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MECHATRONIC DEVICE FOR TWO-STAGE CLAMPING OF CYLINDRICAL OBJECTS IN MACHINE TOOL SPINDLES

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The design of an electromechanical device for fixing cylindrical objects in the spindle units of technological equipment is presented. The new two-stage concept of the clamping process with a separated first stage is developed. The design of the presented mechanism provides advanced capabilities for control and regulation of its operating characteristics. The control system with the possibility of carrying out the first stage of clamping in automatic mode and without connecting to the upper-level control system in a technological machine is proposed. The involvement of electrical devices for the conversion and transmission of energy instead of their mechanical analogues is used as one of the promising ways to increase the performance efficiency of machine units. It helps to simplify and expand control capabilities, as well as reduce energy losses during intermediate transformations. The absence of mechanical energy converters in the proposed structure helps to reduce energy losses on intermediate transformations. The simplicity of the design expands the possibilities of integration of the proposed clamping mechanism into the structure of both new and existing technological machines in order to modernize it. This allows to achieve technical results, such as an expansion of the metalworking machines functionality, increase the level of automation of the clamping process and the accuracy of clamping objects in spindle units. The task is achieved by equipping the jaw of the clamping chuck with a special mechanism for identifying the presence of the object for clamping. For this goal, the clamping jaw is equipped with a probe that is capable of simultaneous force interaction with the object and the plunger. The plunger is rigidly attached to the magnetic element whose magnetic field has the possibility to interact with the magnetic field sensor. The sensor transmits its electrical signals to the control system of the device. The research results are aimed at meeting the requirements for effective control of clamping mechanisms with the possibility of automatic operation according to a preset algorithm for maintenance of optimal characteristics of a clamping process and a wide range of optional settings.

Key words: two-stage clamping, collet chuck, control system, electric drive, spindle unit

Introduction

Under the modern trends in machine tool constructions and the creation of industrial robots, the share of mechatronic modules is increasing. The modules comprise not only electromechanical units but also the final control element of the technological machine. Using mechatronic modules, which have a number of advantages over their functional counterparts, allows performing some movements of output links independently without connection to the main control system of the technological machine [5, 6]. Such a feature can help to increase mechatronic modules autonomy, simplify communication between the modules and the central control device, facilitate the implementation of wireless communications, computer diagnostics, protection, collection of information for comprehensive assessment of a current state of equipment parameters, etc. To use electrical devices for the conversion and transmission of energy instead of their mechanical analogues is one of the promising ways to increase the performance efficiency of machine units. It helps to simplify and expand control capabilities as well as reduce energy losses during intermediate transformations [8, 9].

The possibility of applying the maximum cutting modes (depth, feed, speed), and consequently, getting high productivity and quality of machining on metalworking machines depends on the parameters of fixation of workpieces and tools in spindle units. However, the reliable restraint of the workpieces and tools from displacements under the cutting forces is no longer a sufficient condition. The requirements for effective control of clamping mechanisms (CM) with the possibility of automatic operation according to a preset algorithm for maintenance of optimal characteristics of a clamping process and a wide range of optional settings are relevant. The properties of objects for clamping, such as physical and mechanical characteristics of their materials, features of a design (thin-walled), accuracy requirements to etc should be considered for providing effective settings for CM operation. It is also important that CM operation does not cause distortions in the spindle unit work.

Constantly growing requirements to the efficiency of metalworking machines are forcing the improvement of the performance of spindle units and their characteristics, such as high rotation speed, vibration resistance, reliability, ease of integration into the structure of new and existing machines. The design and performance of CM as a subsystem of the spindle assembly also determine many of its characteristics. In particular, the suitability of spindle assemblies for high precision balancing (absence of radially movable elements), keeping of CM efficiency at high frequencies (absence of influence of centrifugal forces on energy transfer and conversion in the mechanism), energy supply methods for CM etc are important.

The purpose of the research is to improve the device for clamping cylindrical objects in the spindle assemblies of machines by implementing an additional subsystem to separate the stage of pre-clamping object for fixation and the possibility of automatic clamping when installing the object in the clamping chuck.

