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Adaptive mechatronic mechanism information model

Anatoly M. Gushchin[1)]
ORCID: https://orcid.org/0000-0002-1289-9557; guschinanatoliy1@gmail.com
Vasily P. Larshin[2)]
ORCID: https://orcid.org/0000-0001-7536-3859; vasilylarshin@gmail.com. Scopus Author ID: 7801669969
Oleksandr V. Lysyi[1)]
ORCID: https://orcid.org/0000-0002-7389-1161; lenafox107@gmail.com
[1)] Odessa Military Academy, 10, Fontanskaya Doroga Str. Odessa, 65009, Ukraine
[2)] Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine

ABSTRACT

Defect-free machining of materials and products with a strictly organized anisotropic structure (polymer composite materials), with an uneven change in physical and mechanical properties throughout the volume (synthegran) or with high strength properties (artificially grown superhard ruby and leucosapphire crystals) is either impossible or not economically feasible on modern CNC technological machines. The reason for this is the lack of information about the power parameter, e.g., the machining force and torque. Therefore, the use of the developed adaptive mechatronic mechanism (AMM) module, which implements parametric stabilization of the power machining parameter in an open-loop control system, was an effective solution to this technological problem. An analysis of the issue state in the field of mechatronic and intelligent machines has shown that to date, mechatronics as a science systematically combines mechanics, electronics, and informatics (computer science). Moreover, the term informatics indirectly reflects another component of mechatronics – automation. In this regard, two main methods of automatic control are considered: by deviation in a closed system with feedback and by disturbance in an open system without feedback on the controlled parameter. Examples of open-loop systems with disturbance control, in which the "disturbance compensation principle" is implemented, are given. This method cannot be replaced in the absence of sensors – sources of information about physical processes in technological machines for various purposes, for example, in machine tool building, biomedicine, nuclear and military technology. As a rule, in all these machines there is a reciprocating movement of the working body (tool). The information model of the AMM module presented in the article reflects its main elements and characteristics, including driving forces (electromagnetic and electrodynamic), a ball-bearing screw mechanism, a fixed (unmovable) stator with a field winding and a movable armature with armature winding. The place of this article in the general system of scientific research on the formulated new scientific direction "Mechatronic and intelligent technological machines" is shown. This article is an introduction to this scientific direction, when automatic regulation "by disturbance" is performed in a mechatronic machine, i.e., the principle of disturbance compensation is fulfilled.

Keywords: Mechatronic mechanism; machining cycle; reciprocating motion; disturbance control; parametric adaptation

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1. INTRODUCTION

1.1. Technological principle of machining

Typical machining is based on the technological principle of reciprocating movement of the tool. For example, the typical mechanical cycle in drilling includes a tool rapid approach (RA), its machining pass (MP), the tool intermediate withdrawal (for cleaning it and introducing coolant into the cutting zone), and the tool rapid retraction (RR).

It seems to be a simple cycle, but it requires adaptation and intelligent control due to complex physical processes in the zone of interaction between the tool and the machining object. For example, defect-free machining of materials with a strictly organized anisotropic structure, with an uneven change in physical and mechanical properties throughout the volume, or with high strength properties is not economically feasible on modern CNC machine tools.

Such materials include, for example, polymer composite materials, syntegran, artificially grown superhard crystals of ruby and leucosapphire, modern plasma coatings, and many others. The reason is that on such machines, the CNC system provides only kinematic parameters of machining (displacement, speed, acceleration, impact). At the same time, the quality and productivity of machining are primarily determined by power parameters (force and torque in the machining area).

The new technical solution, described below, has passed experimental and production testing and has shown new positive results that allow us to recommend its wide application in the creation of mechatronic machines (including machine tools and robots) of a new generation.

1.2. Means to ensure the technological principle

To implement the controlled reciprocating motion, an adaptive mechatronic mechanism (AMM) module has been developed, in the design of which a "system of counteracting forces" is implemented, ensuring their dynamic equilibrium. The ratio between these forces is adjustable and is determined by the requirements of the machining technology. The AMM module creates and regulates not kinematic, but power parameters in mechatronic and intelligent technological machines.

Mechatronics is a modern science that has fifty years of experience, dating back to 1972. It includes mechanics, computer science and electronics (electricity and magnetism). Currently, mechatronics is associated with all those scientific disciplines that were usually part of cybernetics, including applied mathematics, automatic control theory, telemechanics (telecommunications and telemetry), artificial intelligence, information signals and systems, electromechanics, computer signal and image processing, digital technologies in engineering, etc. New terms have appeared in engineering and technology, for example, "mechatronic machine tools", "mechatronic and intelligent machines", "configurable control", "mechatronic modules", etc.

2. LITERATURE REVIEW

The emergence of new materials and technology of high-strength cladding, on the one hand, and the need for defect-free machining of parts made of superhard and hard-to-machine materials, on the other hand, led to the need to develop mechatronic and intelligent machines.

Existing in-situ monitoring techniques are different depending on the features of laser additive manufacturing. For example, laser induced breakdown spectroscopy (LIBS) was suggested for in situ and real time elemental analysis of clad as well as cladding process failures detection [1]. In-situ monitoring and ex-situ elasticity mapping for laser induced metal melting pool are also examples [2]. Besides, in situ X-ray imaging of defect takes place in laser additive manufacturing [3] as well as in-situ thermal imaging for single layer build time alteration is also used [4].

This section discusses the sources of information related to the features of approaches and phenomena that need to be taken into account when automating design and production.

The last 40-50 years, without exaggeration, can be called the time of development of information industries. Information technology covers all areas of human activity, including politics, economics, industry, education, art and others [5]. To the present, manufacturing has been recognized as a skillful function which is implemented in a workshop. Manufacturing is no longer merely machining or fabrication. Moreover, manufacturing systems are covering everything from order receipt through the product shipment [6]. There is no need to assert (this is clear from the very beginning) that all the stages of developing an integrated manufacturing system (including CAD/CAM/CAE) correspond to the product life cycle, on the one hand, and are based on information and its meaning depending on the stage, on the other hand. In this regard, great (and over time increasing) importance is attached to improving the efficiency of productive technologies based on virtual and physical technologies.

The development of virtual reality brings an old and historic question on the difference between the real world and unreal world as well as between desired and actual. What we call "virtual reality" is a representation of an actual or non-actual world and the criterion of difference between the "real world" and "virtual reality" is whether we present it with the intention of using it as a representation. In other words, "virtual reality" is presented as a simulation or representation of an actual or non-actual world, whereas what we call the "real world" is not presented as such [7].

The linguistic meaning of information includes issues of modeling and simulation [8], on the one hand, and issues of automation of technological processes and technological systems [9], on the other hand.

That is why this research deals with conception, principles, and procedures needed to explain both the essence of and the difference between two production flows, namely the flow of information and the flow of materials. The objective of research is to establish the necessary and sufficient conditions for ensuring the progress of an integrated manufacturing system in terms of efficient product design and manufacturing.

Automation of production is an effective means of increasing the productivity of technological operations. At the same time, the acceleration of the working movements of technological machines often leads to stricter requirements for the speed of automatic systems.

This requirement is partially reflected in the mechatronic technological system (MTS) described

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in [10]. However, this development has a number of disadvantages.

1. Large overall dimensions do not allow MTS to be used as a replaceable tool head for CNC machines.

2. The large weight of the moving parts limits the performance of MTS.

3. Inertia associated with the regulation of the power parameter by its deviation in a closed control system.

For example, the transition from the principle of control “by deviation” to the principle of control “by disturbance” shortens the path of the information signal from the source of its occurrence to the actuator, especially due to a rigid kinematic relationship between the resulting imbalance and the place of its elimination. In this case, the classical principle of automatic control works when the resulting disturbance is self-eliminated (the principle of compensation of disturbances).

