



The Latest Foundations for the Development of Production, Science and Education – 2024

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CHAPTER 3. MECHATRONIC TECHNOLOGICAL SYSTEMS: DESIGN CONCEPT AND APPLICATION IN MODERN MECHANICAL ENGINEERING

3.1. The Essence of the Concept of "Mechatronics"

Mechatronics studies a special methodological approach to building machines with qualitatively new characteristics. This approach is universal and can be applied in machine systems for various purposes. However, it should be noted that high quality control of a mechatronic system can only be ensured taking into account the specifics of a particular controlled object.

The definition emphasizes the synergistic nature of the integration of the constituent elements of mechatronic objects. Synergy is a joint action aimed at achieving a common goal. It is important that the component parts do not simply complement each other, but are combined in such a way that the resulting systems have qualitatively new properties. In mechatronics, all energy and information flows are aimed at achieving a single goal in the implementation of a given controlled movement.

Integrated mechatronic elements are selected by the developer already at the machine design stage, and then the necessary engineering and technological support is provided during the production and operation of the machines. This is the difference between mechatronic machines and traditional ones, when the user was often forced to independently integrate the system into heterogeneous mechanical, electronic and information control devices from different manufacturers. That is why many complex complexes have shown in practice low reliability and low technical and economic efficiency.

The methodological basis for the development of mechatronic systems is parallel design methods. Traditional computer-controlled machine design involves designing the mechanical, electronic, sensor and computer parts of the system, and then selecting the interface blocks. The peculiarity of parallel design is the simultaneous and interconnected synthesis of all system components.

The basic objects of studying mechatronics are mechatronic module, which performs movements along one controlled axis. From such modules, as from functional cubes, complex systems of modular architecture are assembled.

Mechatronic systems are designed to implement a given movement. The criterion for the quality of movement of mechatronic systems is problem orientation, that is, it is determined by the formulation of a specific application problem. The specificity of the tasks of automated mechanical engineering is the implementation of movements of the output links of the working body of a technological machine (a tool on a machine). In this case, it is necessary to coordinate the control of the movement space of mechatronic systems with the control of various external processes.

Examples of such processes include regulation of the force interaction of the working body with the work object during machining, monitoring and diagnostics of the current state of critical elements of mechatronic systems, control of additional technological influences on the work object with combined processing methods, control

of auxiliary equipment, issuing and receiving signals from electrical automation devices. Such complex coordinated movements are called functional movements.

In modern mechatronic systems, intelligent control methods are used to realize high quality and precision of movement. This group of methods is based on new ideas in the control theory of modern computer hardware and software, and promising approaches to the synthesis of controlled motion of mechatronic systems.

Mechatronics as a new field of science and technology is in its infancy; its terminology, boundaries and classification characteristics have not yet been strictly delineated.

The rapid development of mechatronics is caused by sharply increased market demands for consumer properties and quality of modern mechanical engineering products. It is this factor that determines current development trends in the field of mechatronics.

Thus, the creation of new generation equipment based on new technologies for the production of new products is a response of manufacturers to new market conditions. In Ukraine, in recent years, increased attention has been paid to the development of mechatronics.

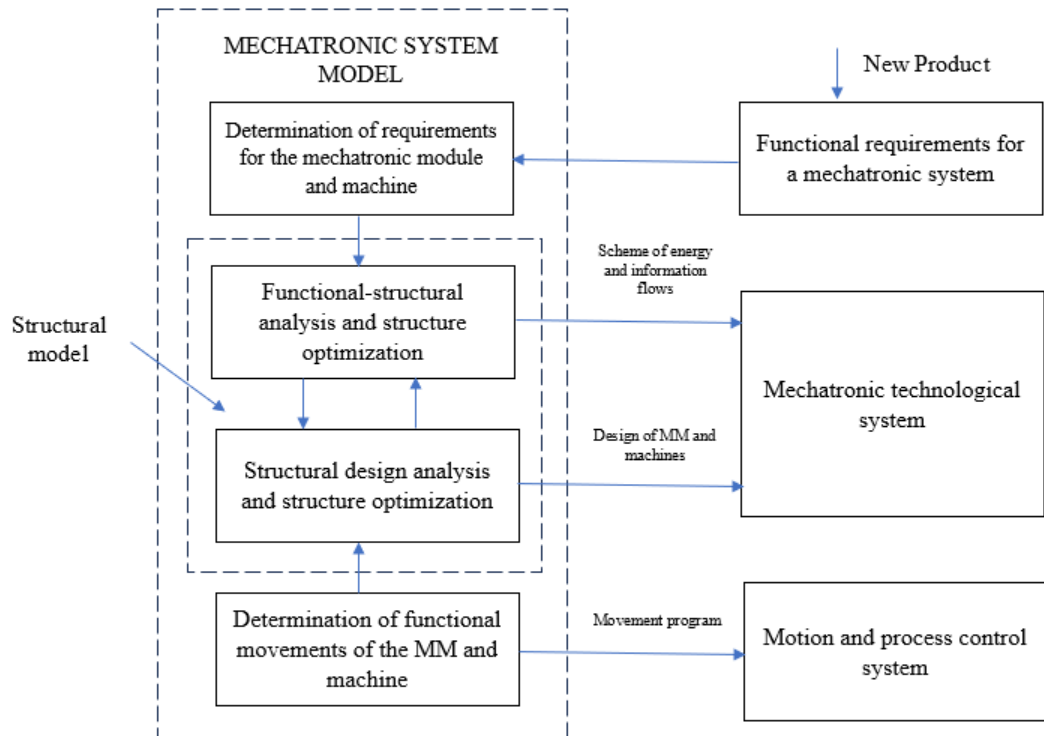
New requirements for the functional characteristics of process modules and machines:

