Serhii ONYSHCHENKO

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Monograph

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INTRODUCTION

The priority direction of the development of science and technology at the current level is the development, creation and implementation of new generation mechatronic systems in the machine-building industry. Domestic developments in this field have been carried out for the past 20 years. Fundamental theoretical and experimental studies are needed to increase the effectiveness of research and development work in the direction of creating mechatronic systems and complexes used in mechanical engineering. They were held at the Department of Vocational Education, Labor Training and Technologies of the Berdyansk State Pedagogical University. The main results of the research are presented in this monograph.

Currently, the development of the industrial and household technosphere and the further implementation of mechatronic automation and robotics systems in various physical and technical processes of all spheres of society contribute to the creation of intelligent physical and technical products, systems and processes that have qualitatively new functions, properties and capabilities.

On the basis of technical achievements in the fields of mechanics, automation, electronics and informatics, the structure of creation of electro mechatronic systems, which affect the operation of automated control of machines and mechanisms, is carried out.

The main concept of electro mechatronic systems is to harmonize the design principles of physically disparate components of mechanical and electrical systems. The joint functioning of such systems and their subsystems makes it possible to ensure the necessary parameters and characteristics of machines and mechanisms already at the early stages of design.

This approach requires a developed system of automated design and control and consists of software modules of automated formation, research of mathematical models of the dynamics of both machines in general and their individual functional parts.

On the basis of the created electro mechatronic systems and subsystems, promising methods of their diagnosis are being developed, which contribute to the creation of modern automated structures that have wide possibilities and interchangeability of elements.

In general, mechatronics is related to practice and technical progress, which is due to the knowledge and skills of specialists and their engineering intuition.

The monograph is aimed at specialists who deal with the development of mechatronic and robotic systems and complexes in the field of mechanical engineering. The monograph will be useful for students and postgraduates of higher education institutions, research institutes and enterprises.

CHAPTER 1
PROSPECTS FOR IMPLEMENTATION OF MECHATRONIC SYSTEMS IN MECHANICAL ENGINEERING TODAY

One of the promising areas for the implementation of mechatronic systems today is the automotive industry. If we talk about car production, the introduction of such systems allows us to achieve a certain flexibility in production, respond more sensitively to fashion trends, quickly implement the latest developments of scientists and designers, and convey them to a specific consumer of the product. The car itself, especially a modern car, is the object of increased attention from design thought. Modern operation of a car requires increased requirements for driving safety, due to the ever-increasing motorization of the population and stricter requirements for environmental cleanliness. This is especially true for large cities. To create such conditions, the creation of mobile tracking systems is intended to monitor and correct the operating parameters of components and assemblies, achieving optimal indicators for environmental friendliness, safety, and ease of use of the vehicle. The urgent need to equip car engines with more complex and expensive fuel systems is largely explained by the introduction of increasingly stringent requirements for the content of harmful substances in exhaust gases, which, unfortunately, is not yet relevant in our country.

What were the specs of your desktop computer five, seven years ago? Today, system units of the late 20th century seem like an atavism and only pretend to be a typewriter. The situation is similar with automotive electronics.

It is impossible to imagine a modern car without compact control units and actuators - actuators. Despite the fears of skeptics, their implementation is progressing by leaps and bounds: we will no longer be surprised by electronic fuel injection, servo drives for mirrors, sunroofs and windows, electric power steering and multimedia entertainment systems. But the introduction of electronics into a car, in fact, began with the most critical area - the brakes.

Back in 1970, the joint development of Bosch and Mercedes-Benz under the modest acronym ABS revolutionized active safety. The anti-lock braking system not only ensured car controllability with the pedal pressed to the floor, but also made it possible to create several related devices - for example, the traction control system (TCS). The idea was first implemented back in 1987 by one of the leaders in the development of on-board electronics - Bosch.

In fact, traction control is the opposite of ABS: the latter prevents the wheels from slipping during braking, and TCS prevents them from slipping during acceleration. The electronic unit monitors traction on the wheels through several speed sensors. Should the driver “stomp” on the accelerator pedal more than usual, creating the threat of wheel slipping, the device will simply “strangle” the engine.

The designers "appetite" grew year by year. A few years later, ESP was created - the Electronic Stability Program. By equipping the car with sensors for steering angle, wheel speed and lateral acceleration, the brakes were forced to help the driver in the most difficult situations. By braking one or another wheel, the electronics minimize the risk of the car drifting when quickly taking difficult turns. The next step: the computer was taught to brake three wheels at once. In other cases, this is the only way to stabilize a car trying to leave a safe trajectory.

But so far only the “supervisory” function has been trusted to electronics. The driver still created pressure in the hydraulic drive with the pedal.

The electro-hydraulic SBC (Sensotronic Brake Control), which has been standard-installed on some Mercedes-Benz models since last year, has broken the tradition. The hydraulic part of the system is represented by a pressure accumulator, the main brake cylinder and lines. Electric - with a pump that creates a pressure of 140-160 atm., sensors for pressure, wheel speed and brake pedal travel. By pressing the latter, the driver does not move the usual rod of the vacuum booster, but presses the “button”, sending a signal to the computer - as if he were controlling some kind of household appliance. The latter calculates the optimal pressure for each circuit, and the pump supplies fluid to the working cylinders through control valves.

The beauty of the new product is its speed, combination of ABS and stabilization system functions in one device. There are other benefits too. For example, if you suddenly take your foot off the gas pedal, the brake cylinders will move the pads to the disc, preparing for emergency braking. The system is even connected to the windshield wipers. Based on the intensity of the wipers' work, the computer makes a conclusion about driving in the rain. Reaction - short and imperceptible for the driver touching the pads on the discs for drying. Well, if you’re “lucky” to get stuck in a traffic jam on an uphill slope, don’t worry: the car won’t roll back while the driver moves his foot from the brake to the gas. Finally, at a speed of less than 15 km/h, you can activate the so-called smooth deceleration function: when you release the gas, the car will stop so softly that the driver will not even feel the final “peck.”

What if the electronics fail? It's okay: the special valves will open completely, and the system will work like a traditional one, albeit without a vacuum booster.

So far, designers have not decided to completely abandon hydraulic brake devices, although eminent companies are already in full swing developing “fluidless” systems. For example, Delphi announced a solution to most technical problems that until recently seemed dead-end: powerful electric motors - replacements for brake cylinders - have been developed, and electric actuators have been made even more compact than hydraulic ones.

Bosch is also ready to start production of electromechanical brakes, but so far is refraining from making bold predictions about mass production. The main reason for the delay is the high cost of the product and the unavailability of other vehicle systems.

According to experts, “we won’t see serial electronic brakes until a redundant 42-volt network appears in the car, which will not allow the car to turn into an uncontrollable projectile in the event of a failure in the main electrical network.

But the so-called control by wire - brakes, accelerator, steering wheel - would solve many technological problems, and at the same time equalize “right-handed” and “left-handed” cars. To turn one into another, it will be enough to move the steering wheel, the instrument cluster and the pedal assembly. Such cars already exist - for example, "Bertone-Filo". True, it is still only a concept. But just five or seven years ago we never thought that such advanced computers would be on our desks.

The mechanical connection is broken: in the SBC system, the command from the brake pedal goes to the electronic unit and only then to the hydraulic actuators.

In extreme situations, the driver is assisted by an "emergency braking assistant". The vacuum brake booster has built-in speed sensors, brake pedal rod movement sensors and a solenoid valve. As soon as the movement speed exceeds a certain threshold, the electronic “brains” open the valve, increasing the air pressure in the amplifier chamber; The braking force reaches its maximum, but the ABS prevents the wheels from locking.