Monitoring of CNC machining applications allows the production to be analyzed and improved, can improve part quality, reduce scrap and help with the overall resource usage associated with a production machine tool. Online process monitoring can allow the machine to become smarter and adapt to its conditions internally [11]. Machine learning and adaptive machining could further help improve manufacturing efficiency. However, in order to allow machines to become “smart”, widespread application of sensing technologies to machine tools must be carried out. Typically state of the art sensing systems for real-time machine monitoring is cost-prohibitive to be applied machine-wide in a plant. Usually, such systems are restricted to R+D and work in a Lab environment. Therefore, there is a need for a low cost, flexible sensor system that is easy to apply to currently existing both CNC technologies and CNC machines.

The same goal is served by the idea of “direct action regulators” expressed by I. A. Vyshnegradsky in his famous work “On direct action regulators” (1877), which later became known as “direct regulation” and “direct action systems” [12].

To illustrate the idea of “direct regulation”, it is enough to recall the principle of operation of the Watt’s centrifugal governor. The governor effectively controlled the process of converting steam energy into mechanical work using the principle of proportional control [13]. The idea of direct regulation is manifested in the fact that in the automatic control system “by deviation”, the information signal of the deviation of the current shaft speed from the set speed is formed by a mechanical converter along a rigid kinematic circuit and without involving an additional energy source. In this case, the efficiency of the system directly depends on the transfer function of the mechanism. The study of this mechanism was carried out by scientists of different age generations, starting from I.A. Vyshnegradsky (1831-1895), who by mathematical modeling established the reason for the low efficiency of the Watt's governor.

To identify the essence of a new technical solution, it is necessary to turn again to the principle of equilibrium of solids in space, the qualitative characteristic of which is defined as “stability” (Fig. 1).

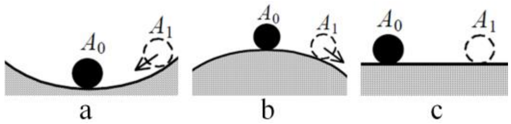

Fig. 1. **Illustration of the stability concept: a – stable system; b – unstable system; c – neutral system**

***Source*: compiled by the [14]**

The equilibrium position of the ball is characterized by the point A_0. When deflecting to position A_1 in the first case, the ball tends to position A_0 (Fig. 1a), in the second it does not tend to this position (Fig. 1b), in the third (Fig. 1c) − the state of the ball is indifferent. In an indifferent state (Fig. 1c), the equilibrium must be restored by the application of any external forces, for example, the weight of a load or a spring (Fig. 2).

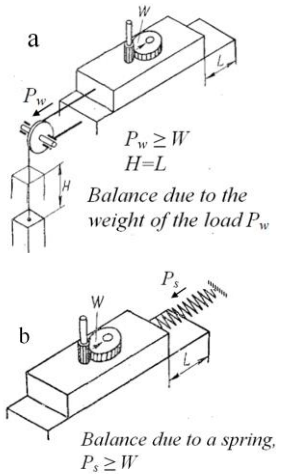

Fig. 2. **Circuits of force closure due to the weight of the load (a) and due to the spring (b)**

***Source*: compiled by the [12]**

Computer-aided design and production [15] as well as the idea of representing a system through its input, state, and output [16] were used in the development of the mechatronic mechanism described below. Another idea of balancing forces [17] with the principle of “configurable control” [18] are also used. The principle of hierarchical control [10] and its features [19] in intelligent systems were also taken into account. The mechatronic mechanism considered below can be applied not only to metal-cutting machine tools, but also to any mechatronic machines in which it is necessary to change the force and regulate the torque according to the program. It may be implants production using additive technologies [20] and online monitoring [21, 22].

Intelligent control algorithms are extensive. It could be genetic algorithm using neural network [23, 24], data processing [25] and machine learning [26] as well as data control [27] and image processing [28]. Therefore, such intelligent data processing must be provided on CNC machines, for example, drilling and grinding machines with an intelligent numerical control system.

The purpose of the article is to develop a design and algorithm for the functioning of the AMM module. In other words, this article discusses the introduction to the problem (when the machining technology determines the structure of the mechanism), the design and principle of operation of the AMM module for the implementation of a typical machining cycle, based on the reciprocating motion of the tool.

3. RESEARCH METHODOLOGY

3.1. Information model in statics

The disadvantages of the mechatronic technological system described in [10] are eliminated in the new design of the AMM module, which is designed to implement a controlled reciprocating motion based on the principle of "dynamic equilibrium" of oppositely directed forces.

The new technical solution – the AMM module – implements a synergistic set of the following technical effects and principles.

1. The principle of separation of electromagnetic effects is used both in the "solenoid – core" subsystem (electromagnetic force $\bar{F}_{em}$) and in the subsystem of force action on a current-carrying conductor located in a magnetic field (electrodynamic force $\bar{F}_{ed}$).

2. The effect of the unilateral action of the electromagnetic force $\bar{F}_{em}$ on the ferromagnetic core in the direction of its movement to a symmetrical location relative to the solenoid (armature coil) is used.

3. The mechatronic mechanism structure has been created to implement the reciprocating movement of the working body of a technological machine due to the simultaneous action of the above forces on it ($\bar{F}_{em}$ and $\bar{F}_{ed}$).

4. The motion direction reverse of the coil with electric current (armature) by changing only the magnitude (but not the direction of action) of the electrodynamic force $\bar{F}_{ed}$. Moreover, without changing the magnitude and direction of the electromagnetic force $\bar{F}_{em}$.

This made it possible to obtain the following technical advantages compared to the design described in [10].

1. The mass of the AMM module has been halved, and its dimensions allow the installation of this module in the seat of the CNC machine spindle (tool shank with a retaining cone of 7:24).

2. The speed of the automatic control tracking system has been increased both by reducing the weight of the moving parts (one armature instead of two) and by switching from the principle of regulation "by deviation" in a closed system to the principle of regulation "by disturbance" in an open system. The disturbance is the inconstancy (variability) of the force parameter in the cutting zone.

3. In the power converter mode, the AMM module is distinguished by a large range of the power parameter regulation, which allows for rough, semi-finishing and final (including surface refinement, smoothing, etc.) processing of difficult-to-machine and superhard materials (up to nanotechnology), for example, anisotropic, crystalline and polymer composite materials.

According to the existing automatic systems classification, the developed AMM module refers to direct-acting systems when the energy for the control action comes from the control object, i.e., from the machining zone (Fig. 3a). The reason for this statement is the fact that direct-acting systems assume a direct mechanical connection of the energy flow regulator with a source of disturbing action, and thus the excess energy generated in the zone of force interaction of the machine with the external environment is used to return the system to an equilibrium state. This eliminates complex feedback loops (Fig. 3b).

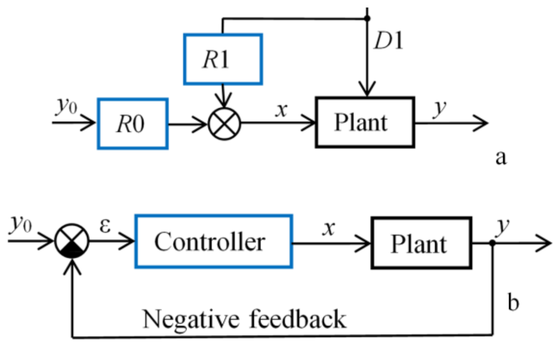

Fig. 3. **Automatic control systems "by disturbance" (a) and "by deviation" (b)**
Source: compiled by the authors

Stabilization of force or torque during machining is carried out by changing the system parameter, including a non-linear change in the parameter. Examples of parametric stabilization are known: stabilization of the electric current strength in the baretter or the electric voltage on the Zener diode (when the Zener diode is switched on reversibly).