1. Ultra-high speeds of movement of the working parts of machines, defining a new level of productivity of technological machines.
2. Ultra-high precision motion, necessary for the implementation of precision technologies (up to micro- and nano-movements).
3. Maximum compactness of the design and minimization of the weight and size parameters of the modules.
4. Intelligent behavior of machines operating in changing and uncertain external environments.
5. Implementation of fast and accurate movements of working bodies along complex contours and surfaces.
6. A significant expansion of the technological and functional capabilities of the equipment is desirable without increasing its cost.
7. The ability of the system to be reconfigured depending on the specific task or operation being performed.
8. High reliability and safe operation.

The world's advanced level in the field of machine tool manufacturing can be assessed by the latest equipment, which leading manufacturers presented at an international exhibition in Japan in November 2022. Drive systems of modern metalworking machines provide the following characteristics: working feed speed up to 25 m/min, no-load speed up to 800 m/min, drive acceleration when accelerating up to 4g, processing accuracy of the order of 4-5 microns, number of simultaneously controlled axes up to 40 in one processing complex.

It is obvious that to create machines with such technical indicators, fundamentally new approaches to the design and production of drive modules and systems are required. Among them, first of all, mechatronics should be included.

The methodology for designing modules and machines based on the mechatronic approach is aimed at the synergistic integration of the element shown in the figure:



The key methodological idea of this approach is the priority of the module function over its structural organization and constructive solution. Using sequential procedures for functional-structural and structural-constructive analysis of mechatronic systems, the developer evaluates the decisions made, trying to achieve the maximum level of synergetic integration of elements.

To use computer-aided design methods, interconnected functional, structural and structural models of mechatronic modules are formed, then the movement of the mechatronic system in space and time is planned, optimizing them, for example, according to the criterion of maximum performance. As part of the innovative mechanical engineering program, a number of organizations have begun to create a new generation of mechatronic machines based on mechatronic modules.

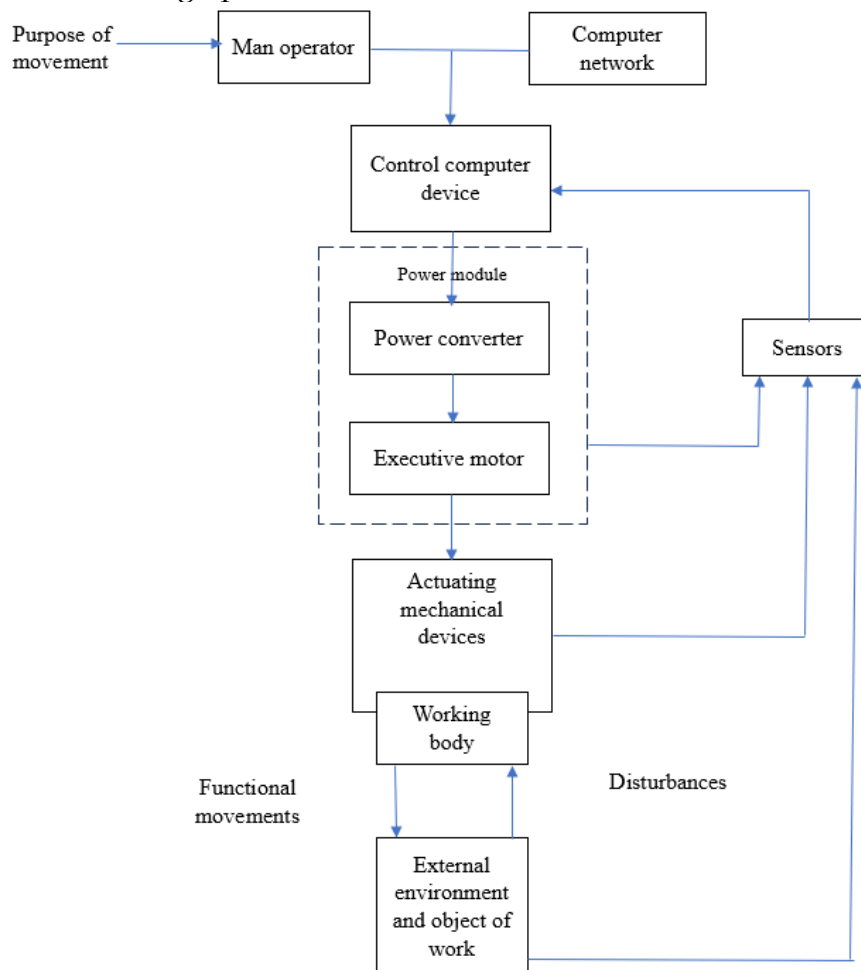
The conceptual projects are the following:

1. Mechatronic machining center MS-630 based on four PMS-630 modules and a high-speed iBAG spindle.
2. Machining centers: MC-1, hexamech-1, MC-2.
3. Robot machine ROOT-300 for grinding turbine blades.
4. Laser complex for layer-by-layer synthesis.
5. Mobile technological robots for inspection and repair of pipelines.

The main advantages of these mechatronic systems are the elimination of multi-stage conversion of energy and information, simplification of kinematic chains and therefore high accuracy and improved dynamic characteristics, structural compactness of the modules and, consequently, improved weight and size characteristics. The ability to combine mechatronic modules into complex mechatronic systems and complexes that allow rapid reconfiguration, relatively low cost of installation, configuration and maintenance of the system, thanks to the modular design, unification of hardware and software, the ability to perform complex movements, thanks to the use of adaptive and intelligent control methods.

3.2. Structure and Principles of Constructing Mechatronic Systems

The external environment for machines of the class under consideration is the technological environment, which contains various main and auxiliary equipment, technological equipment and work objects. When a mechatronic system performs a given functional movement, the objects of work have a disturbing effect on the working body. Examples of such influences include cutting forces for machining operations, contact forces and moments of force during assembly, and the reaction force of a fluid jet during a hydraulic cutting operation.



The computer control device performs the following main functions:

1. Control of the process of mechanical movement of a mechatronic module or multidimensional system in real time with processing of sensory information.
2. Organization of control of the functional movements of the mechatronic system, which involves coordinating the control of the mechanical movement of the mechatronic system and accompanying external processes. As a rule, to implement the function of controlling external processes, discrete inputs/outputs of the device are used.
3. Interaction with a human operator through a machine interface in autonomous programming modes (off-line mode) and directly during the movement of the mechatronic system (on-line mode).
4. Organization of data exchange with peripheral devices, sensors and other system devices.

The task of the mechatronic system is to transform the input information coming from the upper control level into targeted mechanical movement controlled based on the feedback principle. It is characteristic that electrical energy (hydraulic, pneumatic) is used in modern systems as an intermediate energy form.

Let's consider the construction of mechatronic modules based on the synergetic integration of elements.

Mechatronic modules are the basic functional components of mechatronic systems and computer-controlled machines, designed to perform movements, usually along one controlled coordinate.

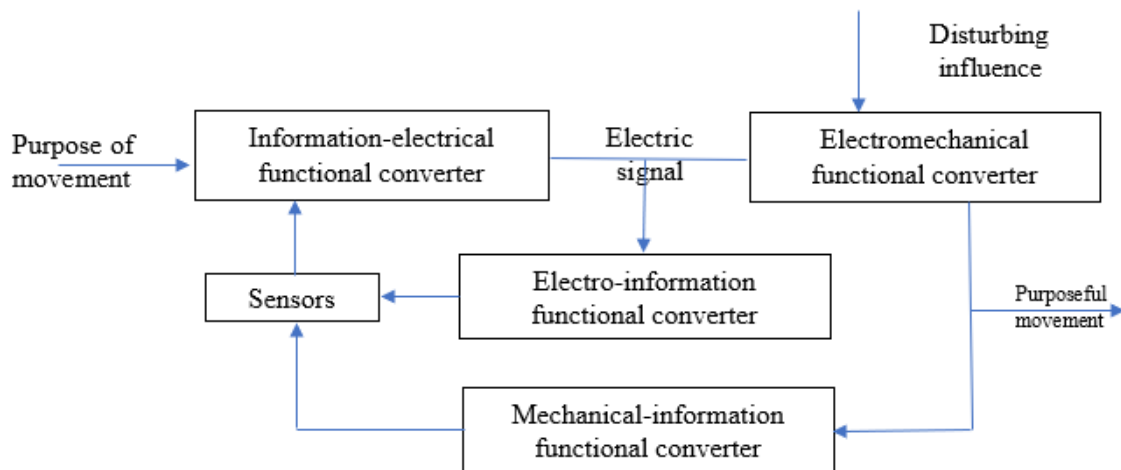
Qualitatively new properties of mechatronic modules compared to traditional drives are achieved by the synergetic integration of constituent elements.

