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MECHATRONIC CONTROL SYSTEM OF EXECUTIVE MECHANISMS OF METALWORKING MACHINES

The use of mechatronic systems which operate subsystems of technological equipment resulting in high level of automation and flexibility of manufacturing is demonstrated. The solved problems are to expand production opportunities in the productivity increase and quick readjustments of processing parameters as well as simplifying the kinematics of the metalworking machines rotation motion by applying mechatronic means. The structure of the control system, which can be built by using an accessible and common element base is developed. A number of subsystems can be highlighted on the grounds of the developed one which provide the operation of the electric drive, transmission and conversion mechanisms, synchronization of movements of actuators, control of auxiliary subsystems, such as control system of limit positions and braking the units that move under inertia forces after shutdown power supply.
Keywords: spindle assembly, control system, mechatronic system.

INTRODUCTION

It is known, the technological capabilities of metalworking machines largely depend on the characteristics of the movements of their executive mechanisms and shaping movements in particular. The most common types of shaping movements which are used in processing on metal-cutting machines are rotational and translational ones. The range of values of torque and angular velocity of the main movement, axial force and linear feed rate largely determines the characteristics of the machine and, as a consequence, the quality and productivity of machining. Ensuring a wide range of characteristics of shape-forming movements requires effective coordinated control of a number of converting mechanisms, as well as the engine and mechanism for clamping workpieces and tools in spindle assemblies.

ANALYSIS OF LITERATURE DATA AND FORMULATION OF THE PROBLEM

The use of mechatronic systems to control the operation of subsystems of technological equipment helps to increase the level of automation and flexibility of production [7, 8]. This expands the possibilities of production in the areas of increasing productivity and speed of readjustment of machining parameters [1-3]. Such opportunities give new competitive production advantages in the conditions of high rates of general technological progress where improvement, modification and new goods are common. It also creates the preconditions for increasing the level of integration of production systems at the technical and functional levels. That is obviously, that the most efficient and common way to supply equipment by energy is to use electricity. There is also a tendency to expand the scope of use of electromechanical components as part of technological equipment, including the replacement of their existing mechanical counterparts. It helps to reduce the number of energy converters and energy losses.

PURPOSE AND OBJECTIVES OF THE STUDY

The structure of the developing control system is aimed to enhance a wide range of characteristics of the movements of the executive mechanisms and provides control both by change of the electric motor characteristics and by switching mechanical gears with electromagnetic clutches. Switching the appropriate electromagnetic couplings provides a kinematic connection between the gears and shafts, which allows to change the speed. The width of the range of characteristics of the executive movements allows choosing more optimal machining modes by providing both high speeds for finishing small-diameter parts and significant torques for roughing large-diameter parts made of hard material.

The aim of the research is to expand the possibilities of providing technological flexibility of metalworking machines. To achieve this goal it is necessary to solve problems aimed at simplifying the kinematics of the mechanisms of spindle assemblies and the drive of the feed (translational) of metalworking machines as well as effective exchange of information between the mechatronic systems which control the operation of subsystems. It can be done through the use of mechatronics means, as well as the development and implementation of optimal control system that can be built by using an accessible and widespread element basis.

RESEARCH RESULT

The results are expressed in the creation of the research stand (Fig. 1), which confirms the possibility and feasibility of designing mechatronic systems and units for the use in metalworking machines of traditional structure. Also, the characteristics of this stand make it possible to conduct experimental studies of the performance of electronic, electrical and mechanical components of metalworking equipment. The developed structure of the control system of forming movements of the machine can be used for carrying out modernization of the metalworking machinery of manufactures of the machine-building branch.