In accordance with the general systems theory (systems engineering) one of the important initial stages of a system development is an adequate representation of the system from the stage of system concept to the running one. The system design includes its description, modeling and simulation, which may be represented in the respective formats: verbal description (text) in ordinary languages, graphical representations (block diagram, graphs), special signs systems (e.g., programming languages), mathematical model, a timing diagram, the combined method, etc. Selecting an appropriate way of the system representation depends on the purpose of the study [15]. If the purpose is to create conditions to ensure the desired course of a process, when the process is the developing system, then it should be said of the system operation and control algorithms. In this case the technical system is being developed in the form of a control system model. In this modeling (versus simulation) the system is a mathematical abstraction that is taken as a model of a dynamic phenomenon which represents the dynamic phenomenon in terms of mathematical relations. According to H. Freeman [16] such a system is characterized by the input $\boldsymbol{u}$, state $\boldsymbol{x}$ and output $\boldsymbol{y}$ (Fig. 4). The input $\boldsymbol{u}$ in the form of a set of time functions (e.g., in time domain) is the external forces (input variables) which are acting upon the grinding process that represents the dynamic phenomenon mentioned. The state $\boldsymbol{x}$ is a form of the system state-space representation, which with the input affects the output $\boldsymbol{y}$.

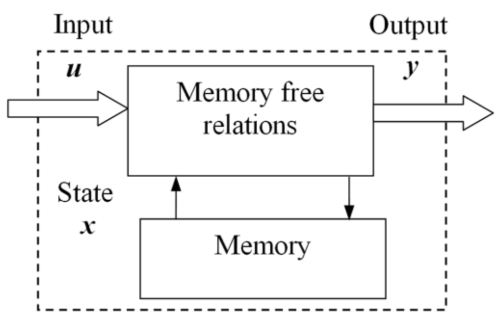

Fig. 4. **Representation of the grinding system based on "input-state-output" model (a)**
***Source*: compiled by the [16]**

The output $\boldsymbol{y}$ in similar form is the measures of the grinding process result, i.e., output quantities belonging to the ground part (part accuracy, surface finish and surface integrity).

A dynamic phenomenon (process) may or may not possess a memory depending on whether or not the effect of past applied forces is stored. In this connection the state $\boldsymbol{x}$ of the system is a vector function of time (e.g., in time domain) as well as both the input $\boldsymbol{u}$ and output $\boldsymbol{y}$. In grinding it may be corresponding signals like those of grinding force F in Newtons, temperature T in Celsius or acoustic emission (AE) in root mean square quantities.

The AMM module (Fig. 5) contains a basic part – housing 1 made of soft magnetic material. The housing 1 performs the function of the external magnetic core of the module; its end is the main design base when connecting the module to the spindle head 2, for example, a CNC machine.

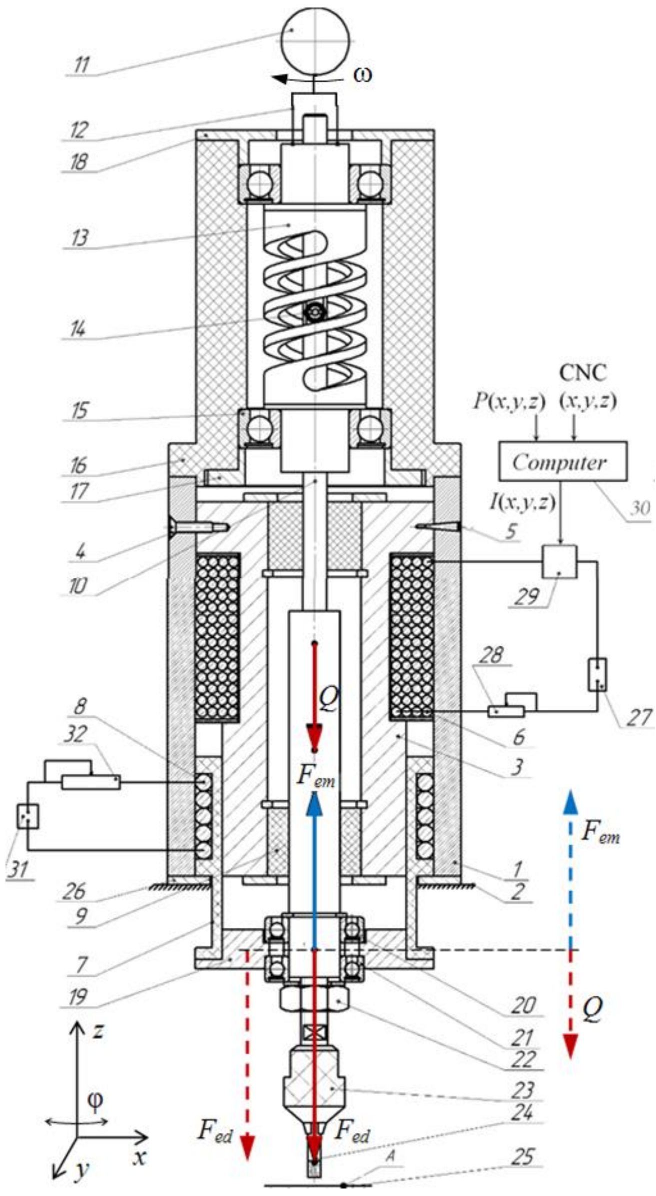

Fig. 5. **Module AMM structure**
Source: compiled by the authors

The hollow internal magnetic core 3 is coaxially fixed in the housing 1 using two screws 4 and two pins 5. The field winding 6 is fixed to the magnetic circuit 3 (provides a magnetic flux of the required magnitude and direction) and a movable armature coil 7 (non-magnetic aluminum alloy) with an armature winding 8 is installed. The armature coil 7 (hereinafter armature) has the ability to reciprocate along the longitudinal axis of the magnetic circuit 3 without backlash and jamming on a sliding fit.

The nut 13 is fixed axially by means of ball bearings 15 located in a non-magnetic (textolite) housing 16 and is fixed from possible axial movements by flanges 17 and 18. The nut 13 receives rotation from the motor 11 (the source of rotational movement of the spindle 10) through the bypass coupling 12; it transmits this rotation to the spindle 10 due to force closure of the contact in the pair "the inclined surface of the thread turns of the nut 13 – the outer ring of the bearing 14".

The spindle 10, receiving rotation from the nut 13, simultaneously has the possibility of reciprocating movements up and down along its longitudinal axis (when the housing 1 is stationary). To do this, it is rigidly connected to the coil 7 of the movable armature (carries the armature winding 8) through a non-magnetic flange 19 made of textolite.

To combine reciprocating and rotational movements, the spindle 10 is installed in the flange 19 using two duplex ball bearings 20. Radial and axial backlashes in these bearings are eliminated using a spacer ring 21 and a clamp nut 22, respectively.

The spindle 10 is provided with a collet 23 in which a machining tool 24, such as a drill, is fixed.

A workpiece 25 (or a product which is marked with point A in Fig. 5) is installed on the table of the CNC machine (point A in Fig. 5); it receives from the CNC device the necessary program movements along the x, y, and z axes (Fig. 5).

To control the vertical movements of the armature 7 and thus the tool 24, the AMM module provides a subsystem consisting of a field winding 6 (creates a magnetic flux) and an armature winding 8 (located in the area of this flux). In the initial state (Fig. 6a), these two windings create oppositely directed, but balancing forces, i.e., $\bar{F}_{ed} = \bar{F}_{em}$. Armature winding 8 creates an electromagnetic force $\bar{F}_{em}$ directed upwards. The field winding 6 creates an electrodynamic force $\bar{F}_{ed}$ directed downward. In Fig. 6, the letter Q stands for the weight of the moving parts of the AMM module.

By adjusting the ratio between these forces, when the condition $\bar{F}_{ed} > (\bar{F}_{em} - Q)$ is, it is possible to carry out rapid (Fig. 6b) and working (Fig. 6c) feed of the tool in the direction of the workpiece (down).

If the field winding 6 is turned off, the tool (for example, a drill) will move up rapidly under the action of the electromagnetic force $\bar{F}_{em}$ (Fig. 6d). Thus, the structure of a typical machining cycle (the algorithm for the operation of the AMM module) contains four repeating states. The motion parameters for each of these states (speed and coordinates of the tool movement) are set by the CNC system of the technological machine, in which it becomes possible to repeat a typical work cycle (Fig. 6e) with adaptive and intelligent control not only of the kinematic, but also of the power parameters of the technological process (algorithm for controlling the AMM module).

