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Information Approach In Constructing Mathematical Models And In Control Of Technological Systems For Processing The Low Rigidity Parts

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Abstract- This article presents an information approach to the consideration and analysis of developed mathematical models of technological systems for processing the parts of low rigidity in an elastically deformed state in dynamic regimes. Mathematical models of technological systems of elastically deformed non-rigid parts have been developed. Hierarchical levels and characteristic structures of dynamic models of technological systems are given. Research has been conducted with an application of a multilevel structure of modeling and optimal control of dynamic regimes in the process of diagnosing the parameters of mechanical processing.
Keywords – mathematical model , mechanical processing, grinding, information approach, hierarchical level, multi-level structure of modeling.

I. INTRODUCTION

Development and implementation of the achievements in information technologies when improving the systems of control and design of technological systems are the tasks to reach a given quality of the products. The task of control of technological systems for mechanical processing of parts of low rigidity that provide the required accuracy and quality of the surface is hampered by the fact that in the processing the part itself, the tool and the machine units, being in relative motion, represent a complex dynamic system; its behavior is practically impossible to determine without targeted and theoretical studies. The most expedient direction of problem solution is the control of technological systems of machining of non-rigid parts in an elastically deformed state on the basis of scientifically grounded technological methods of workpiece shaft processing [1,2].

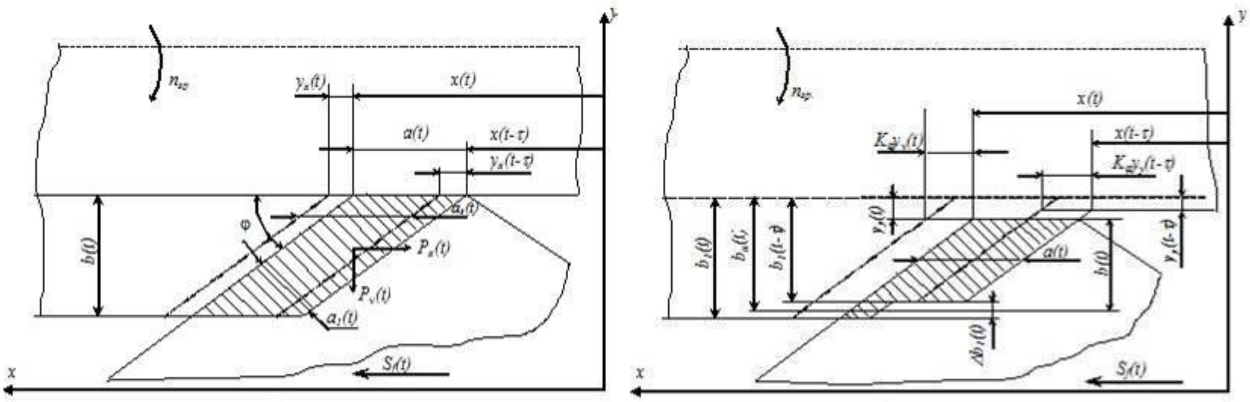
Traditional way to construct an effective automated control and management system, as well as the algorithm of its functioning, is the creation of a structural model of the components of technological process that allows controlling the accuracy of technological process and accounting excitation effects occurring in the process of machining [3].

To develop such models is possible only with a comprehensive consideration of structure, purpose and function of technological system (TS) and their characteristics. This function should convert, with a reasonable degree of accuracy, the initial information and known methods of analysis into information on opportunities (the current situation and prospects) with adequate basic models and analysis tools that meet the accepted criteria. Such an approach to the realization of the function of basic models allows the formation of active, purposeful actions in the process of research, which guarantee, with a high probability, the obtaining of predetermined results under conditions of changes in the external and internal environment [4].

II. MATHEMATICAL MODEL OF TECHNOLOGICAL SYSTEM OF TURNING OF NON-RIGID PARTS

Development in dynamics of mathematical model (MM) of a control object, adequate to the model of real object, is a necessary prerequisite for a subsequent substantiated approach to solving problems of strength analysis and synthesis of a control system based on specified indicators of control quality in transient regimes. In such systems, the indicators of the quality of control of the output coordinate - elastic strains of TS in dynamics - directly characterize the errors in the shape of the unit due to rapidly changing excitations such as the changes in stock material for processing, variations in physical-mechanical properties of the material being processed, and so on [5-7].