Synergetic integration is not just the connection of individual parts into a system using interface blocks, but the construction of a single drive module through the constructive integration and even interpenetration of elements that, as a rule, have a different physical nature.

The purpose of mechatronic modules is to implement a given controlled movement, usually along one controlled coordinate.

Mechatronic motion modules are those functional "cubes" from which complex multi-axis mechatronic systems can then be assembled.

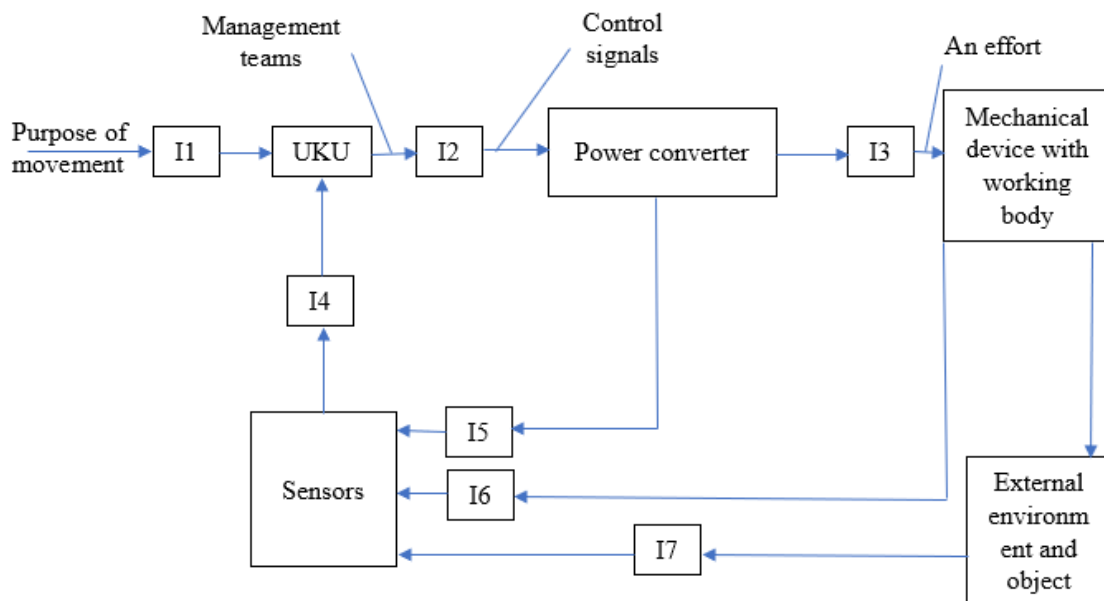
The essence of the mechatronic design approach is to combine the constituent elements into a single drive module. The application of a mechatronic approach to the design of a motion module is based on determining possible points of integration of elements in the drive structure. Having also identified integration points, it is then possible, based on technical, economic and technological analysis, to make specific engineering decisions for the design and manufacture of the motion module. Let us present a diagram of energy and information flows in an electromechanical mechatronic module.



The input of the mechatronic module receives information about the purpose of the movement, which is generated by the upper level of the control system, and the output is the targeted mechatronic movement of the final link, for example, movement of the output shaft of the module.

For the physical implementation of an electromechanical mechatronic module, four main functional blocks are theoretically needed, connected in series: an information-electrical and electromechanical functional converter in a direct circuit and an electrical-informational and mechanical-informational converter in a feedback circuit.

Let us analyze the physical nature of the transformations and the traditional structure of an electro-mechanical module with computer control from the same point of view.



The control unit, based on input information coming from the upper control level and through feedback circuits from sensors, issues control electrical signals in time to the executing drives. In power converters, the power of these signals is amplified and modulated, then the actuators apply appropriate forces to the links of the mechanical device, which as a result causes targeted movement of the final link of the module with the working element.

To connect elements into the system, special interface devices, designated I1-I7, are traditionally introduced.

Interface I1 is a set of hardware and software for interfacing the UKU module with the upper level of the control system. The functions of the upper control level are performed by a high-performance computer or a human operator.

The I2 interface usually consists of a digital-to-analog converter (DAC) and an amplification-conversion device and is used to generate control electrical voltages for actuator drives.

I3 interfaces are, as a rule, mechanical transmissions that connect actuator motors to the links of a mechanical device. Structurally, such transmissions usually include gearboxes, couplings, flexible connections, brakes, etc.

Interface I4 at the input of the UCU, when sensors with an analog output signal are used in an electromechanical mechatronic module, is built on the basis of analog digital converters (ADC).