Perhaps soon the number of pads on each wheel will increase to three. The Delphi company sees the future of a design in which the third pad is located between two “floating” discs. Energy is absorbed by four surfaces at once. The weight of the “double break burger” is two-thirds less than a traditional brake mechanism, and the pressure required for operation is half as much.

The automatic parking brake has already taken root on expensive models. By pressing a button, the driver activates the stabilization system, which automatically increases the pressure in the brake drive, pressing the pads against the discs. A solenoid valve mounted in the cylinder then “locks” the brakes.

Cars are changing literally before our eyes: from a mindless executor of human will they are turning into some kind of intelligent creature that solves problems creatively. Examples: gearboxes that adapt to driving style, or suspensions that “feel” the road. And some cars already have eyes.

In megacities, you have to “catch” millimeters by squeezing into a row of cars at the sidewalk. Systems called “parking sensors” help here.

Ultrasonic sensors (four in the front and rear) are built into the bumpers, scanning the area around the car. The device is triggered when about 1.5 m remains from the obstacle: the LEDs on the instrument panel blink and the buzzer buzzes. The closer the object, the shorter the pauses between beeps and the “redder” the lights. 20 centimeters from the obstacle the car begins to “weep” constantly. In some cars, a picture is displayed on the display in front of the driver: a car and multi-colored zones showing the distance to the obstacle, and the sound, for convincing reasons, comes from the speakers of the standard audio system.

More complex and sensitive devices are able to recognize an object not only from behind and in front, but also from the sides.

Such parking sensors, of course, need more detailed information, and, therefore, additional sensors - at least six in each bumper.

The first devices that maintained a given speed, the so-called cruise controls, were essentially built into a mechanical "chain" (rod or cable) between the gas pedal and the throttle valve.

One of the ancient designs worked like this. The driver operated a special button at the end of the steering column switch. Pressed and released - the speedometer needle froze at the set mark. By holding the button, you can accelerate to the selected speed. The control unit, comparing the specified parameters with the actual ones, commanded the stepper motor, which controlled the accelerator pedal. A person could interfere with the operation of the system, for example, while overtaking.

In later systems, a pneumatic device acted directly on the throttle valve. The electromagnetic valve, which was commanded by the control unit, dosed the vacuum in the cavity of the control mechanism. The diaphragm pulled out a rod connected to the throttle valve actuator.

Electronics gave impetus to the development of "cruises": it eliminated the mechanical connection between the gas pedal and the engine. The control unit now communicates with the engine and gearbox computers. Such devices are more accurate, faster and, importantly, more compact.

There was one step left to the so-called adaptive systems, capable of maintaining not only a given speed, but also a safe distance. An "all-seeing eye" was built into the front of the car - a radar operating in receive and transmit mode. Based on the signal travel time, it calculates the distance from the car to the object and informs the control unit.

The driver sets the speed, and the computer obediently holds the speedometer needle at the desired level. But if there is a slow car on the way, and you do not brake or try to overtake it, the system “strangles” the engine and, if necessary, activates the brakes. The path is clear - it picks up the set speed again.

Of course, even adaptive cruise control doesn't allow you to take your eyes off the road. The developers specifically warn: the device is created primarily for comfort, and not to prevent accidents. For example, the brakes can only be “turned on” at 25% of maximum efficiency. If you need to stop faster, press the pedal yourself. In addition, the system has a rather narrow horizon: even a motorcyclist moving a few meters away from you along the edge of the same lane does not come into view. A passing car on a bend can also mislead smart technology: it occupies the adjacent lane, but becomes a “target” for the radar.

Xenon headlights are slowly replacing halogen headlights. And additional lamps with rotating reflectors are increasingly being installed in headlight units. Adaptive light follows the turn of the steering wheel, illuminating a curve in the road that is “blind” for conventional headlights. When approaching an intersection, when the driver turns on the turn signal, one of the headlights deflects, illuminating the side of the road and the adjacent road. But when changing lanes from lane to lane, the light shining to the side can interfere with other drivers! To avoid this, electronics monitor the vehicle's speed.

Obviously, in the near future the “sense organs” will become even more perfect. In Germany, the Invent project (INVENT - “intelligent transport and useful equipment”) has been approved, in which BMW, Daimler-Chrysler, Volkswagen, Bosch, Siemens and other industry giants participate. In the next few years, they promise to teach the car how to navigate a traffic situation and prevent driver mistakes. Of course, its role in management will remain dominant, project leaders say; electronics are only intended to help in difficult cases.

One of the systems will control cornering and lane changes. The electronic assistant will take into account the influence of side winds, the slope of the road, its unevenness and make adjustments before a critical situation arises.

The stop and go function will help brighten up life in traffic jams. Standing at the tail of the column, you press a special button, and then the car itself controls the engine and brakes. All that remains is to occasionally turn the steering wheel. However, Bosch is working on a modernized ESP system that stabilizes the car not only by the brakes, but also by the steering.

Project participants are also developing even more complex devices, for example, to avoid accidents at intersections. Using infrared and thermal cameras, radars, laser and ultrasonic sensors, the computer will “inspect” the area in advance and calculate the traffic situation (signs, traffic lights, location of cars and pedestrians). If an obstacle appears on the way, and the driver does not take decisive action, the system takes control: reduces the speed, and, if necessary, even brakes urgently.

In the near future, it will be the cars themselves that will deal with traffic jams. After talking with other cars within a kilometer radius, your crew will collect the necessary information and, after analyzing it, navigate the path along the least crowded streets. And the cars will warn each other about danger - a slippery road or a fallen tree around a bend.

Cars are becoming more attentive, surpassing in sensitivity and even insight the crown of creation - man. We don’t know how to read thoughts at a distance and calculate the situation at computer speed. But we know how to reason, feel and create machines that make our lives easier and safer.

When parking, the driver of the BMW 7 Series looks more at the display than at the rear window. The third eye - the cruise control radar on the Audi A8 is built into the front bumper. The Volkswagen Phaeton's adaptive cruise control looks 180 meters ahead and operates up to a speed of 180 km/h. Cars are already being taught to steer and park independently. Electronics will fit a car between other cars more accurately than a human. When turning, adaptive headlights illuminate 89 m of the road, conventional xenon headlights illuminate 65 m, and halogen headlights illuminate only 53 m. A picture from the near future: cars warn each other about traffic jams.

From the increasingly popular hybrid cars, there is only one step left to wheeled "diesel-electric vehicles", where the wheels are driven by electric motors built into them.

The design of compact and high-torque electric motors is no longer a mystery to developers. The main problem is their mass. After all, the stator with the rotor plus the windings heavily load the wheel, being "harmful" unsprang masses. Because of this, the car's behavior on potholes and its stability deteriorates. Perhaps it is precisely this circumstance that is holding back the development of such a drive scheme, otherwise there are only advantages. There is no need for drives or cardan shafts, and the traction of each wheel can be controlled individually - a designer's dream!

At the Frankfurt Salon, the Bridgestone company (it deals not only with tires) demonstrated a "revolutionary dynamic damper for motor wheels." Of course, they didn't talk about the device in detail. But the point is that, firstly, it was possible to suspend the electric motor inside the wheel, and secondly, to ensure that its vibrations were antiphase to the vibrations of the wheel itself and, when added, would cancel each other out.

How effective the experimental system is can be clearly seen from the graphs, which show the vertical force transmitted to the body when the wheel moves over a protrusion 10 mm high and 20 mm wide at a speed of 40 km/h. With the new damper (curve 3), the impact force is significantly less than even in a traditional car (1), not to mention the version with a rigid motor-wheel (2). Dependence of vertical forces on vibration frequency.