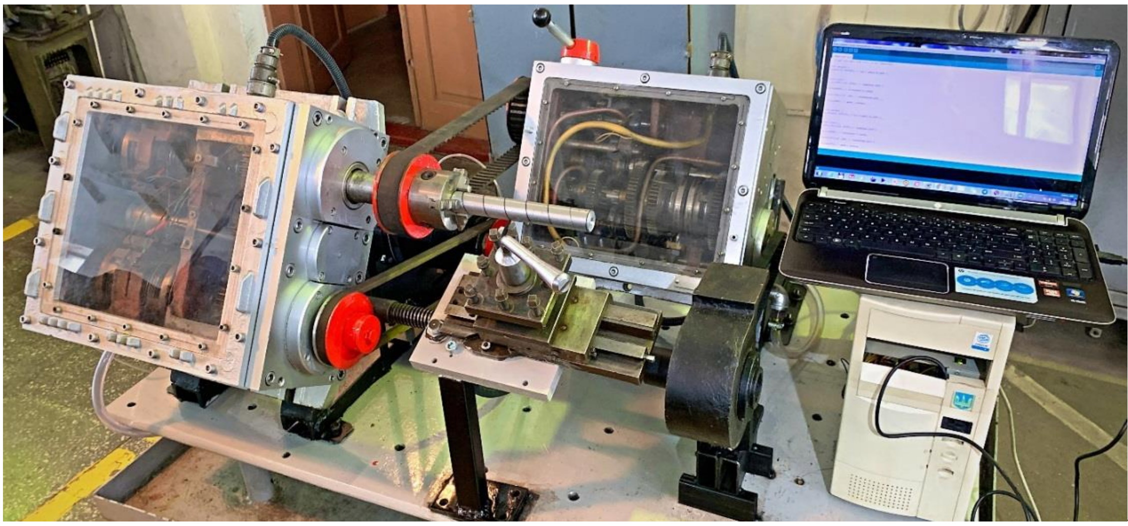

Fig. 1. General view of the created experimental stand with the developed mechatronic control system

The search methods are based on the use of the main provisions and practices relating to technical systems theory, electric vehicles, theoretical mechanics, theory of machines and mechanisms, automation and mechatronics.

The developed structure of control scheme with mechatronics means is created according to standard methods and is suitable for use in structures of metalworking machines. That involves using the rotational motion from the electric motor of the main motion drive with its subsequent transformation through the multiplying structures of the transmission and amplification mechanisms [4]. A feature of the kinematic structure is the requirement to control mechanical transmissions using electrical signals, which determines the need to use electromagnetic couplings to provide kinematic connections.

The developed kinematic scheme contains two mechanical gearboxes of the main drive and feeds, where the transmission of torque is due to gears. Electromagnetic couplings series ETM-104 (YC1 - YC5) in the gearbox of the main drive and electromagnetic couplings series ETM-072 (YC6 - YC10) (Fig. 2) in the gearbox of the feed drive are used to switch the parameters in these gearboxes. The appropriate moods are turned on by applying a discrete signal to a set of couplings from the control system. This provides the transmission of rotational motion to the spindle and the lead screw, which nut is rigidly connected to the toolholder. The structure of the kinematic scheme meets the requirements of shaping movements of the vast majority of metalworking machines and can be used both for equipment with tool spindles and desktop feed and for lathes. To expand the rotation speed, the engine speeds M can be changed as well.

To design a system for automatic control of the gearbox, it is necessary to identify combinations of switching on electromagnetic couplings to obtain the required speed of the spindle. It is necessary to identify all the options for the formation of kinematic chains of this gearbox. Investigations of the kinematic structure of the gearbox begin with the construction of a structural grid (Fig. 2), which reflects the following information [4]:

– number of degrees of rotation frequencies on each of the shafts which can be obtained by multiplier box structure;

– the number of group gears in the drive and the order of their constructive placement;

– the number of gears in each group;

– characteristics of groups, that is their place in the order of their kinematic inclusion.