The process of turning is characterized by the influence of processing traces on the course of the process - the so-called "trail" cutting phenomena. These phenomena are as follows. The components of the sheared metal layer at the current time (Fig. 1) are determined by the position of the cutting edge of the tool at current time t, and by the coordinates of the cutting edge at time $t-\tau$ of previous revolution of the workpiece shaft.



(a) (b)

Cross-section of the cut-off layer with allowance for elastic strain: a - along the x coordinate; b - along the y coordinate (taking into account the change in stock material in processing)

Based on consideration of physical model of the cross-section of a cut-off layer at axial turning, taking into account the internal connections in the object and the features of "trail" cutting, a system of equations in the operator form is obtained; it describes the object of control - a technological system of turning in the form:

$$\begin{cases} P_\xi(S) = m_\xi(S)\cdot a(S) + n_\xi(S)\cdot b(S) + q_\xi(S)\cdot c(S) \\ a(S) = \dfrac{1}{S}(1-e^{-S\tau})S_{np}(S) - (1-e^{-S\tau})y_x(S) - K_\varphi(1-e^{-S\tau})y_y(S) \\ b(S) = \dfrac{1}{S\tau}(1-e^{-S\tau})b_1(S) - y_y(S) \\ c(S) = \dfrac{1}{S\tau}(1-e^{-S\tau})c_1(S) \\ y_\xi(S) = K_\xi(S)\cdot P_\xi(S) + \Delta y_{f\xi}(S) \end{cases}, \quad (1)$$

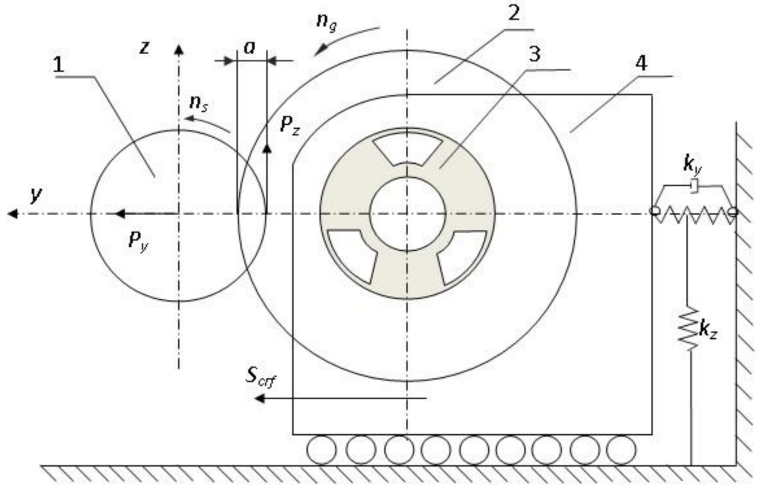
where $P_\xi(S)$ are the components of the cutting forces; $m_\xi = (dP_\xi/da)_0$, $n_\xi = (dP_\xi/db)_0$, $q_\xi = (dP_\xi/dc)_0$ - are the coefficients for the cutting force components by increment: of the reduced thickness of the cut a(s) (here and hereinafter the sign of increment Δ is omitted for simplicity), the cutting depth b(s) and the hardness of the processed material c(s), respectively; $K_\xi(S)$ - is a transfer function equal to the transfer constant $K_\xi = \left(dY_\xi/dP_\xi\right)_0$; $\xi = \{x,y,z\}$; $K_\varphi = ctg\varphi$ - is a coefficient that takes into account the effect of elastic strain along the Y axis on the reduced thickness of the cut. Additional force effects, formed on TS to control the elastically deformed state of the unit, lead, in the general case, to the occurrence of additional strains in elastic system along each of the coordinates; this is taken into account by introducing the second term $\Delta Y_{f_\xi}(s)$ in the last relation of the system of equations (1); a specific kind of relationship is determined by various power control effects. Thus, equations (1) describe dynamic properties of TS under axial turning. The process of cross turning can be considered as a special case of axial turning, and described generalized mathematical model may be used in its algorithmization. The system of equations is simplified due to the fact that there is no axial component of the cutting force in cross turning, and the feed is directed along the y coordinate.