During machining, the resulting force F (Fig. 7) creates a torque T that is balanced, for example, by the cutting torque T_{cut}, i.e., $T = T_{cut}$. When the latter (i.e., T_{cut}) increases, the ball-bearing screw mechanism of the power converter is activated (consists of elements 10, 13, 14 and 15 in Fig. 5). The specified excess of the cutting torque ΔT_{cut} leads to an additional rotation of the ball-bearing screw inside the nut 13 and additional movement of the spindle 10 upwards. As a result, the cutting torque is restored to its previous level, which was before the appearance of the disturbance, i.e., $\Delta T_{cut} \to 0$. This is how the parametric stabilization of the cutting torque T_{cut} (at $F = \text{constant}$) is performed by changing the parameter – the angle of rotation of the ball-bearing screw 10 in the nut 13.

In other words, when the cutting force exceeds a predetermined value, the balance of forces is disturbed, and the excess force acts on the ball bearing screw (spindle 10), causing the spindle 10 with the tool to lift to eliminate the imbalance of forces. This is the adaptability of the mechatronic mechanism.

The power supply of the field winding 6 is carried out from a DC source 27 through an adjustable resistance 28 and a block 29 that changes the current in the circuit according to computer 30 commands.

The armature winding 8 is powered by a DC source 31 through adjustable resistance 32.

Thus, this subsection describes the information model of the AMM module. The information model covers the structure and composition of the mechatronic mechanism, the algorithm of its operation (typical technological cycle) and the control algorithm for parametric stabilization of the cutting moment (regulation "by disturbance", the principle of compensation of disturbances).

3.2. Information model in dynamics

A basic characteristic of any dynamic phenomenon is its behavior at any time and whether or not the behavior is traceable not only to the presently applied forces (input variables) but also to those applied in the past.

The working body of any technological machine makes repetitive movements. Most often, this is a repeating technological cycle based on the reciprocating movement of the working body as it shown in Fig. 6. The technological cycle characterizes the main states of the mechatronic machine, namely: equilibrium (Fig. 6a), rapid approach (Fig. 6b), machining pass (Fig. 6c), and rapid retraction (Fig. 6d). Thus, the working body performs the same repetitive movements: RA, MP, RR (Fig. 6e). Each of these movements can be obtained by adjusting the ratio between forces $\bar{F}_{em}$ and $\bar{F}_{ed}$.

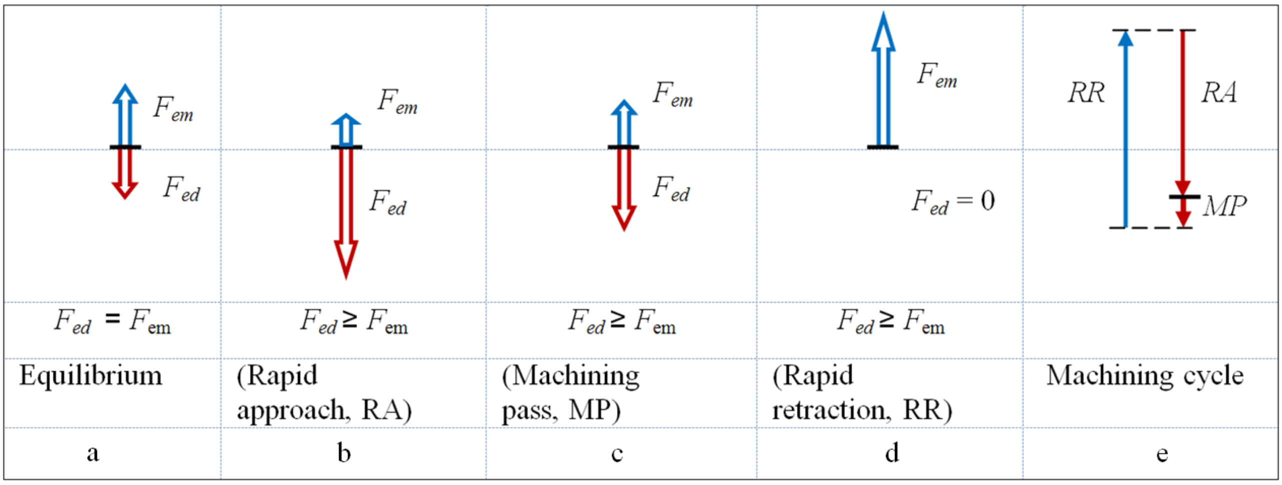

Fig. 6. **Formation of a technological cycle based on a system of two oppositely directed forces:** $\bar{F}_{em}$ and $\bar{F}_{ed}$

***Source*: compiled by the authors**

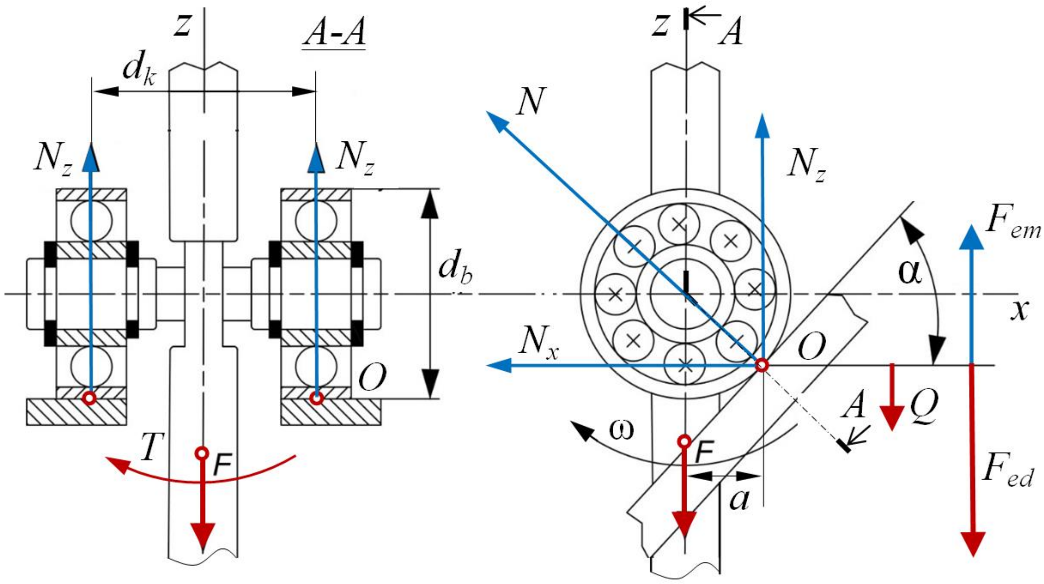

Fig. 7. **An information model of dynamic equilibrium with an rapid approach of a tool based on a system of two oppositely directed forces:** $\bar{F}_{em}$ and $\bar{F}_{ed}$

***Source*: compiled by the authors**

So, we have the following step-by-step procedure.

1. For each point $A(x, y, z)$ of the trajectory of the tool, the value of the force F is set programmatically for each instantaneous position of the tool in space, i.e., function $F(x, y, z)$, which is previously (as a program for the tracking system) entered into the computer 30 (Fig. 5).

And

$$F = F_{ed} + Q - F_{em}. \quad (1)$$

Relative to point O, torques with a shoulder a arise (Fig. 7) that contribute to the rolling of the outer ring of the ball bearing down (T_{down}) and up (T_{up}), and

$$T_{down} = (F - N_z)a, \quad (2)$$

$$T_{up} = F_{em}\, a, \quad (3)$$

where N_z is the vertical component of the force N vector which is a response to the downward force F (Fig. 7), i.e., $N = N_z + N_x$ (Fig. 7).

The equations for determining the forces F_{ed} and F_{em} were found earlier [17]. The magnitude of the electrodynamic force can be found as follows

$$\bar{F}_{ed} = I[\bar{l}, \bar{B}] = I[\boldsymbol{l} \text{x} \boldsymbol{B}], \quad (4)$$

where $\bar{F}_{ed}$ is the force vector, N; I is the current strength, A; $\bar{l} = \boldsymbol{l}$ is the conductor length vector in the current direction, A; $\bar{B} = \boldsymbol{B}$ is the magnetic flux density vector (or magnetic field induction vector), Wb/m^2 or T.