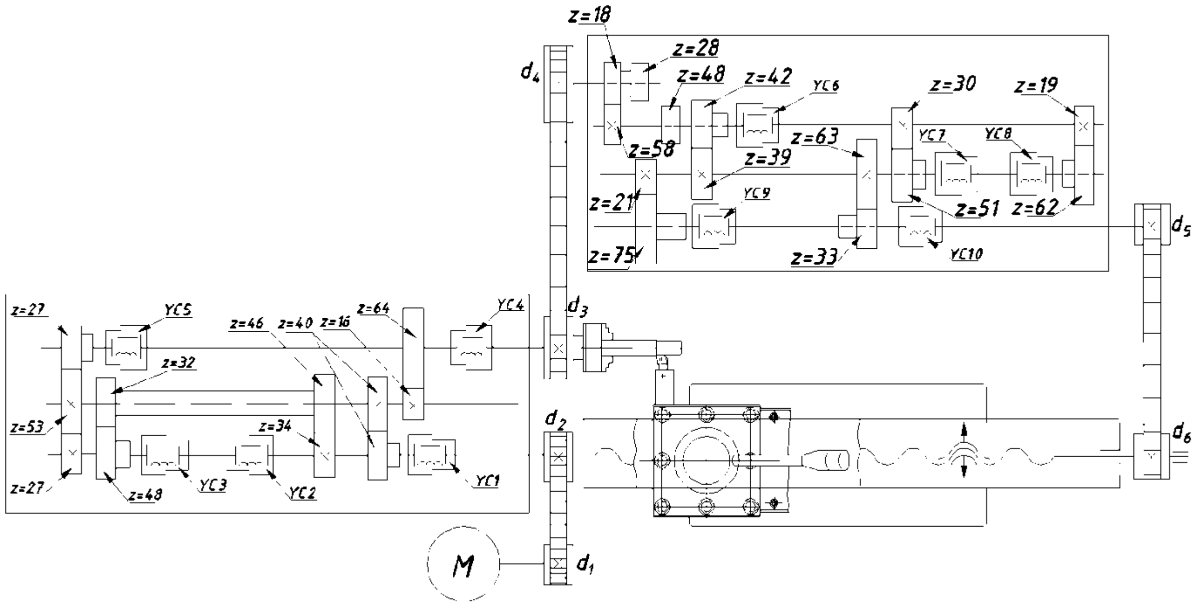

Fig. 2. Kinematic scheme of energy transmission and conversion circuits

The mechatronic control system of the stand can be classified as a multiprocessor, because it contains the processor of a programmable controller of electrical automation, which controls the operation of the stand, and is equipped with a personal computer that acts as a controller programmer [2, 3]. The structure of the control system provides sufficient flexibility of the operator interface, which has a positive effect on the ability to learn the ways to control the operation of equipment faster, including making experiments and laboratory work during the training process.

The basis of the presented control system is a programmable controller Arduino Uno, which was correspondingly chosen within the concept of the structure, which is based on the most accessible and common element basis. A personal computer is used to provide the interface of the developed control system. The controller communicates with the computer via the communication port using the Arduino IDE software. The Control of means of electroautomatics is carried out by processing and amplification of signals of the corresponding outputs ("pins") of the Arduino platform. Electrical appliances controlled by the controller are connected to its board according to the developed scheme (Fig. 3).

The modular 8-channel relay provides power supply to the devices of electroautomatics according to the scheme in fig. 3 and is connected to the control system accordingly:

– GND PIN on the power supply voltage is 0V (ground);

– VCC PIN is supplied with the voltage of + 5V from the power supply;

– Signal PIN (signal pin) is connected to the platform Arduino Uno via Digital Pin (digital pin) through which signals are (5V or 0V) to switch module in one of the modes: with normally open (Normally Open) to normally closed (Normally Closed) with a voltage of + 24V from the power supply.

Each of the electromagnetic couplings is controlled via a separate digital pin that connects the modular relay to the controller board. Each electromagnetic coupling YC1 - YC10 is connected to the modular relay as follows: one of the inputs of the coupling is connected to the GND connector of the power supply, the other input is connected to an 8-channel modular relay in the Common Contact connector. The operation of the relay and, accordingly, the operation of the couplings is controlled in the following sequence:

– according to the commands from the interface of the personal computer digital signals on a board of the Arduino Uno controller are being sent;