III. MATHEMATICAL MODEL OF ROUGH GRINDING PROCESS FOR A NON-RIGID SHAFT PROCESSING

The parameters of the surface macro-relief in the processes of cylindrical plunge grinding are not sufficiently studied, in spite of modern software packages designed for research and modeling of dynamic systems [8].

The control of rough grinding process of low rigidity shafts processing, with corresponding mathematical model, makes possible to increase the accuracy of the sizes and shapes of the processed products, to improve technical and economic parameters of processing and to improve the reliability of normal operation of technological system (TS). Therefore, one of the primary tasks is the task of developing a mathematical description of TS, which functions in dynamic regimes [8-10].

To simulate the process of macro-relief shaping of a polished unit, it is necessary to have a model of a grinding machine with a cutting process and an external influence in the form of rough surface of a unit. The scheme of a grinding machine is shown in Fig. 2.



Simplified scheme of grinding process: 1- machined shaft; 2 - grinding wheel; 3 - grinding head; 4 - grinding machine bed

Mathematical model of the process of circular grinding of non-rigid shafts in an elastically deformed state, taken as an object of control, reflects the interrelations between the cutting forces and the main control actions, and in the general case takes into account the actual cutting process, elastic strains of TS and the features of chip forming [11].

Input effects are the effects that create the elastically deformed states: e - the eccentricity in tension; Mi - the moment created by axial component of the cutting force Px; Px1 - tensile force and cross feed speed - Scrf; and the output variable is an elastic strain of technological system along the Yy coordinate. Besides, only linear elastic strains of the system and rigidity variations ky, kz on the y, z coordinates are taken into account. With the assumptions made, the cutting force is determined by the thickness of the cut a(t) only.

Mathematical model of technological system of grinding of low-rigid shafts in the operator form is written in the form of a system of equations:

$$\begin{cases} P_\xi(S) = m_\xi a(S) \\ a(S) = \frac{1}{S}(1-e^{-S\tau})S_{crf}(S) - (1-e^{-S\tau})y_y(S) \\ y_y(S) = k_y P_y(S) + k_{P_{x1}} P_{x1}(S) + k_e e(S) + k_{Mi} M_i(S) + k_{bz} y_z(S) \\ y_z(S) = k_z P_z(S) \end{cases} \qquad (2)$$

where, $\xi = \{y, z\}$, b=const − is the grinding width, $k_{bz} = \sin(y_{z_0}/R) \approx y_{z_0}/R$ − is the transfer constant that establishes the relationship between the increment in the cutting depth and the cutting force component Pz.

Partial mathematical models for other control actions are obtained similarly [12]. Cutting force arising in the process of circular grinding can be expanded into three components: tangential Pz, radial Py and axial Px [13].

IV. HIERARCHICAL LEVELS OF MATHEMATICAL MODELS OF TECHNOLOGICAL SYSTEMS OF PROCESSING

An information approach is advisable when taking mathematical models of technological systems of metal processing of elastically deformed parts as the system objects that take into account important and various features of the operation of control object [13]. This approach shows that the generalized mathematical model of technological system of axial turning is the most complete one, it has a great informative capacity in the hierarchy of structures and models of technological systems and is located at the I level - the highest hierarchical level (Fig. 3).