Review of designs of the existing mechanisms

There are several designs of electromechanical devices for clamping objects in the machine tools spindle units. There is a device for clamping rod stocks [1]. In the design of the device, a clamping chuck is mounted on the spindle and attached to the drawtube (drawbar made in the form of a tube) which is connected with a movable drive sleeve and is able to interact with the part of the actuator made as an electric motor. The rotor of the electric motor is mounted on a spindle and is capable of simultaneous force interaction with both, the driving plug and the spindle. The stator of the electric motor is attached to a machine body. The disadvantage of this CM is the relatively high complexity of accurate control of magnitude of clamping force and reduction of the reliability of work (holding the clamped state) when the surfaces of the screw transmission-amplifying mechanism are contaminated.

There is also a CM for clamping rod stocks on a multi-spindle lathe [2], which contains a drive for turning the adjusting nut that is made as an electric motor with a reducer which is connected via feedback to the device for measuring the diameter of the rod stocks. The device also includes the camshaft with cams for controlling the clamp and the feed of the rod stocks, lever gears, and the adjusting nut mounted on the drawtube that transmit draw force to the collets placed in the spindles. The device for the measuring rod is equipped with its drive, the rod and the slider of the rod stack feeder are equipped with stops and the limit switches placed on the body. The disadvantage of the CM is the complexity of the design.

There is a device for clamping workpieces in form of rod stocks material [3]. It contains a spindle in which the collet is placed and connected to the drawtube which is carrying a movable drive sleeve. The drive sleeve is fixed to the disk, which is the armature of the electromagnet, the coil of which is mounted on the spindle body. Between the coil and the disk there is a return spring. The disadvantage of the device for clamping rod stocks is that it does not provide for reliable fixation of the rods with large diameter deviations because the clamping force is not stable. The magnitude of the force depends on the deviation of workpiece diameter because it is determined by the proximity of the armature to the magnet coil.

One of the most promising devices is the one for clamping rod stocks [4]. It is located on the spindle and is equipped with a translational motor. The motor stator is rigidly connected to the spindle body and contains a set of electromagnets that have the possibility of step-by-step electromagnetic interaction with the electromagnets mounted on the motor armature and powered by a generator. The rotor of the generator is fixed on the spindle and its stator is rigidly connected with a spindle body. The clamping chuck is located on the front part of the spindle and has the possibility of force interaction with the armature of the motor through the drawtube and a movable drive sleeve.

All the above devices have the following significant disadvantages [7]:

– clamping in one stage accompanied by a rapid movement of the clamping jaws as a result of the action of large efforts at the stage of backlash elimination (without counteracts) which leads to their sharp collisions with the object for fixation and, as a consequence, its oscillations and deterioration of the conditions for precise positioning;

– the absence of a stage of pre-clamping with a force that keeps the object for fixation from falling out (including the vertical position of the spindle) that allows to correct its position, including manually by the operator;

– the inability to identify the occurrence of the object in the chuck to perform the first stage of the clamping process (backlash elimination) automatically in order to reduce the duration of the main clamping stage (to create a nominal force) which is carried out before machining to keep the object of fixation from movement under the action of cutting forces;

– there is a need to keep the object of fixation in the clamping zone while making command for clamping or until the command to clamp comes from the CNC system.

Development of the new design of the mechanism for clamping workpieces and tools in spindle units of machines

In accordance with the set task there had been developed the new design of the CM. The device (Fig. 1) contains a rotor 2 which moves in the axial direction and is mounted on a spindle, as well as electromagnets 3 placed on the rotor's surface. They can interact electromagnetically with the electromagnets 5 mounted on the stator 4. Electromagnets 5 are connected to the electrical system through connectors 6. Stator 4 is rigidly attached to body 7 and rotor 2 has the possibility of force interaction with drawtube 8 through screw 9 , screwed on it, and a disk 10. It provides for the transmission of the axial force to chuck 11 which is rigidly attached to drawtube 8. Rotor 12 of the electric generator is also located on spindle 1. Electric coils 13 are placed on the surface of rotor 12, included in the electric circuit of electromagnets 3 and can interact electromagnetically with electric coils 15 placed on stator 14. Stator 14 is rigidly fixed on body 7 and electric coils 15 are supplied with energy through connectors 16. Clamping jaw 17 (Fig. 2) is equipped with hole 18 in which probe 19 is installed. Probe 19 in the form of a ball is capable of simultaneous force interaction with object for clamping 20 (shown by dot-dash line) and the conical surface of cylindrical plunger 21. The end of the plunger 21 is equipped with magnetic element 22 and has the possibility of force interaction with spring 23. The other end of spring 23 is fixed relatively to clamping jaw 17 by screwed plug 24. On the surface of plug 24 magnetic field sensor 25 which has the possibility of magnetic interaction with magnetic element 22 and is connected via connector 26 to control system unit 27 is rigidly fixed (Fig. 1). Unit 27 is a part of the control system with the electric circuit formed by electromagnets 3 and electric coils 13. Control system unit 27 comprises the set of data storage, data comparison and relay element or their functional analogue implemented on the basis of a microcontroller. As the sensor of a magnetic field the Hall sensor, which is embodied in the small-sized liquid-proof case with the overall dimensions within 3-4 mm can be used.