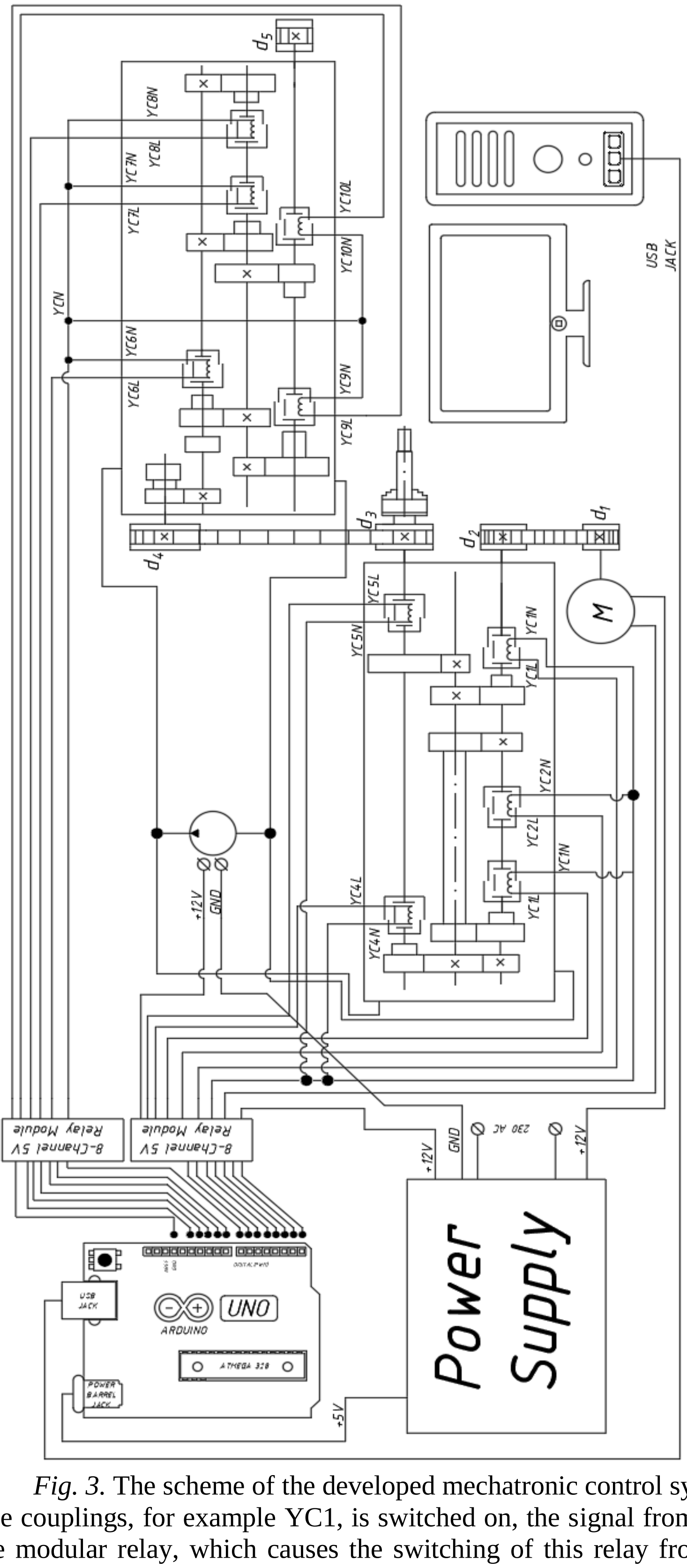

Fig. 3. The scheme of the developed mechatronic control system

– when one of the couplings, for example YC1, is switched on, the signal from Digital Pin 1 is fed to the Signal Pin 1 of the modular relay, which causes the switching of this relay from Normally Closed to Normally Open mode;

– as a result of the received command the contacts of Common Contact and Normally Open are closed and voltage through the relay moves to the YC1 coupling.

This scheme makes it possible to control separately each coupling, regardless of their number. As the motor of the main drive movement is used the electric motor of a direct current of Dynamo Sliven type 1 PI which is also used in mechanisms of drives of industrial robots. The power supply system of the M1 main drive motor provides the possibility of two-stage speed switching as well as braking its rotation when the power is turned off according to the generator circuit, changing the direction of rotation and blocking restart in the same direction after stopping at the sensor signal. A fragment of the connection diagram of this engine is shown in Fig. 4. In addition to the operation of modular relays of the Arduino platform, two car five-contact relays of modes were used 1C12 (Star line).