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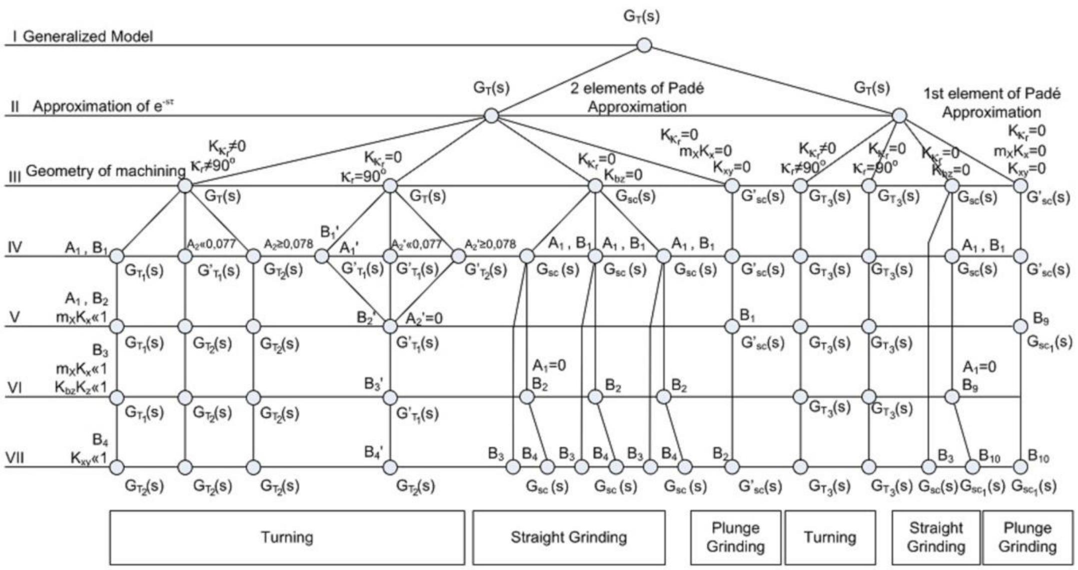

Hierarchical levels of mathematical models of the systems for processing elastically deformed low-rigid shafts

At the II hierarchical level, the generalized mathematical model (by the degree of accuracy of approximation of function e-SJ, when the latter is expanded into the Pade series) can be divided into two models, the first of which takes into account the first two terms of the expansion of function e-SJ, and the second one includes one term of the expansion.

At the III hierarchical level, the generalized mathematical model for technological systems of axial turning of non-rigid shafts is divided into two models depending on the geometry of the cutting tool. Mathematical models for the processes of oscillating grinding and external cylindrical plunge grinding, which may be taken with corresponding assumptions as special cases of the model of technological system of turning, are located at the same level.

At the IV hierarchical level, mathematical models of (1) and (2) types for technological systems of turning, for the process of oscillating grinding and external cylindrical plunge grinding are located.

At the V and VI levels partial mathematical models obtained without the influence of a number of relationships and internal feedback loops in the objects on the dynamics of the process, are located.

At the VII level, there are partial mathematical models of technological systems of metal processing that take into account the effect of elastic strains only in the y coordinate on the increment of the cut thickness at turning, at external cylindrical plunge grinding and two versions of partial models at oscillating grinding [7].

V. DEVELOPMENT OF THE STRUCTURE OF THE SYSTEM OF INTERRELATION IN MODELING, INFORMATION PROCESSING AND CONTROL OF TECHNOLOGICAL SYSTEMS PARAMETERS

In recent years an analysis of the methods of mathematical modeling of TS functioning in machining of law rigidity parts has shown that the corresponding studies have been carried out within the framework of a single-level research structure that does not give exact values of adjusting, damping, rigidity parameters of control objects and testing to maintain transient processes within specified limits, for lack of interacting subsystems of state and control evaluation. The necessity and urgency of research in this area is proved by insufficient knowledge of the application of multilevel structure of modeling and optimal control of dynamic regimes in the process of diagnosing the parameters of machining [14].

The application of a multilevel structure of modeling and optimal control of dynamic regimes in the process of diagnosis allows us to conduct research based on modern information technologies and extends the information database by constructing the structure of functional blocks and cross-effect of the results of solving some functional blocks on others. At the same time, the research strategy is built on the basis of successive, cyclic and iterative actions of approaching the goal by improving the previous stages of the study.

Analysis of research methods for controlling the accuracy of machining in engineering, which cover various means and methods of mathematical modeling and optimal control of technological systems of machining, attests to the achievement of significant theoretical and practical results in this field [8-13]. However, when implementing effective methods, it is necessary to take into account all basic factors affecting the dynamic interaction of the elements of the control system of TS. It is important, to emphasize the optimal values of control parameters in dynamic regimes.