The company promises to bring its invention to fruition in the near future, that is, to serial maturity, and at the same time is developing special tires that will make it possible to make the most of the advantages of the invention.

Cutaway view of the new motor-wheel:

Cunning cross-shaped elements allow the motor to move inside the wheel and transmit torque.

Nowadays, automatic systems in cars are taken for granted. But automation is different. It's one thing, say, to provide a microclimate, but driving a car or, for example, changing stability and controllability parameters is quite another. Automotive automatic systems differ in the level of tasks they solve. Still, maintaining a constant temperature in the cabin and even a constant speed is somewhat easier than, for example, controlling braking in an extreme situation (which is at least somewhat different every time). There is also a big difference in responsibility (I think this word is quite applicable here, if not to technology, then to its creators). Because the consequences of inaccuracies in the trip computer cannot be compared with what can happen on a slippery road if the traffic stabilization system does not work correctly. It is not enough to make an automatic control system "in hardware": for example, the general principles of the construction and operation of the same ABS are widely known. But in any self-propelled gun there is also a processor, which must make the right decision and issue the appropriate command to the actuators. And the "mental activity" of the processor is determined by its level and the programs embedded in it. And first of all, it is precisely the ultra-fast development of computer technology that we owe to the fact that even on relatively inexpensive cars of the compact class, correctly functioning ABS, traction control and stabilization systems are no longer a curiosity. But not only them. The Japanese mastered rear-wheel steering quite a long time ago (which is also done automatically): the Mazda 626 4WS (4-Wheel Steering) modification was mass-produced already in the mid-eighties, and the Honda Prelude coupe has not parted with "full control" for three generations in a row. Of course, the "tidbit" is the suspension adjustment: too much depends on it (ground clearance, ride comfort, stability and handling), and all this can be influenced based on the vehicle load, driving style and driving conditions. Well, the driver's wishes, if, of course, they are reasonable.

Many manufacturers have been regulating the suspension system, and for quite some time. The most famous example is the hydropneumatic suspension of Citroen, but you can find it closer: already a veteran of passenger transportation, LiAZ-677 had a primitive (by today's standards) body level regulator depending on the load.

The European leader in the "automation" of serial passenger cars, without a doubt, should be recognized as the DaimlerChrysler concern, which inherited all the merits of

Daimler Benz. The names of many now well-known automatic systems are firmly associated with the Mercedes-Benz S-Class, on which they were first introduced into mass production, and from where they were then migrated to mass models. But Daimler Benz took quite a long time to equip its cars with adjustable suspension. After all, we were talking about something truly worthy of an eminent concern, and not about some kind of system for maintaining ground clearance.

The first harbinger of "combat readiness" was the Adaptive Damping System (ADS) for adjusting shock absorbers, which was installed to order on the Mercedes-Benz S-Class and the previous generation CL coupe. The new S-Class and the new Coupe introduced the world to two systems, adapted to the same platform.

The first is the AIR-matic air suspension with the ADS shock absorber control system as standard on S-class sedans. The second is Active Body Control, installed on all CL coupes.

"Struts" (as DaimlerChrysler calls devices that combine an elastic element and a shock absorber) of these suspensions are similar in appearance and have the same overall and mounting dimensions. Which is natural, since they are installed in virtually the same place. But everything else, including the principle of operation, is radically different.

The strut of the S-class sedan contains a pneumatic elastic element: the role of the usual springs here is played by compressed air enclosed under a rubber-cord casing. The strut also has a shock absorber with an unusual "extension" on the side.

Naturally, the car is equipped with a full-fledged pneumatic system (compressor, receiver, lines, valve devices). And also a network of sensors and, of course, a processor.

How the system works. At the command of the processor, the valves open access of air from the pneumatic system to the elastic elements (or bleed air from there). In this way, the level of the body floor changes: the system incorporates its dependence on the speed of the vehicle. The driver can also "show will" - raise the car, say, to drive over significant bumps.

ADS performs a more "delicate" job - it controls the shock absorbers. As the shock absorber rod moves, part of the fluid flows not only through the valves in the piston, but also through the very "extension" within which the actuator is a system of valves that provides four possible modes of shock absorber operation. Based on the information received from the sensors and in accordance with the algorithm selected by the driver ("sporty" or "comfortable"), the processor selects for each shock absorber the mode that best matches the "current moment" and sends commands to the actuators.

The S-Class suspension adapts to driving conditions, but is not able to deal with a serious drawback of large comfortable cars - roll and sway during turns, acceleration, and braking. Pneumatics are powerless here (due to the compressibility of air, they do not have sufficient speed), and shock absorbers counteract the roll only for a very short time - they do not "hold" a static load. That's why the S-Class suspension has conventional anti-roll bars. But the sportier CL does not have them! Active Body Control, a system that crowned almost twenty years of joint research work between Daimler Benz and Mannesmann Sachs, made it possible to do without them.

The coupe's suspension struts have many familiar elements: these are ordinary springs (with progressive characteristics, of course), and ordinary twin-tube gas-filled shock absorbers. Another thing is unusual: with its upper coil, the spring rests against a movable element - a plunger, moved along the rod by liquid pressure.

On board the vehicle there is a high-pressure hydraulic system (up to 200 atm), which includes a pump, pressure accumulators, actuator valve devices, and plungers in racks. Cooling and damping of fluid vibrations are also provided.

The electronic part of ABC consists of acceleration and suspension travel sensors, plunger movement sensors and, of course, a control processor.

Analyzing the sensor readings, the computer produces a solution that corresponds to the driving conditions and the selected algorithm ("sporty" or "comfortable"). Having received the command, the actuator valve devices change the pressure under the plungers of the struts. And so - 10 times per second.

Thus, ABC effectively counteracts longitudinal and lateral rolls and changes the level of the body floor (depending on speed, as well as on the driver's command). It also affects the smoothness of the ride: springs and shock absorbers have "comfortable" characteristics, and the plungers create the necessary additional forces (in dynamics, of course). But in this regard, ABC's capabilities are limited: it is subject only to vibrations with a frequency of no more than 5 Hz (in principle, the most noticeable and harmful to the human body). Higher frequencies are left to the springs and shock absorbers.

At the present time, we can observe how technological progress continues to take its toll. Finally, the automotive industry began to widely introduce new types of fuel supply systems and equip cars with anti-lock braking systems.

For a real impetus in the development of adaptive control systems, new approaches are needed in the development of technical documentation aimed at increasing the competitiveness of products and increasing the requirements of the consumer of the product. It is necessary to boldly introduce new progressive technologies into production that make it possible to obtain a finished product, which, of course, has been tested in advance under real operating conditions.

CHAPTER 2
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.

This definition especially emphasizes the unified essence of the mechatronic system, the construction of which is based on the idea of a deep interconnection of mechanical, electronic and computer elements. Therefore, the mechatronics emblem is 3 intersecting circles included in a common shell:

– production;

– management;

– market requirements.

Thus, system integration of the 3 indicated types of elements is a necessary condition for building a mechatronic system.

There are several definitions of mechatronics as a science.

The following special formulation of the subject of mechatronics is proposed:

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

Explanations for the definition:

1. Mechatronics studies a special methodological approach to constructing 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.

2. 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.

3. 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.

4. 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.