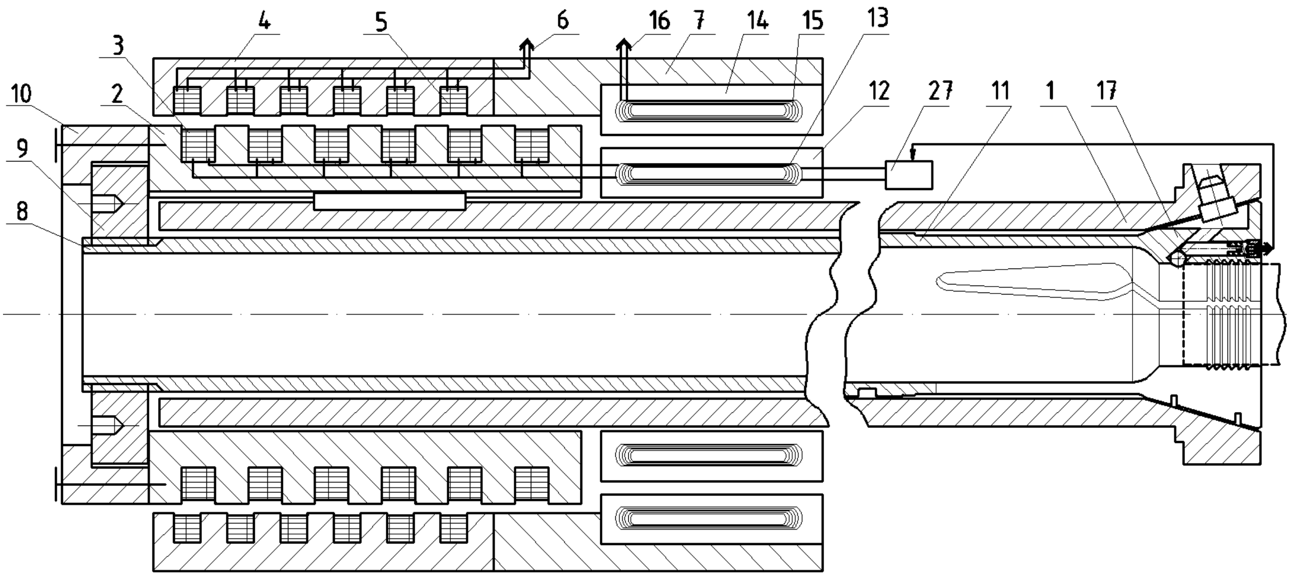

Fig. 1. Clamping mechanism with electric actuator for machine tool spindles

The proposed device operates as follows. At the initial state, the device is waiting for an object to clamp with the wide-opened clamping jaws 17 (Fig. 2). Probe 19 is in the position when its surface protrudes as much as possible above the surface of clamping jaw 17. Inserting object for clamping 20 in the chuck causes probe 19 to move by the value of t which also leads to its simultaneous force interaction with the surfaces of hole 18 and plunger 21. There is a movement of plunger 21, which is larger than the value t due to the presence of an angle formed by the shaped part of the surface of plunger 21 and the surface of hole 18 with which probe 19 is in interaction. This causes the motion of magnetic element 22 to magnetic field sensor 25. That determines the change in the characteristics of the sensor's signal, which is transmitted through connector 26 to the input of control unit 27. Control unit 27 generates an output signal according to the settings, which leads to changes in characteristics of the electric circuit of electromagnets 3 and electric coils 13. This causes the generation of current in electric coils 13 under the action of the magnetic field created by electric coils 15, and, as a result, the appearance of a magnetic field around electromagnets 3. The interaction of the magnetic field of electromagnets 3 with electromagnets 5 is the reason for the axial movement of rotor 2. It also causes the axial movement of disk 10, nut 9, drawtube 8 and clamping collet 11, which provides clamping of object 20 due to the convergence of the clamping jaws 17. The translational movement of rotor 2 stops when the required magnitude of clamping force is reached and the counteraction of its axial movement is increased. The magnitude of the pre-clamping force is determined by the characteristics of the supply current of electromagnets 5 and electrical coils 15. The current is supplied respectively through connectors 6 and 16 and corresponds to the settings of the control system for standby mode. The clamping force is increased to the nominal value required to keep the object under the action of cutting forces by changing the characteristics of the supply current on connectors 6 and 16. This happens following the command of the machine tool control system or by the operator before machining.