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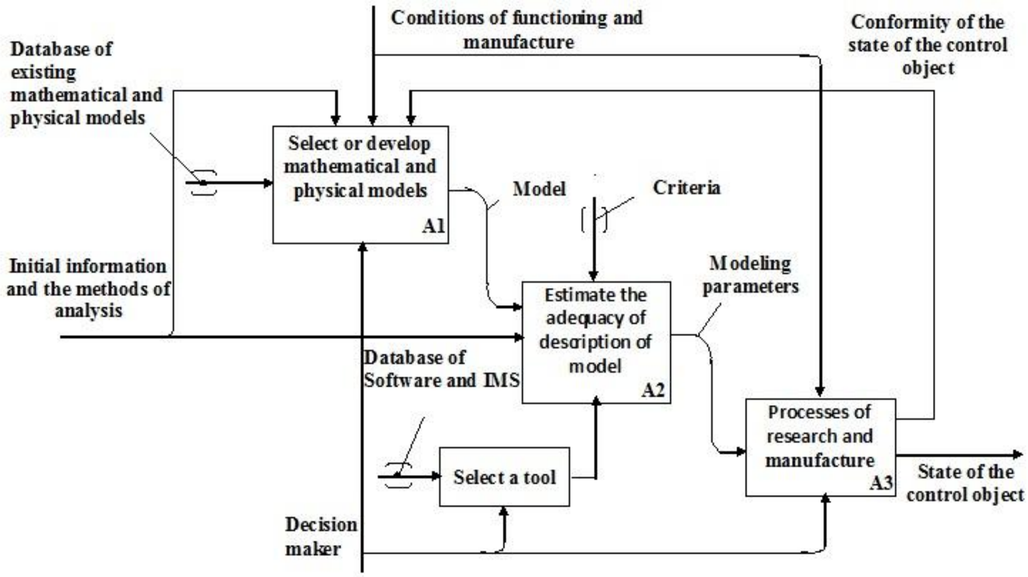

Decomposition of functional block of the process of functioning and manufacture

For effective representation and analysis of formalized interrelations of the multilevel structure of research, diagnosis and control, the methods of graphic modeling IDEF-methodology (ICAM-Integrated Computer-Aided Manufacturing - Integration of computer and industrial technologies DEFinition) are used. In this case, all functions of the simulated system are represented in the form of corresponding functional blocks that convert the inputs into outputs with necessary resources (mechanisms) under controlled conditions [15-17].

Figure 4 shows the decomposition of a functional block for mathematical and physical modeling of the processes of technological systems and machines functioning.

As seen from Fig. 4, three arcs: "Database of Existing Mathematical and Physical Models", "Database of Mathematical Support (Software) and Information-Measuring Systems (IMS)" and "Criteria" are providing a character to study the functioning of technological system.

By activating these arcs, the existing formalization apparatus and research methods are analyzed; they allow passing from simple to perfect systems in research of the functioning of technological system.

“Database of existing mathematical and physical models" is the accumulation of a certain amount of studies in a corresponding field of research. It is supplemented by new information technologies, which are an integral part of the system being developed.

“Database of mathematical support (Software) and IMS" is a set of mathematical and computational methods, mathematical models and algorithms of research, and means of information-measuring systems (IMS). IMS is a system of sensors, converters, transmission channels and other means that provide data on experimental process; these data are necessary to perform research of technological system presented in a given form.

"Criteria" is an estimation of the degree of adequacy of these models to the initial data and to the analysis of information in accordance with the requirements of the tasks set for the study of the process of parts machining.

Naturally, the activation of these arcs depends on the interaction of a decision-maker with the modules of functional blocks of the processes of investigating TS functioning; these blocks provide for control over these arcs.

VI. CONCLUSION

Developed mathematical models of technological systems for processing non-rigid elastically deformed parts are the models of technological modules of any production system; this fact creates the prerequisites for the development of a methodology for systematic approach to the design of technological processes, taking into account dynamic characteristics of technological systems.

Information approach to the analysis of developed mathematical models of technological systems for processing parts of low rigidity allows us to divide them by the number and quality of information in the models, and makes it possible to systematize the efforts of researchers in developing control systems to solve the problems facing them.

Functional model developed for investigating the structure and characteristics of technological system based on the IDEF0 methodology allows to graphically displaying the simulated system in the form of a decomposition of functional block that converts inputs into outputs with necessary control resources.

This decomposition reflects the hierarchical structure of modeling and the strategy of research of the processes of functioning of technological systems and machines with adequate models and analysis tools that meet the accepted criteria.

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