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

6. 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 and stimulates scientific and technological progress 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 technological 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 building can be assessed by the latest equipment, which leading manufacturers presented at an international exhibition in Japan in November 2002. Drive systems of modern metalworking machines provide the following characteristics: working feed speed up to 15 m/min, no-load speed up to 200 m/min, drive acceleration when accelerating up to 3g, processing accuracy of the order of 2-3 microns, number of simultaneously controlled axes up to 20 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. First of all, mechatronics should be included among them.

The methodology for designing modules and machines based on the mechatronic approach is aimed at the synergistic integration of the element.

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.

CHAPTER 3
STRUCTURE AND PRINCIPLES OF CONSTRUCTION OF MECHATRONIC SYSTEMS AND MODULES

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.

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 required, 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 electromechanical 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 UCU 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.

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

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

Geared motors 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 gearmotor 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 hexapods, 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.

CHAPTER 4
MECHATRONIC TECHNOLOGICAL MACHINES IN MECHANICAL ENGINEERING

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

– integration of technology and knowledge;
– intellectualization of production technologies:
– mechatronic technologies for machines and robots;
– 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 involve expansion, but rather the replacement of functions traditionally performed by mechanical elements of the system with electronic and computer units.

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?:

– market requirements;

– new relationships between consumer and producer. In this regard, qualitatively new requirements have emerged for the formal 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. At the same time, the domestic industry has an excellent foundation in this area.

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. Note that the development of machines from traditional mechanics to modern mechatronics goes through a series of stages, such as the development of electromechanical systems by combining an electric drive and mechanical transmission with electronic units in the drive.

In the structural basis of mechatronics, electromechanics is shown as one of the faces of the “Pyramid of Mechatronics”.

Historically, mechatronics developed from electromechanics, relying on its achievements and going further by systematically combining electro mechatronic 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 are the regulation of the force interaction of the working body with the objects of work during machining, the control of additional technological interactions on the object of work with combined processing methods, and the control of auxiliary equipment of the complex.

CHAPTER 5
STRUCTURAL ANALYSIS OF MECHATRONIC SYSTEMS BASED ON FUNCTIONAL LOAD DISTRIBUTION INDICATORS

An analysis of the scientific and technical evolution of mechatronic modules and mechatronic systems shows that their construction is based on the concept of "embedded design". This concept involves the synergistic combination 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", 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 a 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 criterion of "functional structural integration." For the structural assessment of mechatronics modules and systems, it is proposed to use a new quantitative measure called the functional load distribution indicator. The functional load distribution 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.

Traditional structural management system.

The structure of the system under study includes a control subsystem and an electromechanical part: an electric motor and photo pulse feedback sensors, which will remain unchanged during the analysis.

The analysis is carried out in accordance with the algorithm developed on the basis of monographs [13 – 16, 18].

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

For the second option, the distribution of functional load 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 indicator of functional load distribution among all the components under consideration (14%).

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

CHAPTER 6
MECHATRONIC TECHNOLOGIES FOR PROCESSING MATERIALS BY CUTTING ON LATHE MACHINES

There is a point of view that mechatronic technologies include technologies of new materials and composites, microelectronics, photonics, micro bionics, 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 V1, 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 V2, 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.

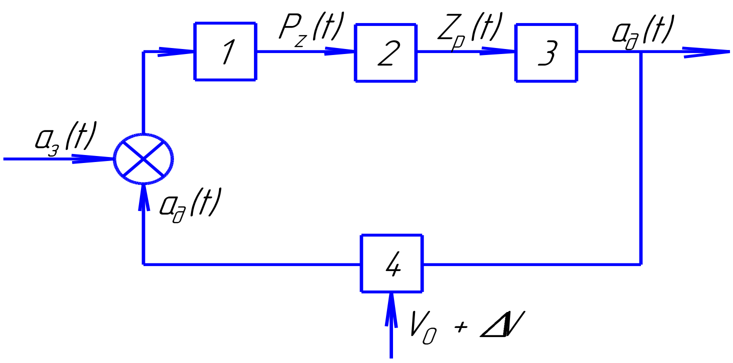
Over time, natural resonant frequencies begin to dominate in the spectrum and the process of self-oscillations intensifies again, which requires a repeated change in the cutting speed.

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-oscillation.

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 $a_д$ 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. A change in P_z causes a oscillation in the Z_p of the cutter. 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. 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}.

CHAPTER 7
CONSTRUCTION PRINCIPLES AND LEVELS OF INTEGRATION ELECTROMECHATRONIC SYSTEMS

General trends in the development of technology and features of mechatronics, as well as robotics, directly determine the main principles that have a systematic approach in accordance with the law of degree 3/2, step-by-step miniaturization, unification, integration, intellectualization.

In view of the development of mechatronic systems and robotics, some general principles on which their work is based are defined [1–4].

The first principle is system design (that is, the synthesis of mechatronics products) based on system-wide criteria without decomposition into individual functional components. The implementation of this principle became possible only at a certain stage of the development of science and on the way to its further improvement. At the same time, there are still many problems in terms of the formation of system-wide criteria and the development of synthesis methods based on them.

The second principle is the step-by-step miniaturization of elements through the successive mastering of different dimensions of products in the form of separate generations of technology. Each such generation requires new, appropriate technologies. At the same time, technological equipment based on the technique of preliminary dimensioning is necessary for the implementation of ideas.

For example, the implementation of this principle in micro mechatronics involves the development of 3D mechatronic and microsystem technologies based on 2D microelectronics technologies. The development of nanotechnology, for its part, involves the use of microtechnology (for example, micromanipulators, etc.).

The third principle is the unification of functional components. In the course of miniaturization for systems down to decimeter dimensions, this principle is implemented in the form of modular construction of systems from the type of dimensional series. They have structurally unified functional components, such as: power supply, sensor, information and control, executive (drive).

Considering the main requirements for components, they can be divided into two groups: informational and power.

With the reduction of overall dimensions of product elements to the level of centimeter dimensions, system-wide optimization leads to mutual penetration (convergence) of these functional components. This leads to a reduction in weight and size parameters, an increase in speed and reliability (primarily by reducing intercomponent connections).

The first mastered stage of the process is the dissemination of artificial intelligence methods with informational and control components that affect other functional components from sensory to executive.

A similar trend exists in energy supply and energy consumption through its decentralization and the introduction of secondary energy sources into separate functional components. The basis of these processes, as before, is system-wide optimization.

The fourth principle is the integration of functions on the basis of homogeneous structures. The principle of building systems is replaced by the modular one when moving to millimeter dimensions. This is preceded by the above-mentioned gradual mutual penetration of functional components, which ends with the transition to a qualitatively new type. Such a transition includes two stages.

The first stage covers informational components (sensory, informational and control, communication), and the second - power (executive, power supply).

Currently, the first stage is implemented on the basis of neuro-like structures. Each function is performed by separate sections of such structures with the possibility of their operational redistribution and boundary changes. Such an organization is similar to a multi-agent system in computer networks. Individual components lose their constructive independence and turn into a software product, namely into software agents-modules functioning in a homogeneous material environment.

The second stage of mastering homogeneous structures is the implementation of this principle in power functional components. This task requires the search for new physical principles and ways of their technical implementation. Research is being conducted on the creation of "artificial muscle" actuators. They consist of hundreds of elementary micro actuators based on electroactive polymers and have energy sources (nanobatteries or nano fuel cells). This contributes to the improvement of the weight and size parameters of the drives and allows to dramatically increase the reliability of their components and modules in general.

The fifth principle is the intellectualization of both individual functional components and system-wide functions. The further development of this principle will be the technical development of creative (creative) human abilities.