In general, with the simultaneous action of multidirectional magnetic fluxes (one of which is created by the stator field winding) on a current-carrying conductor, the resulting mechanical force $(\bar{F}_\Sigma)_{ed}$ acting on this conductor can be found based on vector summation and multiplication, i.e.

$$(\bar{F}_\Sigma)_{ed} = \sum_{i=1}^{k} I_j \left[\bar{l}_{j,} (\sum_{i=1}^{m} \bar{B}_i)\right], \quad (5)$$

where $\sum_{i=1}^{m} \bar{B}_i$ is the total induction (resultant vector) of magnetic field sources in the field winding, T; $\left[\bar{l}_j, (\sum_{i=1}^{m} \bar{B}_i)\right]$ is the vector product of the vector $\bar{l}_{j,}$ (conductor length j-th vector) and resulting vector $\sum_{i=1}^{m} \bar{B}_i$; I_j is the current strength in the j -th conductor (j = 1, 2, …, k), A; $\bar{l}_j$ is the length of the j −th conductor, m.

Electromagnetic force can be found as follows

$$F_{em} = \frac{1}{2}\mu_0(\mu_r - 1)n^2 I^2 S, \quad (6)$$

where F_{em} is the traction force developed by the armature winding, N; $\mu_0\mu_r = \mu_a$ and μ_r are the absolute (in N/A^2 or H/m) and relative (dimensionless) magnetic permeability of the magnetic core substance, respectively; μ_0 is the magnetic permeability of vacuum (magnetic constant), $\mu_0 = 4\pi \cdot 10^{-7}$ N/A^2 or H/m); n is the number of turns of the winding on the current coil (i.e., the number of turns of the armature winding) per unit length of this winding, 1/m; I is the current in the coil winding (current in the armature winding), A; S is the area of the circular cross-section of the coil winding (i.e., armature winding), m^2.

In the same computer 30, when the control program of the CNC system is executed, the instantaneous values of the current coordinates of the tool (x, y, z) are received. At each moment of time, the computer through block 29 maintains a variable level of electric current $I(x, y, z)$, which ensures the performance of the function $F(x, y, z)$ mentioned above. Thus, when the control program is executed, the current $I(x, y, z)$ of the required value, shape and duty cycle flows through the field winding 6.

When the source 27 is turned on by a signal from the computer 30, the electric circuit of the field winding 6 creates a magnetic flux. It passes, in particular through the armature winding 8. This causes the appearance of an electrodynamic force $\bar{F}_{ed}$, the action of which brings the armature (in the direction of the force $\bar{F}_{ed}$), and with it the machining tool, to its original working position, i.e., until the power closure of the armature housing 19 with split rings 26. The closure of these rings generates a signal to the CNC system about the readiness of the spindle to execute the control program of the CNC system.

2. The CNC system of the machine is activated, which starts the electric motor 11 and sets the required cutting depth (in accordance with the control program) for the spindle head of the machine. Further, the cutting process is carried out as usual, for example, on drilling, milling, or grinding CNC machines. In the absence of any deviations in the trajectory of the tool from the prescribed trajectory, the final geometric accuracy of the product will correspond to the accuracy class of the CNC machine. However, for this class of hard-to-machine materials with pronounced anisotropic properties, this condition is not enough. It is also required to ensure the product surface integrity.

It is known that some places of the product to be machined with increased physical and mechanical characteristics cause the appearance of force and cutting torque in the cutting zone, which significantly exceed the permissible values. In this case, the "excess" of the force and torque causes the tool to move in the direction "from the product" and the transition of this tool to a reduced cutting depth. When the cutting depth is reduced by $\Delta t = \Delta z$, the cutting force will return to the required value.

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This kind of "transition" (from one cutting depth to another) occurs continuously during the removal of the stock allowance and the machine, as a whole, goes into "configurable control" mode [18]. This mode is characterized by mechanical instability, which manifests itself as "vibrational cutting" with variable frequency and amplitude of vibrations of the tool cutting edge (the frequency and amplitude of vibrations are determined by the material anisotropy).

To achieve the specified accuracy of complex-shaped parts, it must be taken into account that in the "configurable control" mode, the specified accuracy of the product to be machined must be achieved, for example, in the following two ways:

1) introducing additional strokes into the technological process and performing the operation until the remaining stock allowance is finally removed. This kind of technology is ineffective, but it is quite feasible, especially when it is necessary to achieve precision machining parameters lying in the field of nanoscale;

2) equipping the CNC system of the technological machine with an algorithm for accounting for the remaining stock allowance. The essence of this method boils down to the fact that it becomes possible to cut in the product's places only where the stock allowance (material to be remove) has not yet been removed.

This method should not be confused with the function of additional machining. For example, the PowerMILL program developed by Delcam allows forming a 3D model (algorithm) of the remaining stock allowance after the end of each stroke. This model is used to form the tool movement trajectory by the CNC machine system to remove the remaining stock allowance, i.e., selectively in those product's places where the stock allowance remained.

This allows saving time on idling. The operation of such a program can be seen visually on the monitor screen of the CNC system.

4. RESULTS

4.1. General layout of the machine

The movements of the workpiece in the direction of the x and y axes are carried out due to the longitudinal and transverse feedings of the machine (Fig. 8). These movements are not interconnected (in this particular case) with any responses of the AMM module and are carried out by means of the CNC system of the CNC machine in accordance with the established control program.

The movement of the tool along the z axis (in this particular case) is the result of the addition of two movements: the first movement is from the control system of the AMM module, the second is from the CNC system of the machine. The contradiction that arises in this case is eliminated due to the interaction of two levels of the hierarchical control system: the lower level is the clamping force and cutting torque stabilization during automatic control "by disturbance", the upper level is the standard machining of the vertical movement z from the CNC system.

Fig.8. **CNC mechatronic technological system based on AMM module**
***Source*: compiled by the authors**

In this case, the implementation of the size along the z coordinate is ensured by the fact of a force closure between the end surface of the recess in the housing 1 and two thrust plates 26 (Fig. 5). They limit the axial movement of the armature and thereby fix the extreme axial position of the tool, at which the dimension along the z coordinate is executed (this dimension is set by the CNC system).

4.2. Power converter mechanism

Nut 1 (Fig. 9) is given rotation from the driving motor with an angular speed , and an axial force F is applied to the screw 2. The force F is directed along the screw axis and is variable in accordance with the machining technological cycle. Under the action of the force F, the "screw-nut" pair is forcefully closed through ball bearings 3 at a point located on an inclined surface at an angle α (Fig. 9).

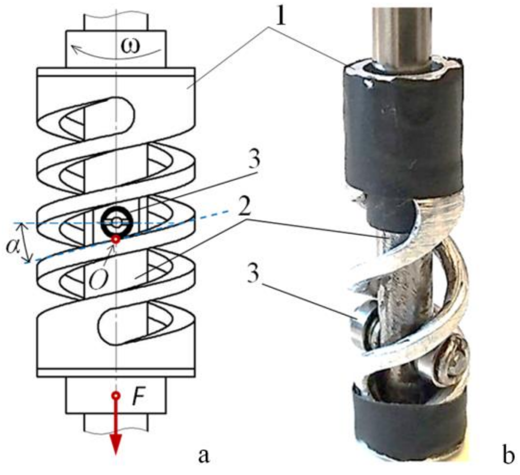

Fig. 9. **Ball bearing screw mechanism: an idea (a) and embodiment (b)**
***Source*: compiled by the authors**

Ball bearing screw has an original structure (Fig. 10).

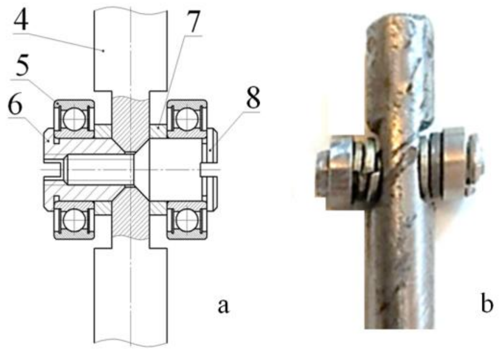

Fig. 10. **Ball bearing screw: an idea (a) and embodiment (b)**
***Source*: compiled by the authors**

The screw is made in the form of a straight cylindrical rod 4, on which two ball bearings 5 are coaxially fixed perpendicular to the longitudinal axis of the rod using pins 6 and 7, as well as spring washers and seals 8.