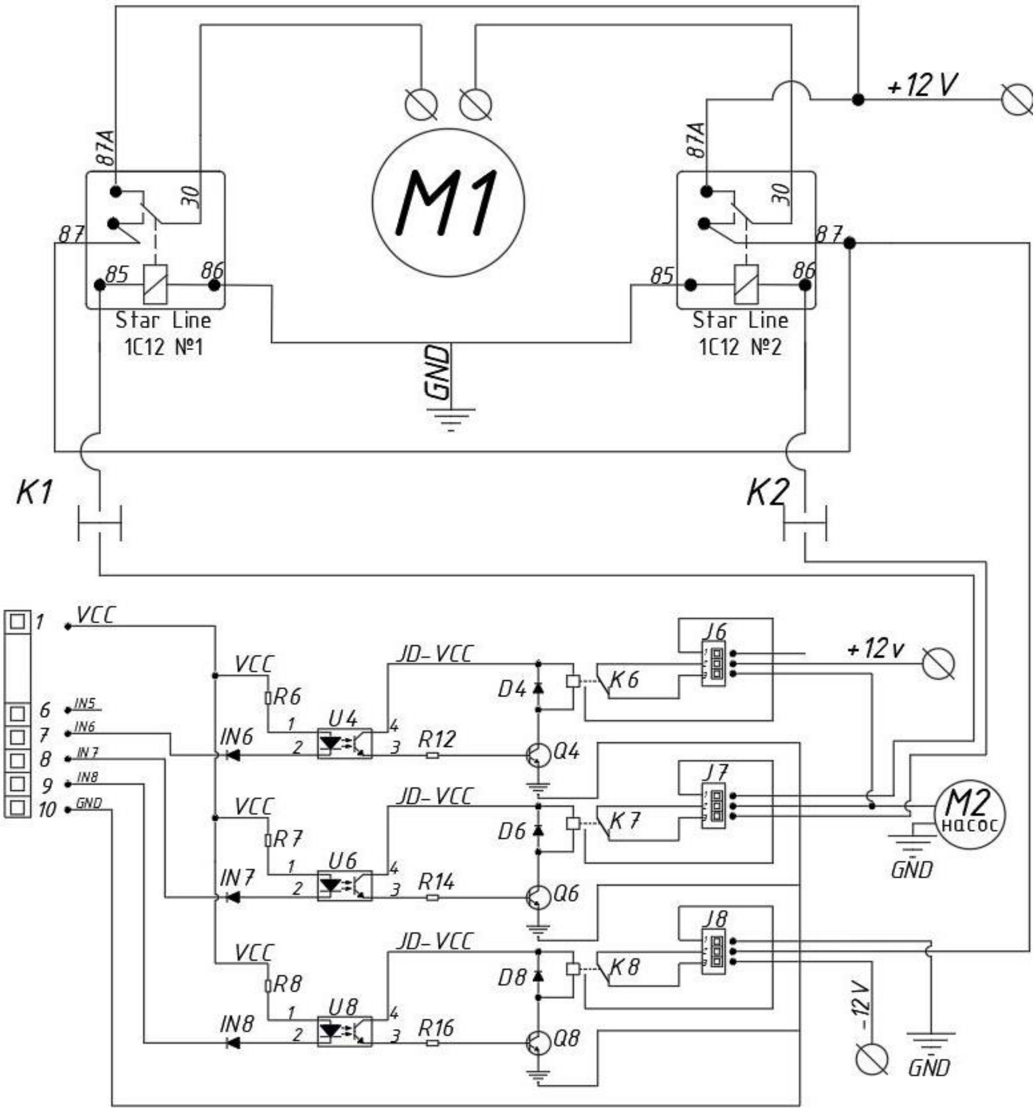

Fig. 4. A fragment of the diagram showing the connection of the main motor

The M2 motor of the electric oil pump is connected in such a way that the oil supply does not occur when the gearbox of the main movement or feeds is not working. To do this, the voltage of + 12V is applied to the common contact J6 with digital input IN6 (Fig. 4), to the Common Contact of contacts. This relay is responsible for unlocking the motor control as well as for the oil supply. When a signal is applied to relay J6, i.e. the Common Contact and Normally Open contacts are connected, voltage is applied to the electric oil supply pump and to the Common Contact contact of the next relay J7, through which the next two Star Line 1C12 relays are controlled. The other contact of the pump is connected to the GND power supply.

Switching relay J8 (Fig. 4) is designed to select the motor speed by switching the voltage difference. It is supplied with voltage -12V from the Normally Open side, and the Normally Closed contact is connected to the "ground". The Common Contact is connected to terminal 87 of both Star Line №1 and Star Line №2 relays. This allows you to apply different voltages to the motor M1 to change the speed of rotation of the motor shaft. When a signal is applied to relay J7, the Common Contact and Normally Open contacts are closed and voltage is applied to terminal 86 of the Star Line relay №2, due to inductance switching and contacts 87 and 30 are connected. The result is a change of potentials on the motor. Depending on the state of the switching relay J8, a voltage of 12V or 24V can be applied to the motor.

When a discrete signal is applied to relay J7, the Common Contact and Normally Closed contacts are closed. Voltage is applied to contact 86 of the Star line №1 relay. As a result, contacts 87 and 30 are connected and the motor is reversed because the voltage is connected to other motor contacts.

To limit the area of movement of the tool provides the connection of one or two limit switches K1 (K2) which stop the engine in case of their operation. This breaks the coil circuit of one of the relays Star Line 1C12 motor and the state of the contacts go to the initial position when 87A and 30 are closed. This causes the engine to stop. Further engine starts possible by changing the signal to the switching relay J7, which also leads to a change in the direction of rotation.

The described control system is small and mounted in the case of the computer system unit (Fig. 5).

