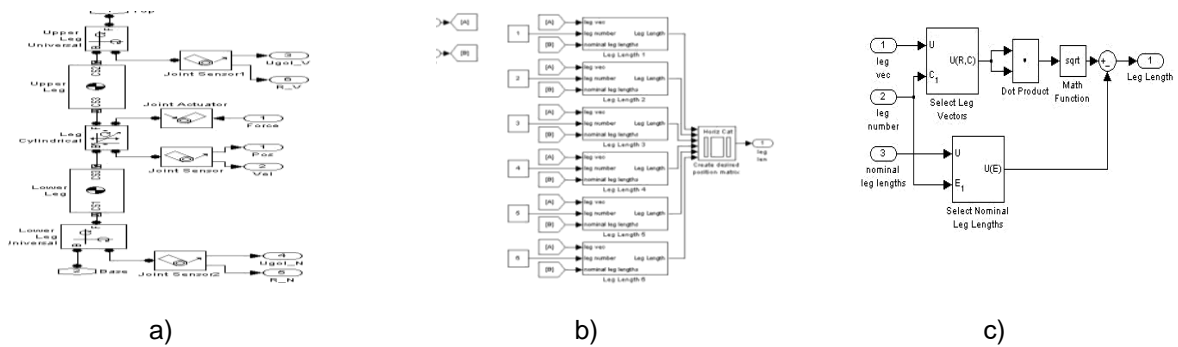


Fig. 5. Mathematical models for determining bar movements: a) - rod movement simulation module; b) - the module for determining the current length of the mechanism rods; c) - the module for calculating the current length of the i-th rod

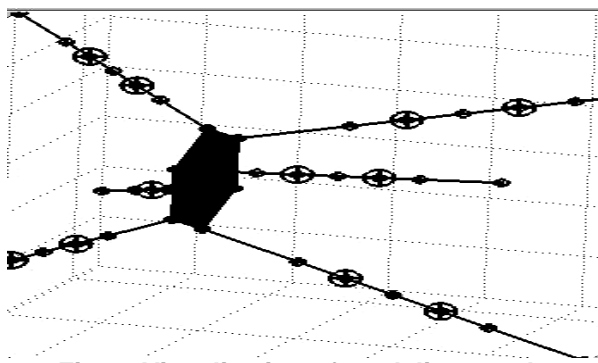


Fig. 6. Visualization of modeling results

Conclusions. The considered software allows you to automate the process of programming and modification and settings of the CHPK system in order to reduce the labor-intensiveness of conducting control works. The use of the results of the work will significantly increase the efficiency and reliability of production systems of mechanical processing and will make it possible to introduce a correction in the work schedule of the automated line, which ensures its more effective use and reduction of energy consumption. The established processing conditions ensure the requirement for tool wear, processing accuracy, surface quality characteristics, and productivity.

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ІННОВАЦІЙНІ МЕТОДИ МОНІТОРИНГУ ПРОЦЕСУ МЕХАНІЧНОЇ ОБРОБКИ

Проблема забезпечення необхідної якості та експлуатації властивостей деталей машин набуває в машинобудуванні все більш важливого значення. Основна ідея роботи полягає в розробці принципово нового підходу до моніторингу верстатного комплексу механічної обробки, сутність якого полягає в організації методики керування процесом механічної обробки на основі єдиного інтегрованого

інформаційного середовища адаптованого до універсального комплексу комп'ютерного моделювання Matlab/Stateflow та Matlab/Simulink, при структурному поданні всіх складових процесу механічної обробки та моделювання як інструменту розв'язання задачі, що розширює функціональні можливості верстатних комплексів. Проте до теперішнього часу не розроблені узагальнені теоретичні залежності між параметрами якості поверхні, точністю обробки, експлуатаційними властивостями деталей і параметрами процесів механічної обробки, що дозволяють вирішувати задачу технологічного забезпечення заданих експлуатаційних властивостей деталей. Керування процесом формування поверхні з необхідними властивостями здійснюється переважно шляхом використання часткових експериментальних залежностей і таблиць режимів обробки. Складність проблеми полягає в тому, що при обробці деталей необхідно встановити такі умови обробки, які б забезпечували комплекс вимог щодо зносу інструменту, точності обробки, характеристикам якості поверхні, продуктивності тощо. Області найбільш ефективного використання виробничих систем перш за все визначаються технологічним обладнанням, яке є складовою частиною системи, номенклатурою оброблюваних деталей та автоматизованою системою керування.

Ключові слова: верстатний комплекс, функціональні можливості, моніторинг, калібрування обладнання, процес механічної обробки, інформаційний, матеріальний та енергетичний потоки, багатоцільові та багатокоординатні верстати, верстати з паралельною кінематикою.

Відомості про автора

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