The interfaces of sensors I5, I6, I7, depending on the physical nature of the observed variables, can be divided into electrical and mechanical. Mechanical interfaces include connecting devices for feedback sensors of drives (photopulse, code, tachogenerator, etc.), force-torque and tactile sensors, as well as other means of sensing and information about the movement of mechanical chain links, motors and external objects. The conversion and transmission of signals about variable system states that are electrical in nature is carried out by electrical interfaces. In addition to amplification and conversion boards, they also include connecting cables and switching equipment.

Comparing the presented block diagrams, we can come to the conclusion that the number of conversion and interface blocks in the traditional structure of a computer-controlled drive is excessive in relation to the minimum required number of functional conversions.

This conclusion provides grounds for searching for new solutions for constructing a drive based on the synergetic integration of elements.

The difference between the mechatronic and traditional approaches to the design and manufacture of modules and computer-controlled machines lies in the concept of constructing and implementing functional converters. In traditional design, interfaces are separate independent devices and nodes. Usually these are separate blocks that are produced by specialized companies, but often individual elements have to be manufactured by the users themselves. The mechatronic approach aims the developer at integrating drive elements into single blocks, minimizing intermediate transformations and eliminating interfaces as separate blocks.

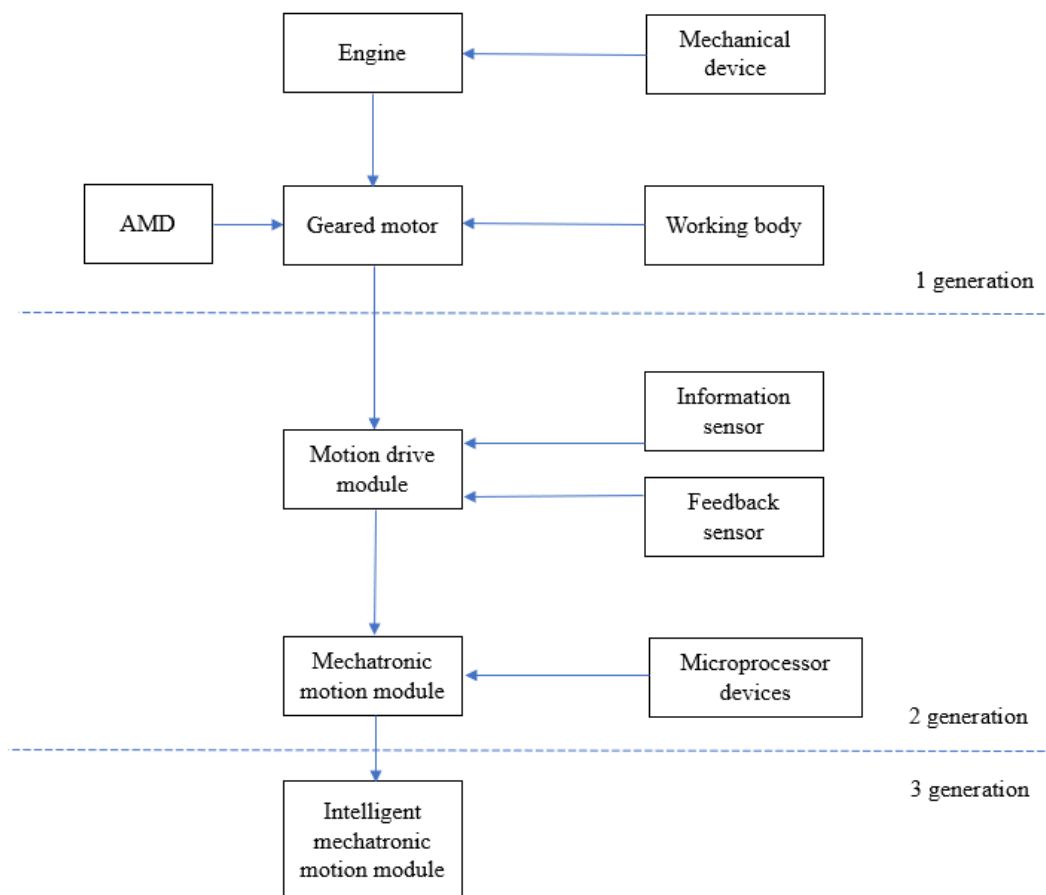
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Following the logic of the mechatronic approach, potential points of hardware integration of elements can be attributed to interface blocks I1 - I7 in the structure of the electromechanical drive.

Mechanical modules and elements	Components		Excluded Items
	basic	additional	
Drive module	Execute engine	Power converter	I3
Mechatronic motion module	Drive module	Power converter	I5
Smart sensor	Sensor	Microprocessor	I4
Intelligent mechatronic motion module	Mechatronic motion module	Boosting device	I2

Of promising interest for mechatronics is the construction of mechatronic modules based on several integration points, which opens up enormous opportunities for scientific research.