The connection made in this way leaves the possibility of free rotation of the outer rings of the ball bearings, which, in this case, are double-start threads and bearing surfaces in contact with the surfaces of the nut slotted grooves.

The design of the fixed (i.e., unmovable) stator and the movable armature is quite technological from the point of view of organizing lot production of the AMM module (Fig. 11).

To give the AMM module intellectual properties, the stator coil contains several sections, each of which performs the corresponding function of a sense organ. For example, the auditory function is performed by a winding that takes into account the sound signal in the cutting zone. When a sound signal appears about the wear of the cutting tool, a control electric current appears in this winding, which changes the cutting force and torque based on the provision of favorable working conditions for the tool.

Changing the current strength in the field winding (at a constant armature current) allows obtaining the necessary modes of roughing, semi-finishing and finishing/smoothing, up to an infinitely small (almost zero) clamping force (Fig. 12).

4.3. Products made of superhard materials

The AMM module is used as part of the working bodies of various technological machines,

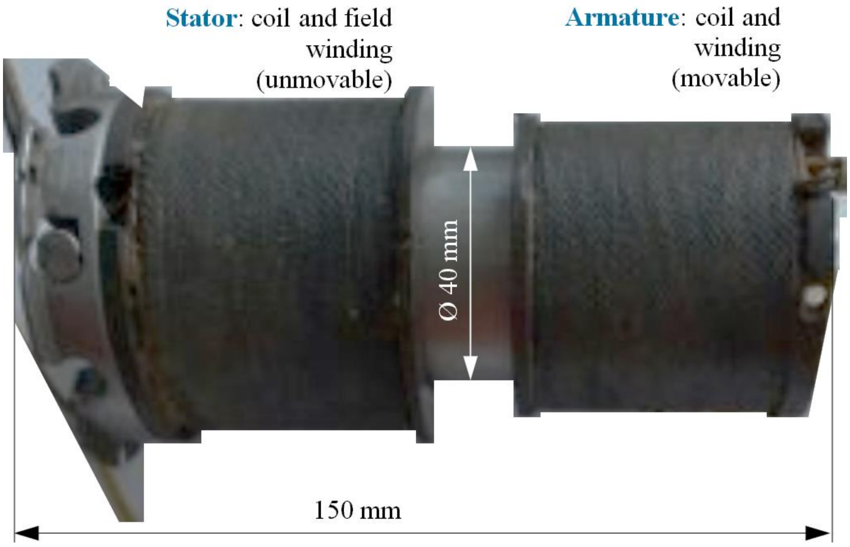

Fig. 11. **Stator and armature assembly on a ferromagnetic core**
***Source*: compiled by the authors**

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for example, in CNC machine tool building, biomedicine (in the manufacture of implants and prostheses), nuclear and military equipment. It is used in stone cutting and engraving (Fig. 13).

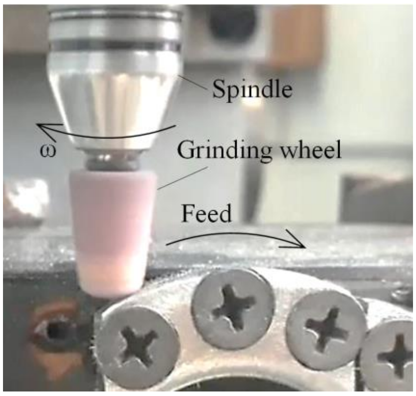

Fig. 12. **Contour grinding with infinitesimal tool pressure (nanotechnology)**
***Source*: compiled by the authors**

Fig. 13. **Products made of ruby (left) and mammoth tusk (right)**
***Source*: compiled by the authors**

The convenience of computer programming makes it possible to implement various technological cycles based on reciprocating movements of the tool, including roughing, semi-finishing, finishing and smoothing modes of machining and assembling machines and mechanisms. Separate prospects open up for the development of equipment for the repairing technological machines, in particularly in the field conditions on the basis of mobile repair complexes (military equipment).

4.4. Educational process on mechatronic automation devices

The problem follows from the following reasoning. The educational process in higher education institution (hereinafter university) is one of the most complex technological processes (with elements of intellectual control), the result of which is an unusual "product", namely the worldview and a set of special competences of the trained specialists. For the successful creation of such a "product", the corresponding hierarchical "control program" (with a large number of relevant subprograms, e.g., in the form of syllabuses) is compiled and continuously improved. Such "control program" is similar to the control program for CNC machines, which is created on the stage of technological preparation of production, for example, by mechanical engineering technology specialists.

Such analogy makes it possible to conclude that the educational process (teaching and learning) in a university is also technological one, i.e., contains the appropriate technological operations as well as high-tech equipment and production tooling. The latter additionally contains high-tech distance learning devices (computer-aided devices) with the special software, namely: Moodle, Google Classroom, Google Meet, Zoom, Skype, Google Suite/Docs as well as WhatsApp, Viber, Telegram, etc. Educational program – in the form of educational-professional (EPP), educational-scientific (ESP) or educational-creative (ECP) ones – is a system of educational components at an appropriate level of higher education within a specialty, which determines the requirements for the level of education of persons who can start studying under this program (e.g., EPP), a list of educational disciplines (EDs) and a logical sequence their study, the number of ECTS credits which are necessary for the implementation of this program, as well as expected learning outcomes (competences), which must possess an applicant of appropriate degree of higher education [10].

A university on the basis of the relevant educational program (such as EPP) with each specialty develops a curriculum that defines the list and volume (scope) of EDs in ECTS credits, a sequence of the EDs study, volume and forms of conducting studies (lectures, practices, laboratory works, etc.), schedule of the educational process (course work), forms of current and final control. Thus, within the limits of legislation, a university independently establishes names of EDs. The academic council of a university approves educational programs (e.g., EPP) and a curriculum for each level (bachelor, magister) of higher education and for both specialty and specialization. The latter is registered in Ukrainian National Agency for Higher Education Quality Assurance.

A manufacturing (technological) process has an analogy with the educational (technological) process through both blocks and links (direct and reverse) as well as according to their functional significance. The use of the "technological approach" allows obtaining new conclusions about the connection of categories “information” and “knowledge” (through the engagement between them) and their place in productive technologies of different nature. For this, feedbacks are used (method of iterations) in the direction from the lower levels of hierarchy to the higher levels.

5. PROSPECTS FOR THE STUDY FURTHER DEVELOPMENT

With this publication, the authors begin a series of articles on new technologies of mechanical and biomedical engineering in the shaping of complex and arbitrary surfaces of both machine parts and implants made from difficult-to-machine and superhard materials.

The authors do not aim to give an alternative solution to the design features of already existing technological machines, e.g., CNC machines, but offer a new scientific direction to expand their technological capabilities, i.e. the authors intend to solve those “difficult” tasks of mechanical engineering technology that cannot be simply and efficiently implemented on existing technological machines, for example, on CNC metal-cutting machines.

From the general series of “difficult” tasks, the following priorities can be distinguished.

1. High-quality shaping of products from superhard single crystals, both artificially grown and natural.

2. High-performance abrasive machining of complex-shaped parts made of hard-to-machine materials without the formation of grinding defects (burns and microcracks) on their surfaces with variable arbitrary curvature.

3. Machining of materials with an anisotropic or strictly organized structure, e.g., synthetic fibers, fiberglass and other polymer-composite materials.

The list of the materials to be machined is given as an example only for the reason that their machining using new technology not only provides high quantitative and qualitative indicators of the machining process, but also creates prospects for further improvement of these indicators.

Turning to the practice of automation of machining processes by cutting, it should be noted that in this field of knowledge a paradoxical situation has developed, to put it mildly, when there are complaints about the “unpredictability” of changes in the values of cutting forces in the contact zone “tool-product” and this fact is one of the most important reasons preventing the widespread dissemination and implementation of the ideas of adaptive and intelligent control of machining processes, e.g., cutting, milling, grinding, etc.