The sixth principle is the so-called power law of 3/2. It belongs to miniaturization and consists in the fact that due to the different order of dimensions of the volume (3) and surface (2) of the objects, when they are miniaturized, the significance of surface phenomena increases. For example, heat exchange with the external environment compared to volumetric phenomena (inertia, etc.). As a result, the principles of construction, methods of calculation and design of mechatronic systems in the process of their miniaturization are subject to revision.

Considering the construction structure and levels of integration of electro mechatronic systems, we must define a mechatronic device.

Mechatronic devices are a class of machines or assemblies based on the use of advances in precision mechanics, electric drive, electronics, and computer control. All these elements can be found in a huge number of traditional techniques.

Mechatronic devices are generally defined by a number of features:

1. Availability of integration of the following functional elements:

– the output mechanical link, which performs the external functions of the mechatronic device;

– engine of the output link with a mechanism for transmitting motion to the output mechanical link;

– amplifier-converter of engine power supply energy;

– device for digital program control of the drive;

– an information system that monitors the state of the external environment and the internal parameters of the mechatronic device.

2. A minimum of information and energy transformations (for example, direct digital control of a gearless drive).

3. Using one and the same element of a mechatronic device to implement several functions (for example, motor parameters: current, EMF resistance), which are used to measure its moment and speed (principle of combining functions).

4. Designing the functions of various elements of the mechatronic device in such a way that the purpose of the service purpose of the product is achieved by joint performance of these

functions without their duplication and with maximum effect (principle of synergy).

5. Combining the housings of mechatronic device nodes (principle of combining housings).

The computer control device performs the following functions:

– control of the process of mechanical movement of a mechatronic module or multidimensional system in real time with processing of sensory information;

– organization of control of functional movements of a mechatronic system, which involves coordination of control of its mechanical movement and accompanying external processes. Usually, discrete inputs/outputs of the device are used to implement the control function of external processes;

– interaction with the "man-operator" system through the machine interface in autonomous programming modes (off-line mode) and directly during the movement of the mechatronic system (on-line mode);

– organization of data exchange with peripheral devices, sensors and other devices of the system.

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

Synergistic integration is not simply the connection of separate parts into a system using interface blocks, but the construction of a single drive module through the constructive combination and even interpenetration of elements that usually have different physical origins.

The purpose of mechatronic modules is the implementation of a given controlled movement, usually by one controlled coordinate.

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

The essence of the mechatronic design approach is to combine components into a single drive module.

The application of the mechatronic approach to the design of the motion module is based on the determination of possible points of integration of elements in the drive structure. On this basis and taking into account technical, economic and technological analysis, it is necessary to make specific engineering decisions on the design and manufacture of the movement module.

For example, the input of the mechatronic module receives information about the purpose of movement, which is formed by the upper level of the control system. The output is a purposeful mechatronic movement of the final link (movement of the output shaft of the module).

So, for the physical implementation of an electromechanical mechatronic module, four functional blocks are theoretically necessary, which are connected in series. For example, informational-electrical and electromechanical, functional converter in a direct circuit and electrical-informational and mechanical-informational converters in a feedback circuit.

CHAPTER 8
DEVELOPMENT TRENDS AND PRINCIPLES OF BUILDING MODULES MECHATRONIC SYSTEMS

The process of miniaturization is based on the implementation of this trend in the basic components of any equipment - sensor, information and control, executive (power), power supply.

Classic solutions in the field of design and construction of technical modular systems are based on the possibility of decomposition of general technical requirements for the system at the stage of design of the technical task, which is widely used for machines and complexes at the macro level.

An example of convergence in a different sense (the process of convergence, reaching compromises) or interpenetration of functional subsystems are MEMS devices, in which sensor, information-control and executive components are placed on a single micro-platform.

At the same time, for example, photo sensors are integrated with microprocessors, and piezo elements are simultaneously executive devices.

Acceleration of the convergence process is dictated not only by the need for miniaturization, but also by the wide opportunities that open up with each new level of interpenetration of subsystems. At certain stages of integration, real opportunities appear for self-organization and self-reproduction processes.

The latest complex components have already become examples:

– energy sources are miniature chemical current sources in which polymer membranes with a nanoporous structure are used as effective electrolyte fillers;

– information and control – radiation-resistant micro analogues of electronic lamps, as well as micro mechatronics, in which the cold cathode is formed from carbon nanotubes;

– sensors are chemical sensors based on transistor structures with pre-formed chemisorption centers;

– distributed tactile sensors, the sensitive elements of which are made of nanocomposite materials;

– encoders of angular velocities and linear accelerations for orientation and navigation systems, in which moving elements are manufactured by growing methods in the process of creating the module component as a whole.

When building mechatronic modules, robotics and mechatronics are inextricably linked. If progress in modern robotics is determined mainly by the success of mechatronics, which ensures the miniaturization and integration of functional components, then the process of robotization of technical means is one of the most important stimulators and catalysts of the development of mechatronic technologies. Robotization involves steadily increasing requirements in the field of intellectualization and complex automation of complex systems. Mechatronic technologies ensure this process by creating a design and technological base.

Robotics technologies are based on the same principles as mechatronic technologies. In addition to intellectualization and miniaturization, they include a number of macro-level technologies: unification of components and their interface interconnection, integration of functions and mutual penetration (convergence) of heterogeneous functional subsystems [11, 12].

Let's consider each functional subsystem in more detail.

The sensory subsystem is represented by transducers that implement the functions of hearing, touch, technical vision, orientation and geometric parameters of the control object, its position in space for the purpose of navigation, etc.

The executive subsystem makes it possible to move the platform (locomotion), as well as functional movements - fixing, grabbing, folding, positioning, etc. Manipulation of systems takes place through the use of drives, mechanical gears, grippers and other elements of influence.

The information and control subsystem provides collection, processing and storage of information, generation of control signals, static and dynamic feedback, as well as interaction with the operator or an external control system of a higher level by means of receiving and transmitting information by means of communication.

The energy subsystem regulates the supply and distribution of energy of other subsystems, as well as the accumulation of energy from external sources and its storage during the operation of the machine. Internal energy components can be represented by chemical, electrical, nuclear, micro-explosive, pneumatic and other similar energy sources.

Critical from the point of view of the need for fundamentally new approaches to development are the executive and energy components, which require the organization of conditions for basic innovations in these areas.

Sensor and information-control components are widely adopted, which improves further innovation and emphasizes the development of new subsystems. For example, the development of modern means of global navigation ensured their widespread use at the household level. This makes it possible to predict the equipping of vehicles with navigation equipment and to use them as integral requirements for such systems already in the near future.

The given analysis of the objective development trend of approaches to the construction of technical systems shows the need for large-scale measures regarding the system development and software implementation of mechatronic technologies, as well as for the realization of the needs of industry today and in the perspective of the next 5-10 years.

On the basis of the forecast and systematic analysis of the prospective needs of all branches of the country's economy, it is necessary at the state level to undertake the anticipatory development of the above-mentioned components in the form of a system of unified mechatronic modules, covering the entire standard size range of machine-building products, based on promising production technologies.

As the first steps in this direction, it is advisable in the near future on the basis of large scientific centers that have the necessary experience in the development of the systems in question, to launch the production of micro-robotic systems of the new generation, which are built using mechatronic design technologies. At the same time, it is necessary to use modern MEMS components as a technological basis.

Thus, the use of micron-sized mechatronic modules makes it possible to talk about the development of distributed component systems based on multiplexing and on the basis of microchips with a high level of intellectualization.

This ensures the reliability and stability of the received data and information. Such an approach increases the level of system reliability many times due to the possibility of transferring part of the functions of failed components to others without significantly reducing technical characteristics during critical operations.