Let's look at typical examples of single-axis motion modules designed to solve problems in automated mechanical engineering.



Motor-gearboxes are historically the first mechatronic modules based on the principle of their construction, which are mass-produced and are widely used in drives of machines and mechanisms.

The gear motor is a compact structural module that combines an electric motor and a gearbox.

Advantages: reduction in overall dimensions, reduction in cost and costs for installation and commissioning of the module. The design depends on the type of gearbox and motor being combined.

A complex step in the development of drive technology was the emergence of VMD of rotational motion, which made it possible to completely exclude the gearbox from the electric drive.

VMDs are available in commutator and valve types (without brush). The main disadvantage: the presence of expensive magnets and a winding switching control unit.

The mechatronic approach to the construction of rotational motion modules has also been developed in linear motion modules.

Mechatronic modules based on linear VMDs (LVMDs) are widely used in hexopods, high-speed machines in complexes for laser and hydraulic cutting, and auxiliary equipment. Another disadvantage of all VMD and LVMD is the need for a cooling system and the relatively low efficiency of the module.

3.3. Mechatronic Technological Machines in Mechanical Engineering. Structural Analysis of Mechatronic Systems

Constructing a diagnostic forecast for the development of mechanical engineering and choosing the main trends and strategies for its development concentrates on:

1. integration of technology and knowledge;
2. intellectualization of production technologies;
3. mechatronic technological machines and robots;
4. end-to-end information systems.

In many areas of technology, MSs are replacing traditional mechanical machines, which no longer meet modern quality requirements. The mechatronic approach to building a new generation of machines is to transfer the functional load from mechanical components to intelligent, electronic, computer information components that are easily reprogrammed for a new task and are relatively cheap. Thus, a formal analysis of production machines shows that the share of the mechanical part has decreased from 70% in the early 90s to 25-30% currently. It is fundamentally important to emphasize that the mechatronic approach to design does not imply expansion, but rather the replacement of functions traditionally performed by mechanical elements of the system with electronic and computer units.

The analysis shows that back in the early 1990s, the vast majority of machine functions (more than 70%) were implemented mechanically. The next decade saw a gradual displacement of mechanical components, first by electronic and then by computer units. Currently, in mechatronic systems, the scope of functions is distributed almost equally between mechanical, electronic and computer components. The share of

the computer part has doubled over the past decade and there is every reason to predict that this trend will continue in the future.

It is fundamentally important that the trend of transition from purely mechanical to mechatronic technologies in modern mechanical engineering does not close mechanics. On the contrary, it stimulates its development against a background of intellectual components within a single mechatronic system. The systems approach dictates new requirements for embedded mechanical and hybrid components, which in turn leads to the development of new technologies and design solutions in the field of mechanics.

What caused the transition from mechanics to mechatronics:

1. market requirements;
2. new consumer-producer relationships. In this regard, qualitatively new requirements have emerged for the functional characteristics of drive technology for technological machines.

Mobile technological robots, which can move independently in space and have the ability to perform technological operations, have been further developed. This type of equipment is already actively used in various sectors of the economy, for example in water supply systems.

The P100 robot performs telescopic inspection of pipes, is based on a wheeled chassis, has a color television camera and the lighting system is controlled remotely via a 100m cable.

The robot's sensor system consists of a path sensor and camera orientation sensors. Information received from the sensors can be used as feedback for drive control loops, as well as to accurately determine the location of pipes in the ground and the location of local defects.

Development of electromechanical systems by combining an electric drive and a mechanical transmission with electronic units in the drive.

Historically, mechatronics developed from electromechanics, relying on its achievements and going further by systematically combining electromechanical systems with computer control systems, built-in sensors and interfaces. High accuracy, extreme speed, complex laws of movement of the working body in space and time. The set of these requirements is determined by the technological formulation of the control problem; in addition, it is necessary to coordinate the control of the spatial movement of the MS with the control of various external processes. Examples of such processes include regulation of the force interaction of the working body with work objects during machining, control of additional technological interactions on the work object with combined processing methods, control of the auxiliary equipment of the complex.

An analysis of the scientific and technical evolution of mechatronic modules and mechatronic systems shows that their construction is based on the concept of "built-in design". This concept involves the synergistic integration of mechanical, electronic and computer elements. Through their structural and constructive penetration, the introduction of deep energy and information relationships into the system. A number of works consider an approach to the design and analysis of mechatronic systems based

on a joint analysis of their functional and structural models. Based on the introduced criterion of “functional structural integration” (FSI), a classification and formulation of the problem of optimizing the mechatronic structure and subsystems at the initial level is given.

The considered approach can be illustrated by a comparative analysis and examples of computer control systems for the manipulation robot.