Thus, the solution of the problems of adaptive and intelligent control of the processes of mechanical cutting of structural materials, in our opinion, should begin with the organization of the supply of a dosed amount of mechanical energy necessary and sufficient to perform the operation or a specific technological operation step.

The metered supply of energy to the machining zone is only the first side of the problem, because the anisotropy inherent in each workpiece material, tool wear and other known phenomena will inevitably cause the level of the established cutting forces to be exceeded.

Therefore, the second side of the problem is the solution of the problem of controlling the cutting force parameter in the mechanism for stabilizing the cutting process based on optimal technological conditions.

This kind of control over the actions of the working bodies of a technological machine is quite feasible and in some cases is implemented in existing machines, for example, in the form of a “floating” spindle, i.e. spindle, which has freedom of movement along its longitudinal axis, and only in the direction “from the product”, i.e., in the direction of the machining stock allowance, followed by the unconditional removal of this allowance. If this condition for removing the allowance is not met, then it makes no sense to talk about the accuracy of dimensional shaping and the machining quality.

6. CONCLUSIONS

1. Analysis of the state of the issue in the field of mechatronic and intelligent machines has shown that by now the science of mechatronics systematically combines mechanics, electronics, and computer science. Moreover, the term informatics indirectly reflects related disciplines, for example, automation and telemechanics (measurement and control at a distance, communication and telemetry). In this regard, two main methods of automatic control are considered: “by deviation” (in a closed system with feedback) and “by disturbance” (in an open system without feedback on the controlled parameter). It is shown that the developed AMM module implements parametric stabilization of power machining parameters, for example, stabilization of cutting force and torque.

2. It has been established that the main disturbance during the operation of the technological machine is the fluctuation of the power load and torque on the working shaft. Therefore, the development of an automatic control system that implements the “disturbance compensation principle” is an urgent task in the development of modern technological

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machines, for example, machine tools with reciprocating tool movement.

3. Defect-free machining of materials with a strictly organized anisotropic structure (polymer composite materials), with an uneven change in physical and mechanical properties throughout the volume (synthegran) or with high strength properties (artificially grown superhard crystals of ruby and leucosapphire) is either impossible or not economically feasible on modern CNC machine tools.

The reason for this is the lack both of information about the force parameter and the system that is able to stabilize this force parameter, e.g., such as cutting force and torque. Therefore, the use of the developed AMM module, which implements parametric stabilization of the power cutting parameter in an open control system, was an effective solution to this technological problem.

4. In the current sample of the AMM module, the possibility of creating a dynamic equilibrium of oppositely directed electromagnetic and electrodynamic forces is realized. They act on a coil with a current (armature), which performs a reciprocating movement when the ratio between these forces changes.

5. To increase the speed of the AMM module, the direction of movement of the coil with current (armature) is reversed by changing the value of the control current in the field winding without reversing the direction of this current. The absence of current reversal means that there is no transient process of current change due to the influence of inductive resistance.

6. The created AMM module contains the possibility of tactile sensuality in the range from macro- through micro- to nano-efforts, which made it possible to implement roughing, semi-finishing and finishing (smoothing) machining modes.

7. The information model of the developed mechatronic mechanism covers its structure and composition, the operation algorithm (technological machining cycle) and the control algorithm (parametric stabilization, regulation "by disturbance", the principle of compensation of disturbances).

8. The place of this article in the general system of scientific research on the formulated new scientific direction "Mechatronic and intelligent technological machines" is shown.

REFERENCES

1. Lebedev, V. N., Sdvizhenskii, P. A., Asyutin R. D. et al. "In situ elemental analysis and failures detection during additive manufacturing process utilizing laser induced breakdown spectroscopy". *Optics Express* 2019; 27(4): 4612–4628. DOI: https://doi.org/10.1364/OE.27.00461 2.

2. Yang, T., Jin, Y., Squires, B. et al. "In-situ monitoring and ex-situ elasticity mapping of laser induced metal melting pool using ultrasound: Numerical and experimental approaches". *Journal of Manufacturing Processes*. 2021; 71: 178–186. DOI: https://doi.org/10.1016/j.jmapro.2021.08.031.

3. Leung, C. L. A., Marussi, S., Atwood, R. C. et al. "In situ X-ray imaging of defect and molten pool dynamics in laser additive manufacturing". *Nat Commun.* 2018; 9 (1): 1355. DOI: https://doi.org/10.1038/s41467-018-03734-7.

4. Borish, M., Post, B. K., Roschli, A. et al. "In-situ thermal imaging for single layer build time alteration in large-scale polymer additive manufacturing". *Procedia Manufacturing*. 2019; 34: 482–488. DOI: https://doi.org/10.1016/j.promfg.2019.06.202.

5. Larshin, V. P. "Meaning of information in virtual and physical technologies". *Computer Games and Multimedia as an Innovative Approach to Communication*. *Materials of the All-Ukrainian Scientific and Technical Conference of young Scientists, Postgraduates and Students*. *ONAFT Publishing House*. Odessa: Ukraine. 2021. p. 77–79.

6. Hitoni, K. "Strategic integrated manufacturing systems: the concept and structures". *International Journal of Production Economics*". 1991; Vol. 25 No.1-3: 5–12. DOI: https://doi.org/10.1016/0925-5273(91)90125-D.

7. Wang, W. "Difference between the real world and virtual world". *Proceedings*. Jun. 2020; Vol. 47 No.1, 35. DOI: http://dx.doi.org/10.3390/proceedings2020047035.

8. Lishchenko, N. Larshin, V. "Gear-grinding temperature modeling and simulation". *Proceedings of the 5th International Conference on Industrial Engineering (ICIE 2019). Lecture Notes in Mechanical Engineering. Publ. Springer*. Cham: 2020. p. 289–297. DOI: https://doi.org/10.1007/978-3-030-22063-1_32.

9. Larshin, V. & Lishchenko, N. "Technological processes and systems automation principles. Towards industry 4.0: Information technology, modeling, artificial intelligence and automation". Monograph: the author's team: V. B. Artemenko, L. V. Artemenko, O. V. Artemenko [et al.]; edited by S. V. Kotlik. Odessa: Ukraine. *AstroPrint Publ.* 2021. p. 121–131.

10. Larshin, V. P. & Gushchin, A. M. "Mechatronic technological system information support". *Applied Aspects of Information Technology*. 2021; Vol. 4 No. 2: 153–167. DOI: https://doi.org/10.15276/aait.02.2021.3.

11. Machine Monitoring. – Avaible from: https://stoneycnc.co.uk/cnc/wireless-strain-measurement-in-cnc-turning. – [Accessed Jul 2020].

12. Druzhinskiy, I. A. "Complex surfaces: a mathematical description". Handbook. *Mechanical engineering, Leningrad branch* (In Russian). Leningrad: Russian Federation. 1985.

13. Artobolevsky, I. I. "Theory of mechanisms and machines". Textbook for technical colleges. – 4th ed., revised and additional (in Russian). *Science, Main edition of physical and mathematical literature.* Moscow: Russian Federation. 1988.

14. Lazareva, T. Ya. & Martemyanov, Yu. F. "Fundamentals of the theory of automatic control". Textbook. 2nd ed., revised and additional. *Tambov Publishing House. State Tech. University*. Tambov: Russian Federation. 2004.

15. Larshin, V. P., Lishchenko, N. V., Babiychuk, O. B. & Piteľ, J. "Computer-aided design and production information support". *Herald of Advanced Information Technology*. 2021; Vol.4 No.2: 111–122. DOI: https://doi.org/10.15276/hait.02.2021.1.

16. Freeman, Herbert. "Discrete-time systems: an introduction to the theory". *Publ: J. Wiley*. New York: 1965.

17. Gushchin, A., Larshin, V., Lysyi, O. & Dudarev, I. "Mechatronic actuator for adaptive machining control". In V. Ivanov et al. (Eds.): DSMIE 2021, LNME. p. 3–12. DOI: https://doi.org/10.1007/978-3-031-06025-0_1.