The complex nature of the approach to the development of mechatronic modules requires a systematic integration of all the work carried out, which is confirmed by the experience of developing and creating foreign analogues. A typical example is integrated computer production complexes of domestic and foreign systems.

The scientific and technical relevance of this problem logically follows from the advantages of a technical modular system built according to the mechatronic principle: intelligence, adaptability, reliability, miniaturization.

The principles of robotics and mechatronics are interconnected and have a common theoretical basis [1, 11, 12].

Only the principle of unification, which determines the peculiarities of the use of robotics, has significant specificity:

– wide nomenclature;

– the complexity of the technical requirements for the means of robotics, which is often at the limit of the capabilities of modern technology;

– insignificant needs of elements in certain types of robotic systems.

These features are the basis for solving the task of unifying robotics tools by building them from functionally and constructively unified components - mechatronic modules in the form of their standard size series with a modular software system.

The advantages of the modular construction principle are as follows:

– shortening the terms of creation, development in production and operation of technical modular systems;

– system design, which comes down to assembling from standard components, and their production - to assembly from them, which can be organized at almost any machine-building enterprise;

– the possibility of practically unlimited expansion of the range of technical systems, in particular, the operational composition of their various modifications for specific one-time applications;

– reducing the cost of systems by several times due to the cheaper parts of them when switching to unified serial modules and reducing structural and parametric redundancy;

– reduction of costs for the development, operation and repair of technical modular systems;

– the growth of their technical level, in particular reliability, the use of proven standard modules.

The effectiveness of the modular principle does not exclude the use of other engineering principles in robotics. For example, the experience of industrial robotics shows that when designing transport and loading and unloading robots, the optimal principle of their construction is the creation of such systems based on previously developed basic structures. When creating technological robots to perform such operations as welding, cutting, assembling, the aggregate design principle often turns out to be the most effective.

It is also necessary to take into account the fact that the modular construction of equipment has its own disadvantages, which are caused by the inevitable overestimation of weight and size characteristics and the number of intermediate mechanical and electrical connections.

Organizational principles. The development of mechatronics and robotics as a complex interdisciplinary scientific and technical direction requires an adequate state organization. This is how the development of robotics began.

For example, in Japan, which is recognized as a leader in this field, all the achievements were obtained precisely because the anticipatory development of robotics was recognized as a strategic state task. A similar approach was implemented in a number of European countries.

The main state tasks include:

– determination of the nomenclature of functional components and technical requirements for mechatronics and robotics (with the selection of priority needs) based on the analysis of financial needs.

– unification of these components, their development and organization of industrial production. This will make it possible to reduce the range of products by 2-3 times, and, accordingly, the development costs, increase the serial production, reduce the cost and increase the quality;

– development of primary basic mechatronic and robotic systems and complexes on this basis;

– their industrial production and testing in operation.

According to the tasks, the following works are provided:

- creation of priority systems of mechatronics and robotics of the new generation;

- organization of training and retraining of personnel, in particular organizers and managers.

In general, the development program should be focused on the solution of the most important state tasks (security, technological independence, technical support, development of critical technologies and types of equipment according to priority areas of development). In the future, these solutions should be replicated and developed to meet other needs in mechatronics and robotics funds.

When developing and organizing the production of relevant products, it is necessary to be guided by the following:

– creating products that are guaranteed to be competitive on the world market;

– a solution to the problems of import substitution and organization of the production of the best examples of this technology in the world, but at a significantly lower cost.

As mentioned above, the solution to this problem is based on the further development of the following critical technologies:

– mechatronics technologies and creation of microsystem equipment;

– technologies for creating intelligent systems;

– bioinformation technology;

– information processing and protection;

– biosensor technology.

So, the considered complex problem immediately belongs to several priority areas of development of science and technology. First of all, this is the industry of nano systems and materials, living systems, information and telecommunication systems. The proposed approach is of particular importance in the creation and implementation of technical means for ensuring security and countering terrorism.

CHAPTER 9
ROBOTIC ELECTRO MECHATRONIC SYSTEMS AND MODULES

The modern trend in the design and production of equipment is the use of the block-module principle. For mechatronic systems, such modules are mechatronic motion modules - a synergistic combination of mechanical (hydromechanical, pneumomechanical), electrotechnical, electronic components and information and software tools that realize the achievement of a given controlled movement. This makes it possible to decompose complex systems, reducing the number of degrees of freedom, and obtain their necessary hierarchical structure.

In many areas of technology, mechatronic systems replace traditional electrical and mechanical machines that no longer meet modern quality requirements. The mechatronic approach in the construction of new-generation machines consists in transferring the functional load from mechanical units to intelligent, electronic, computer-informational components, which are easily reprogrammed for a new task and at the same time have a low cost. For example, the functional analysis of new production machines proves that the share of the mechanical part has today decreased from 70% (in the early 90s) to 25–30%. It is fundamentally important to emphasize that the mechatronic approach in design involves not expanding, but rather replacing the functions traditionally performed by the mechanical elements of the system with electronic and computer units.

Modern technological and mobile machines (NPC machines, automatic lines, industrial robots, etc.) contain several mechatronic movement modules that carry out movement in space of working bodies and executive mechanisms according to a predetermined program trajectory.

The characteristics of the technological environment are determined with the help of analytical and experimental studies and computer modeling methods. If such research requires complex and expensive devices and measuring technologies, then it is advisable to use adaptive control methods that make it possible to automatically adjust the laws of movement of working bodies directly during the operation using external sensors of the machine's information system.

Currently, technological machines – hexapods (Fig. 9.1), which are used in the energy and transport industries, are widely used for diagnostics and maintenance of power lines and contact lines urban electric transport networks and protection systems.

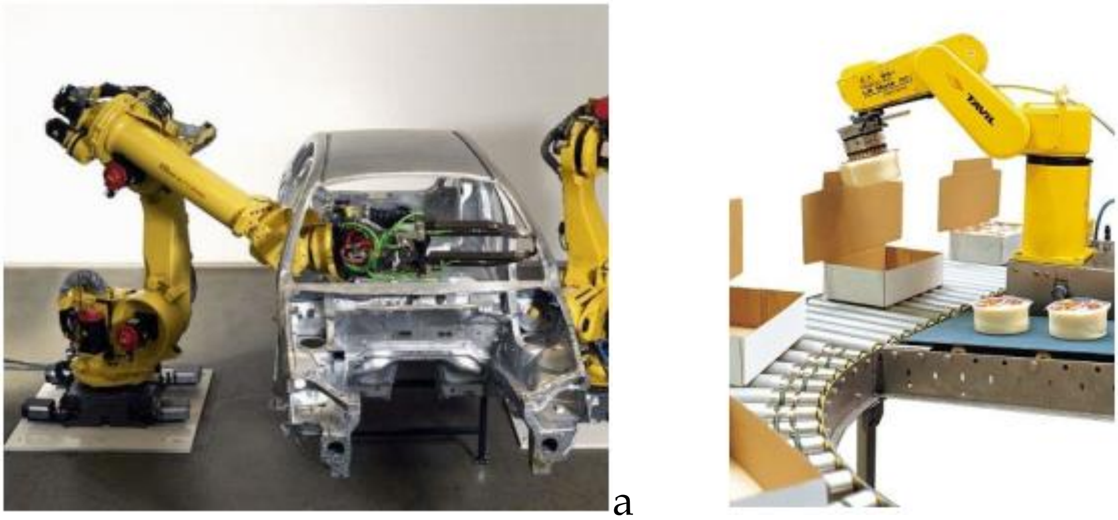
Figure 9.1 – General view of hexapod technological machines

Such hexapods can also be machine tools, coordinate measuring machines. At the heart of their design scheme is the Hugh-Stewart platform. A feature of such machines is the mechanism, which has six independent legs on hinged joints. The length of the legs can be changed, which leads to a change in the orientation of the platform.