At the same time, a calculation methodology is specified and estimates are obtained for three options for constructing a control system according to the FSI criterion. For the structural assessment of mechatronic modules and systems, it is proposed to use a new quantitative measure called the functional load distribution indicator. The RFN indicator is a numerical measure that allows one to estimate the amount of functional load carried by each of the structural elements or blocks in the system under study. The higher the value of this indicator, the greater the impact this element has on the quality of the system as a whole, its cost, reliability and other complex functional characteristics.

The structure of the system under study includes a control subsystem and an electromechanical part. Electric motor and photopulse feedback sensors that will remain unchanged during analysis. The on-load tap-changer indicators obtained below are calculated for three options for constructing a control subsystem:

- CPU – central processing unit;
- DM – demultiplexer;
- MP – microprocessor;
- EM – executive motor;
- PPS – photopulse sensor;
- PWM – pulse width modulator.

In a traditional control system, the CPU and demultiplexer are the most loaded elements. While 6 MP carry a load several times less (RFN for them is 2%).

For the second option, the RFN indicator for each of the 3 computer components significantly exceeds the load of other elements of the system.

The motion controller in the system of the 3rd level of integration has the highest RFN indicator among all the components under consideration (14%).

The RFN indicators for a group of elements containing electronic and computer components responsible for information, information-electrical and electrical-informational functional transformations in the mechatronic system are added up as follows into the RFN value.

- Traditional structure – 7.6%.
- Level 2 structure – 12.4%.
- Level 3 structure – 21.3%.

3.4. Mechatronic technologies for processing materials by cutting

There is a point of view that mechatronic technologies include technologies of new materials and composites, microelectronics, photonics, microbionics, laser and other technologies.

However, in this case, a substitution of concepts occurs and, instead of mechatronic technologies, which are implemented based on the use of mechatronic objects, these works deal with the technology of manufacturing and assembly of such objects.

Most scientists currently believe that mechatronic technologies only form and implement the necessary laws of executive movements of computer-controlled mechanisms, as well as units based on them, or analyze these movements to solve diagnostic and prognostic problems.

In machining, these technologies are aimed at ensuring precision and productivity that cannot be achieved without the use of mechatronic objects, the prototypes of which are metal-cutting machines with open CNC systems. In particular, such technologies make it possible to compensate for errors that arise due to vibration of the tool relative to the workpiece.

However, it should first be noted that mechatronic technologies include the following stages:

1. Technological statement of the problem.
2. Creation of a process model in order to obtain the law of executive motion.
3. Development of software and information support for implementation.
4. Supplementing the information management and design base of a standard mechatronic object that implements the proposed technology, if necessary.

An adaptive way to increase the vibration resistance of a lathe.

In the conditions of using a variety of cutting tools, processed parts of complex shape and a wide range of both processed and tool materials, the likelihood of self-oscillations and loss of vibration resistance of the technological system of the machine increases sharply.

This entails a reduction in processing intensity or additional capital investments in the technological process. A promising way to reduce the level of self-oscillations is to change the cutting speed during processing.

This method is quite simple to implement technically and has an effective effect on the cutting process. Previously, this method was implemented as a priori regulation based on preliminary calculations, which limits its use, since it does not allow taking into account the variety of causes and variability of the conditions for the occurrence of vibrations.

Adaptive cutting speed control systems with operational control of the cutting force and its dynamic component are much more effective.

The mechanism for reading the level of self-oscillations during processing with variable cutting speed can be represented as follows.

Suppose that when processing a part with cutting speed V_1 , the technological system is in conditions of self-oscillation. In this case, the frequency and phase of vibrations on the machined surface coincide with the frequency and phase of vibrations of the cutting force and the cutter itself (these vibrations are expressed in the form of crushing, waviness and roughness).

When moving to speed V_2 , oscillations on the machined surface of the part relative to the cutter during the subsequent revolution (when processing “along the mark”) occur with a different frequency and synchronization of oscillations, that is, their phase coincidence is disrupted. Due to this, under “trace” processing conditions, the intensity of self-oscillations decreases, and high-frequency harmonics appear in their spectrum.

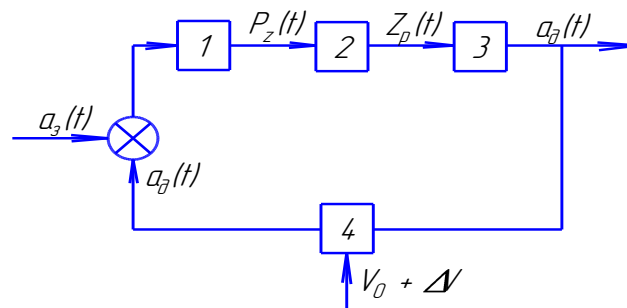
Over time, natural resonant frequencies begin to dominate in the spectrum and the process of self-oscillations intensifies again, which requires a repeated change in the cutting speed.