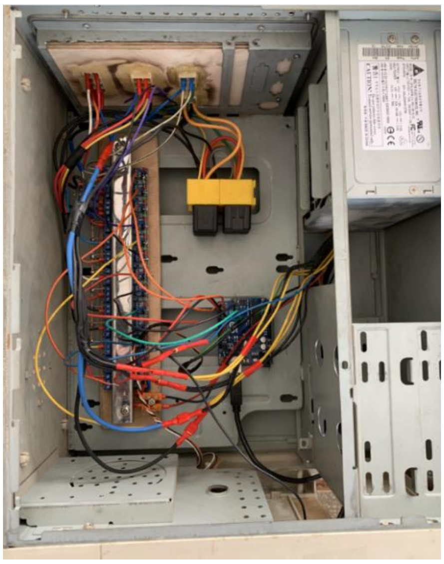

Fig. 5. The developed control system is mounted in a case of the system unit of a personal computer

DISCUSSION OF THE RESULTS OF THE STUDY

The use of a mechatronic system to control the drive of the main motion in machine tools expands the possibilities for integration with the control systems of other components, clamping mechanisms of workpieces and tools in the machine spindles in particular. There are electromechanical devices [9, 10], which are part of the spindle units of machines and provide the possibility of automatic clamping of workpieces or cylindrical tools in the spindle units. Electromechanical clamping devices have a wider ability to control their operation compared to their mechanical and hydraulic counterparts. That is, it is possible to control the amount of clamping force of the object, which is fixed in accordance with current requirements and external perturbations. For example, when increasing the spindle speed, it is advisable to increase the amount of input force applied to the clamping chuck to compensate the loss of clamping forces due to the influence of centrifugal forces on its clamping jaws.

CONCLUSIONS

Based on the results of engineering research, the structure of the mechatronic control system of the movements of executive mechanisms has been developed and embodied in the form of an operating stand. The obtained range of gear ratios in the main drive and feed drive makes it possible to provide a wide range of speeds and forces of mutual movement of the workpiece and the tool, which determines the possibility of productive machining of a wide range of diameters and materials. For a more optimal method of obtaining a range of characteristics of the technological movements, the possibility of controlling the performance characteristics of the main drive motor is implemented. The developed system also makes it possible to establish a rigid kinematic connection between rotational and translational shaping movements, which is necessary for the machining of helical surfaces. The control system also provides the necessary elements to protect equipment and personnel and provides engine braking when the power is turned off and the ability to set restrictions on movement. The use of a personal computer as a controller programmer that forms control commands, as well as the availability and prevalence of the element base on which the presented system is developed expands the possibilities of its creation for use in technological machinery and training stands with low budget. The effective exchange of information between the mechatronic systems which control the operation of the spindle drive and the electromechanical clamping mechanism helps to increase the efficiency of processing.

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Придальний Б.І., Гезун П.М. Мехатронна система керування виконавчими механізмами металообработних машин.

За результатами інженерно-пошукових досліджень розроблено та втілено у вигляді діючого стенда структуру мехатронної системи керування рухами виконавчих механізмів. Отриманий діапазон зміни передатних відношень в приводі головного руху та приводі подач дає можливість забезпечення широкого ряду швидкостей та зусиль взаємних переміщень деталі і інструмента, що визначає можливості продуктивної обробки поверхонь широкого діапазону діаметрів і твердих матеріалів. Для більш оптимального способу отримання діапазону характеристик формоутворюючих рухів реалізована можливість управління характеристиками роботи двигуна привода головного руху. Розроблена система також дає можливість встановлення жорсткого кінематичного зв'язку між обертальними та поступальними формоутворюючими рухами, що необхідно для обробки гвинтових поверхонь. Система керування також забезпечує необхідні елементи захисту обладнання і персоналу та передбачає загальмовування двигуна при вимкненні живлення і можливості встановлення обмежень на переміщення. Запропоновані рішення розширюють можливості взаємодії з іншими підсистемами технологічного обладнання, наприклад, механізмом затиску заготовок та інструментів у шпиндельних вузлах верстатів. Використання персонального комп’ютера як програматора контролера, що формує команди керування, а також доступність та поширеність елементної бази на основі якої розроблено представлену систему розширює можливості її виготовлення для використання у складі технологічного обладнання і навчально-дослідних стендів в умовах необхідності економії коштів.

Ключові слова: шпиндельний вузол, система керування, мехатронна система.

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