18. Ishii, T., Shimoyama, I., Inoue, H., Hiros, M. & Nakajima, N. "Mechatronics" (in Russian). *Mir. Publishing House*. Moscow: Russian Federation. 1988.

19. Lima, P. U. &, Saridis G. N. "Design of intelligent control systems based on hierarchical stochastic automata". *World Scientific Publishing Co. Pte.Ltd.* Singapore: 1996.

20. Pasichnyk, V., Kryvenko, M., Burburska, S. & Haluzynskyi, O. "Design and engineering assurance for the customized implants production using additive technologies". "*Advances in Design, Simulation and Manufacturing IV". DSMIE 2021. Lecture Notes in Mechanical Engineering*. *Springer*. Cham: 2021. DOI: https://doi.org/10.1007/978-3-030-77719-7_9.

21. Lishchenko N, Piteľ J. & Larshin V. "Online monitoring of surface quality for diagnostic features in 3d printing". *Machines*. 2021; Vol. 10 No.7: 541. DOI: https://doi.org/10.3390/machines10070541.

22. Larshin, V., Lishchenko, N. & Pitel, J. "Intermittent grinding temperature modeling for grinding system state monitoring". *Applied Aspects of Information Technology*. 2020; Vol. 3 No.2: 58–73. DOI: https://doi.org/10.15276/aait.02.2020.4.

23. Komarov, O. Reducing the search area of genetic algorithm using neural network autoencoder. *Herald of Advanced Information Technology*. 2020; Vol.3 No. 3: 113–124. DOI: https://doi.org/10.15276/hait.03.2020.1.

24. Dydyk, A., Nosovets O. & Babenko V. "Setting up the genetic algorithm for the individualized treatment strategy searching". *Herald of Advanced Information Technology*. 2020; Vol.3 No. 3: 125–135. DOI: https://doi.org/10.15276/hait.03.2020.2.

25. Shcherbakova, G., Krylov V. & Plachinda O. "Determination of characteristic points of electrocardiograms using multi-start optimization with a wavelet transform. *Herald of Advanced Information Technology*. 2020; Vol. 3 No. 2: 23–33. DOI: https://doi.org/10.15276/hait.02.2020.2.

26. Khoma, Y., Szmajda, M. & Pelc, M. "Development of scientific-methodological approaches of machine learning application in biosignals. *Herald of Advanced Information Tech*nology. 2020; Vol.3 No.1: 383–394. DOI: https://doi.org/10.15276/hait.01.2020.5.

27. Shibaev, D., Vychuzhanin, V., Rudnichenko, N., Shibaeva N. & Otradskaya T. "Data control in the diagnostics and forecasting the state of complex technical systems. *Herald of Advanced Information Technology*. 2019; Vol. 2 No. 3: 183–196. DOI: https://doi.org/10.15276/hait.03.2019.2.

28. Romanyuk, O., Vyatkin, S., Antoshchuk, S., Mykhaylov, P. & Chekhmestruk, R. "Blending functionally defined surfaces". *Applied Aspects of Information Technology*. 2019; Vol.2 No.4: 271–282. DOI: https://doi.org/10.15276/aait.04.2019.2.

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Інформаційна модель адаптивного мехатронного механізму

Анатолій Михайлович Гущин [1)]
ORCID: https://orcid.org/0000-0002-1289-9557; guschinanatoliy1@gmail.com
Василь Петрович Ларшин [2)]
ORCID: https://orcid.org/0000-0001-7536-3859; vasilylarshin@gmail.com. Scopus Author ID: 7801669969
Олександр Васильович Лисий[1)]
ORCID: https://orcid.org/0000-0002-7389-1161; lenafox107@gmail.com
[1)] Військова академія (м. Одеса), Фонтанська дорога, 10. Одеса, 65009,Україна
[2)] Одеський національний політехнічний університет, пр. Шевченка, 1. Одеса, 65044,Україна

АНОТАЦІЯ

Бездефектна механічна обробка матеріалів зі строго організованою анізотропною структурою (полімерні композиційні матеріали), з нерівномірною зміною фізико-механічних властивостей по всьому об'єму (синтегран) або з високими властивостями міцності (штучно вирощені надтверді кристали рубіна та лейкосапфіру) або неможлива, або економічно недоцільна на сучасних металорізальних верстатах з ЧПК. Причина цього полягає у відсутності інформації про силовий параметр – силу і крутний момент різання. Тому застосування розробленого модуля адаптивного мехатронного механізму (АММ),що реалізує параметричну стабілізацію силового параметра різання в розімкнутій системі управління, стало ефективним вирішенням зазначеної технологічної проблеми. Аналіз стану питання в галузі мехатронних та інтелектуальних машин показав, що на цей час мехатроніка як наука системно поєднує механіку, електроніку та інформатику. Причому термін інформатика побічно відбиває ще одну складову мехатроніки – автоматику. У зв'язку з цим розглянуті два основні способи автоматичного управління: за відхиленням у замкнутій системі зі зворотним зв'язком і за обуренням у розімкнутій системі без зворотного зв'язку за регульованим параметром. Наведено приклади розімкнених систем із регулюванням "за обуренням", у яких реалізується "принцип компенсації обурень". Такий спосіб не замінимо за відсутності датчиків – джерел інформації про фізичні процеси в технологічних машинах різного призначення, наприклад, у верстатобудуванні, біомедичній, атомній та військовій техніці. Як правило, у всіх цих машинах має місце зворотно-поступальний рух інструменту. Представлена у статті інформаційна модель модуля АММ відображає його основні елементи та характеристики, у тому числі рушійні сили (електромагнітна та електродинамічна), шарикопідшипниковий гвинтовий механізм, нерухомий статор з обмоткою збудження та рухомий якір. Показано місце цієї статті у загальній системі наукових досліджень щодо сформульованого нового наукового напрямку "Мехатронні та інтелектуальні технологічні машини". Ця стаття є запровадженням у цей науковий напрям, коли у мехатронній машині здійснюється автоматичне регулювання за обуренням, тобто виконується "принцип компенсації обурень".

Ключові слова: мехатронний механізм; цикл обробки; зворотно-поступальний рух; керування за збуренням; параметрична адаптація

ABOUT THE AUTHORS

Anatoly M. Gushchin - Candidate of Engineering Sciences, Odessa, Ukraine. Odessa Military Academy, 10, Fontnskaya Doroga St. Odessa, 65009, Ukraine
ORCID: https://orcid.org/0000-0002-1289-9557; guschinanatoliy1@gmail.com
Research field: Mechatronic technological systems

Анатолій Михайлович Гущин - кандидат технічних наук (1978), доцент (1986).
Військова академія, Фонтанська дорога, 10. Одеса, 65009, Україна

Vasily P. Larshin - Academician of the Ukrainian Academy of Economic Cybernetics, D.Sc (Eng.), Professor of Department of Digital Technology in Engineering. Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine
ORCID: https://orcid.org/0000-0001-7536-3859; vasilylarshin@gmail.com. Scopus Author ID: 7801669969
Research field: Production and technological processes information ensuring

Василь Петрович Ларшин - академік Української академії економічної кібернетики (2020), доктор технічних наук (1995), кандидат технічних наук (1980), професор кафедри Цифрових технологій в інжинірингу. Одеський національний політехнічний університет, пр. Шевченка, 1. Одеса, 65044, Україна

Oleksandr V. Lysyi - Candidate of Engineering Sciences, Associate Professor of the Department of Military Vehicle Equipment, Head of the Department of Military Vehicle Equipment. Odessa Military Academy, 10, Fontnskaya Doroga St. Odessa, 65009, Ukraine
ORCID: https://orcid.org/0000-0002-7389-1161; lenafox107@gmail.com
Research field: Information ensuring of the vehicle diagnosing systems

Олександр Васильович Лисий - кандидат технічних наук, доцент кафедри Автомобільної техніки, начальник кафедри Автомобільної техніки. Військова академія, Фонтанська дорога, 10. Одеса, 65009, Україна