From the above it follows that the main parameters of the described method are the magnitude of the change in cutting speed ΔV , as well as the sign and frequency of this change. The effectiveness of the influence of changes in cutting speed on processing performance should be assessed by the duration of the recovery period of self-oscillations. The larger it is, the longer the reduced level of self-oscillations persists..

The development of a method for adaptive cutting speed control involves simulation of this process based on a mathematical model of self-oscillations, which should:

1. Take into account the dynamics of the cutting process.
2. Take trail processing into account.
3. Adequately describe the cutting process under conditions of self-oscillations.

Structural model of self-oscillations



- 1 - model of dynamic characteristics of cutting force;
- 2 - conversion of P_z into cutter vibrations Z_p ;
- 3 - transformation of Z_p into oscillations on the surface of the part;
- 4 - delay block for the time of one revolution of the workpiece.

Initially, the disturbing input effect of the developed model is the allowance on the workpiece.

Changes in the allowance lead to fluctuations in the cutting force P_z , which is determined by the model of its dynamic characteristics. The change in P_z causes the Z_p of the cutter to oscillate. Further transformations of the cutter vibrations into vibrations of the part will allow us to move on to vibrations on the machined surface of the part.

The introduction of feedback by applying an oscillation ad to the input of the model with a delay for the time of one revolution of the workpiece takes into account processing “on the trail”.

As a result of the simulation, the following was established:

1. By adjusting the cutting speed under conditions of self-oscillations, it is possible to reduce their amplitude. Subsequently, the amplitude may increase again, which requires a repeated change in the cutting speed.

2. The magnitude of the change in cutting speed significantly affects the duration of the period of reduction and restoration of the level of self-oscillations.

3. For each self-oscillation frequency there is its own optimal value for changing the cutting speed.

4. The higher the frequency of self-oscillations, the lower the value of ΔV should be.

5. The smaller the specified permissible amplitude of self-oscillations, the higher the frequency the cutting speed should be changed.

The latter indicates that the scope of application of the proposed method for suppressing self-oscillations is limited by the dynamic characteristics of the main motion drive (MMD). Based on the simulation results, an adaptive control algorithm for the main motion drive has been developed in order to reduce the level of self-oscillations. Based on technological conditions, the permissible amplitude of self-oscillations of the technological system is set. In the absence of a task, the system itself sets the imaginary value of a_{dop} .

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CHAPTER 2. INNOVATIVE AND MODERN FOUNDATIONS OF PEDAGOGY AND PSYCHOLOGY

2.1. Nina Hordii FORMATIO OF SPEECH READINESS OF CHILDREN FOR SCHOOL USING SCHEMATIC MODEL AND CORRECTIVE TABLES

The issue of utilizing visual aids in the educational process, which fosters the activation of speech and renders it effective, is addressed. Researchers have proposed a specific means of developing preschoolers' speech - visual schematic models, in which a child reproduces the structure of objects and their relationships. One such tool is working with the application of schematic models, which activates the cognitive mental processes of older preschoolers, promotes the development of communicativeness, improves perception, attention, memory, and ensures interest in intellectual activity.

Keywords: older preschooler, speech, speech activity, schematic models.

2.2. Nataliia Hromova ACTIVE LEARNING METHODS IN UKRAINIAN LANGUAGE LESSONS

The relevance of the research is due to the fact that today society has a particularly acute need for independent, creative individuals who know how to think critically. The process of forming such personalities takes place directly in the lessons thanks to the skillful use of active methods by the teacher.

The author describes active methods of learning in Ukrainian language classes in 5th grade of NUSH while studying the lexicology section.

Keywords: Ukrainian language lesson, teacher, student, active methods.

CHAPTER 3. Serhii Onyshchenko MECHATRONIC TECHNOLOGICAL SYSTEMS: DESIGN CONCEPT AND APPLICATION IN MODERN MECHANICAL ENGINEERING

Mechatronics is a new field of science and technology dedicated to the creation and operation of machines and systems with computer motion control, which is based on knowledge in the field of mechanics, electronics and microprocessor technology, computer science and computer control of the motion of machines and assemblies.

Mechatronics - studies the synergistic combination of precision mechanics units with electronic, electrical and computer components for the purpose of designing and manufacturing qualitatively new modules, machines, systems and machine complexes with intelligent control with their functional movements.

Keywords: mechatronics, mechanical engineering, technological system, design.

CHAPTER 2. INNOVATIVE AND MODERN FOUNDATIONS OF PEDAGOGY AND PSYCHOLOGY

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CHAPTER 3. MECHATRONIC TECHNOLOGICAL SYSTEMS: DESIGN CONCEPT AND APPLICATION IN MODERN MECHANICAL ENGINEERING

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