The synthesis of new precision, information and measurement science-intensive technologies provides a basis for the design and manufacture of intelligent mechatronic modules and systems. In the future, mechatronic machines and systems will be combined into mechatronic complexes based on unified integration platforms.

The purpose of creating such complexes is to achieve a combination of high productivity and at the same time flexibility of the technical and technological environment due to the possibility of its reconfiguration. This will make it possible to ensure the competitiveness and high quality of mechatronics products produced in the markets of the XXI century.

Robots and manipulators are a vivid example of a mechatronic system (Fig. 9.2). They are increasingly used for welding and painting, assembly operations, electronic printed circuit board manufacturing, metalworking, in space research and even in everyday life.



a b

Figure 9.2 – Industrial works: a – welding; b – packing

Some types of robots are similar in design and purpose to a human hand. Other robotic systems create automatic movement of loads, so they look like carts (Fig. 9.3).

A typical mechatronic system is a machine tool with numerical program control (hereinafter referred to as NPC), which is used for mechanical processing of metal, wood, and plastic products (Fig. 9.4). The operation of the movement modules is coordinated by the digital NPC system, which is preloaded with the processing program.

Figure 9.3 – Robocar (automatic cart)

Mechatronic modules and systems are also used:

– in the automotive industry (for example, anti-lock brake systems, vehicle motion stabilization and automatic parking systems, autopilots);

– 3D-printers (Fig. 9.5);

– non-traditional means of transport (electric bicycles, segways, wheelchairs, drones, Fig. 9.6);

– office equipment (for example, copiers and fax machines);

– elements of computing equipment (printers, plotters, disk drives);

– technological lines and packaging machines of the food and processing industry;

– printing machines;

– household appliances (washing machines, sewing machines, dishwashers and other machines) and photo and video equipment;

– medical equipment (rehabilitation, clinical, service);

– simulators for training pilots and operators, etc.

Today, intelligent systems are widely used in other countries and in Ukraine. These control systems can be used for any type of transport: railway, urban electric, road, air and water.


a

b

Figure 9.4 – CNC machine tools: a – lathe; b – milling

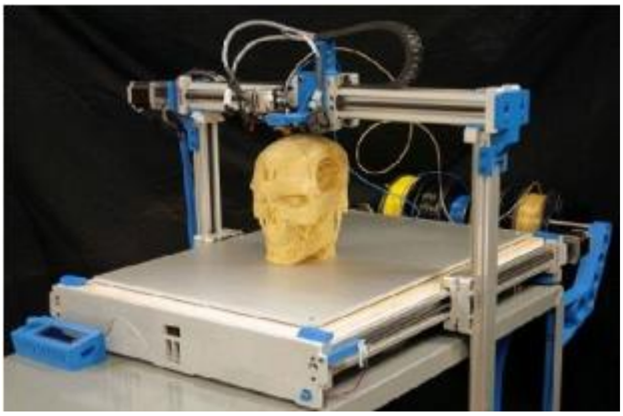


Figure 9.5 – 3D-printer

Figure 9.6 – Drone

An example of another innovative solution is the use of electromechatronic systems in nuclear energy.

Such complexes or systems include work in radiation exploration. As the experience of conducting radiation surveys proves, there are many sources of radiation that may not be recorded by radiometric systems in space. Therefore, the use of standard radiometers is ineffective. In this regard, robotic systems (Fig. 9.7) with collimated radiometry technologies can be used for measurements.

Figure 9.7 – Robotic mechatronic systems for nuclear energy

Such robots are equipped with open and collimated detectors, video cameras, etc. Open detectors measure the power of the radiation dose at the point of placement of the measuring unit. The collimated detector measures radiation fluxes. Video cameras usually have an optical zoom, which allows you to examine the subject in detail.

Robotic systems can function in very difficult conditions: at high and low temperatures, collapses, gassing, dustiness, radiation and electromagnetic fields, etc.

Robots can perform the functions of equipment carriers for the examination of radiation-hazardous objects. Therefore, robotics makes it possible to carry out the most effective radiation reconnaissance, bypassing the presence of a person at the object.

Robots are widely used to eliminate the consequences of accidents by collecting radiation samples, cleaning buildings from debris and deactivating nuclear reactors. The impetus for the development of the global market of robotics for the purpose of eliminating the consequences of accidents at nuclear power plants was provided by the disaster that occurred at Fukushima-1. In this case, remotely controlled robotic systems were used to decommission a nuclear reactor in order to reduce high levels of radiation.

Today, the global market continues to develop in the direction of creating intelligent mechatronic systems.

CHAPTER 10
MODELING OF THE DYNAMICS OF MECHATRONIC COMPLEXES AND MODULES

Methods of mathematical modeling and design of mechatronic systems being developed should be based on a single, comprehensive approach to the design object [12].

A model (from the Latin Modulus – sample, measure) is a device that possesses the main properties of the object under study.

Modeling as a research method is used when the research object is partially or completely unavailable for any reason. Such a situation arises in the case of designing a fundamentally new technique, since in order to substantiate the adopted design decisions, it is necessary to study a system that does not yet exist physically.

Modeling can be:

– natural, when the model has the same physical origin as the object under study;

– analog, when the model and the object have different physical origins.

If the properties of the object under study are expressed by mathematical relations (equations, inequalities), then it is said that there is a mathematical model.

The high level of development of computer technology and software, achieved up to now, allows to consider mathematical modeling as a powerful tool of scientific research. Due to the fact that mechatronic systems are technically complex products, their design and preparation for production, as well as the importance of mathematical modeling using computers, is decisive.

Therefore, the system of automatic design (hereinafter referred to as SAD) of mechatronic systems necessarily includes a subsystem of mathematical modeling of dynamics, which allows to develop dynamic models of the designed product in an automated mode, conduct research, and solve engineering problems of optimization and synthesis.

The tasks of automation of modeling, research and design of mechatronic complexes and systems use the following forms of presentation of mathematical models of dynamics:

– a system of differential equations;

– connected graphs;

– structural and dynamic scheme.

The dynamics equation is the most general form of presentation of a mathematical model of a mechatronic system or its individual subsystems. They are equations that relate the coordinates of the system, its velocities and accelerations to the forces acting on the system. Coordinates can be not only the linear and angular positions of the links of the mechanical part of the machine, but also the volumes of the working fluid of the hydraulic drive, electric charges flowing through the cross-sections of the conductors, etc.

Power parameters in the equations of the dynamics of a mechatronic system, in addition to "mechanical" forces and their moments relative to any axes, can also be the pressure of the working fluid (gas), electric voltage, etc.

The formation of the dynamics equations of the electromechanical system in generalized coordinates can be carried out by the Lagrange method, as well as on the basis of the connected graph of the system, by applying Kirchhoff's laws to its nodes.

A promising approach in modeling the dynamics of mechatronic systems is the approach, which consists in the fact that the dynamics of an executive mechanism with several degrees of freedom in the space of generalized coordinates is represented as dynamics depicting points in Riemannian space (manifolds are differentiated, in which the tangent space at each point is finite-dimensional Euclidean space).

The dynamics of mechatronic systems and complexes is usually described by nonlinear differential equations. The application of effective methods of analysis and synthesis, developed in the theory of linear automatic control systems, involves the linearization of dynamics equations [12]. For its part, a linear model of system dynamics can be presented in the form of a structural-dynamic diagram. In other words, in the form of a limited set of linear dynamic links, combined into a general structure with the help of direct and feedback links. Computer analysis and synthesis of automatic control systems, which is carried out on the basis of the representation of system dynamics by structural-dynamic schemes, has developed intensively since the 70s of the last centuries and is currently quite widespread (special software complexes Simulink, VisSim and others). The significant results obtained in this direction are a package of DSD (Dynamic Systems Design) programs [11].

A number of tasks of designing mechatronic systems having spatial mechanisms with a large number of degrees of freedom, or controlling their motion, can be solved without compiling and integrating a complex system of equations. At the same time, we can limit ourselves to the study of invariants of the mechanical part (work of generalized forces on small displacements, kinetic energy) using the tensor-geometric method [12].

One of the directions of scientific research in mechatronics is the development of general theoretical provisions, on the basis of which it is possible to create effective methods of mathematical modeling of mechatronic systems and simulation automation algorithms. Since the properties of the control object, executive drive and information system must be considered in a complex and taken into account already at the early stages of designing a mechatronic system, it is necessary to develop dynamics models of both mechanical and electrical subsystems using a single method. At the same time, the method of mathematical modeling of the dynamics of a mechatronic system should have the following properties [11]:

– invariance to the physical nature of the simulated objects;

– the formality of the actions performed during the implementation of the method;

– convenience of calculation results for analysis and use in design.

Manipulator robots, mobile robots, multi-coordinate NPC machines, etc. have spatial actuators that can have a large number of degrees of freedom and contain closed kinematic loops. This complicates the mathematical modeling of the dynamics of such mechatronic systems. Multi-stage transmission mechanisms of drives, for their part, represent known difficulties in modeling dynamics, since they have significant deviations from ideal mechanical transmission, such as inertia, elastic compliance of links, backlash, and dry friction in kinematic pairs. In some cases, the mechanical part of the machine can be a non-holonomic system (with the presence of differential non-integrated connections). Therefore, the method based on the algorithms for the automated formation of models of the dynamics of mechatronic systems should have a commonality sufficient to account for all the listed factors.

Creating mathematical models of the dynamics of multidimensional systems consisting of physically heterogeneous functional parts is a time-consuming and science-intensive task. To solve it under conditions of strict time constraints, effective and maximally full use of the capabilities of modern means of automating calculations is necessary. The new possibilities of hardware and software tools for automating calculations include:

– high computing power;

– automation of creating spatial and geometric models (computer graphics);

– automation of mathematical calculations in symbolic form (computer algebra);

– developed systems of information exchange between software modules of different purposes;

– free access of project participants to intermediate design results, the possibility of prompt use of previously obtained results in the development of new projects;

– accessibility to a wide range of users, visualization and animation of simulated objects and processes.

According to the task, the automation of the simulation of the dynamics of the mechatronic system consists of:

– in the analysis of the existing methods of dynamics and justification of the choice of the method, on the basis of which the mathematical support of the software module for the automated formation of the dynamics model of the mechatronic system will be developed;

– in the development of mathematical, algorithmic and software, focused on the possibilities of modern means of automating calculations.

Today, there are five methods of obtaining the dynamics equations of multi-link executive mechanisms [7, 9, 11]:

– the Lagrange method, based on the Lagrange equations of the II kind and the description of the kinematics of the system by matrices of homogeneous coordinate transformations;

– the modified Lagrange method, based on the Lagrange II equations of the kind and the recurrent description of the kinematics of the mechanical system;

– Euler's method, based on the application of the second law of dynamics and D'Alembert's principle;

– the Gaussian method, based on the principle of least forcing;

– method of connected graphs.

Lagrange's method and Euler's method are considered traditional and are most often used in practice. The derivation of the equations of motion of holonomic mechanical systems by the Lagrange method is distinguished by the simplicity and unity of the approach, and the equations obtained by this method provide a description of the dynamics and can be used to develop control laws in the space of attached variables [3]. Expressions for the kinetic and potential energy of the links can be written relative to the coordinates of the links in a fixed coordinate system. The advantage of the Lagrange method makes it possible to use it to derive the equations of motion of mechanical systems containing closed loops. As already mentioned, the dynamics equation in Lagrange form can be formulated for an electrical system. Equations and algorithms of manipulator robot dynamics based on the application of the Lagrange method [7, 9, 11].

The application of Euler's method leads to a system of direct and inverse recurrent equations, successively applied to the links of the mechanical system. This method is the most effective from a computational point of view, which allows you to use it for real-time control of the system and for simulating its movements on a computer [11]. The advantage of Euler's method is also the ability to calculate forces and moments of reaction forces in kinematic pairs of the mechanism. From an analysis point of view, recurrence relations are not convenient. Therefore, Euler's method is practically not used in problems of synthesis of control laws.

The modified Lagrange method makes it possible to obtain the dynamics equation in a vector-matrix form, which is convenient for analysis. In addition, these equations provide a reduction in computational costs for calculating dynamic coefficients compared to Lagrange equations. With the use of coefficients, it is possible to distinguish dynamic effects due to the rotational and translational movement of links. This must be used during control synthesis in the state space of systems. The computational efficiency of these equations is due to the use of rotation matrices and relative position vectors to describe the kinematics of links. The use of the modified Lagrange method for the analysis of systems containing closed kinematic loops is associated with difficulties, because this method involves recurrent computational procedures.

The method based on the Gauss principle, in contrast to the methods based on the Lagrange equations, makes it possible to obtain the dynamics equations of mechanical systems, both with holonomic and non-holonomic couplings. When using the Gaussian principle, the task is reduced to determining the accelerations of the true motion, which provide a minimum expression for forcing. This is achieved by numerically minimizing the forcing as a function of the generalized accelerations of the mechanical system using dynamic programming or uncertain Lagrange multipliers. An undoubted advantage of the Gaussian method can be considered the possibility of its application to study the movement of mechanical systems with unregulated connections. The advantage of the Gaussian method is achieved precisely in those cases when numerical methods are used to minimize the forcing at each step of the integration of the dynamic's equations.

The method of connected graphs is based on the presentation of a system (mechanical, electrical, hydraulic or combined) in the form of some finite number of elements that have a formal mathematical description and are connected to each other in a general structure by means of connections. This method is the result of the development of graph theory, one of the founders of which was L. Euler.

The mathematical model of system dynamics is displayed in the form of a diagram (graph), on the basis of which the dynamics equations are derived, while the mechanical part of the system can be non-holonomic. The main advantage of the method of connected graphs is the structural-graphic representation of the dynamics of the studied systems, which makes it possible to trace all the interactions of the system elements visually and obtain the dynamics equation by applying Kirchhoff's simple laws to the connected graph. The use of the method of connected graphs gives the greatest effect in the description, analysis and design of branched systems with the presence of closed kinematic contours.

Therefore, the method of connected graphs is adopted as the theoretical basis of equations and algorithms for automated modeling of the dynamics of mechatronic systems.

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Serhii ONYSHCHENKO

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The priority direction of the development of science and technology at the current level is the development, creation and implementation of new generation mechatronic systems in the machine-building industry. Fundamental theoretical and experimental studies are needed to increase the effectiveness of research and development work in the direction of creating mechatronic systems and complexes used in mechanical engineering. They were held at the Department of Vocational Education, Labor Training and Technologies of the Berdyan State Pedagogical University. The main results of the research are presented in this monograph.