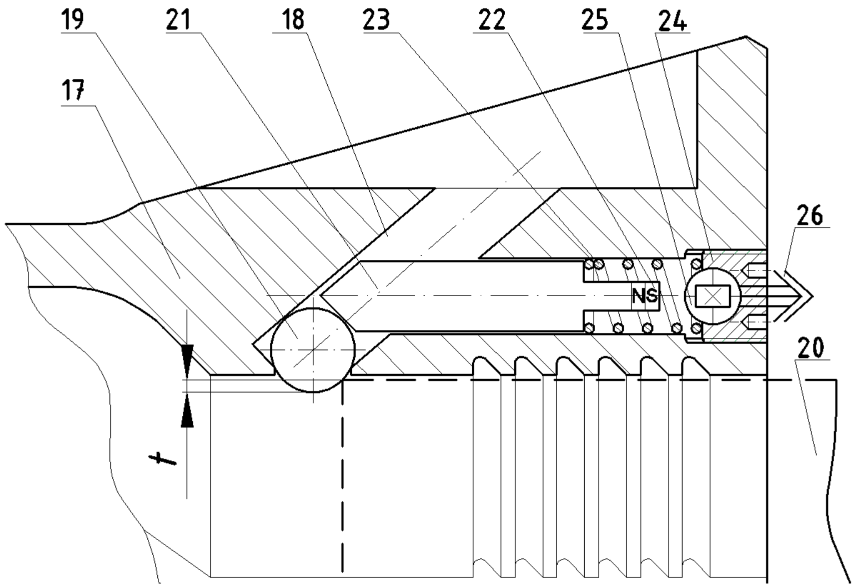

Fig. 2. Fragment of the clamping jaw of the collet

To perform the unclamping, connectors 6 should be supplied with current the characteristics of which determine the movement of rotor 2 in the opposite direction compared to the clamping process. This also causes disk 10, nut 9, drawtube 8 and chuck 11 to move in the opposite direction comparatively to the clamping process. Clamping jaws 17 move to open position which causes the release of clamped object 20 and the termination of its force interaction with probe 19. Probe 19 and plunger 21 take the initial position under the force of spring 23. It causes distancing of the magnetic element from magnetic field sensor 25 and the signal change at the input of control system unit 27.

The structure of control system unit 27 (Fig. 3) of the proposed CM contains two-level data storage 28, data comparison device 29 and relay element 30 with a logic output. Before object 20 is inserted in the hole of the chuck, the current value of the signal L_i from magnetic field sensor 25 (Fig. 2) is transmitted through the connector 26 to two-level data storage 28 (Fig. 3) and recorded at its lower level. When an object for clamping is inserted into the clamping chuck its interaction with probe 19 leads to the active movement of magnetic element 22 to sensor 25. This changes the magnetic flux through sensor 25 and the level of its output signal to L_{i+1}.

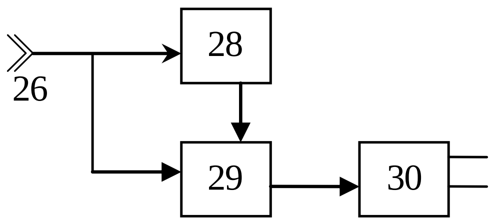

Fig. 3. The structure of the control system unit

Simultaneously with the control signal for the drive motor CM the value L_i is rewritten at data storage device 28 from its lower level to the upper and transmitted to comparison device 29, where it is compared with the current input value L_{i+1} of the magnetic field sensor 25. Then, the level of current output signal L_{i+1} is written to the lower level of storage device 28. In comparison device 29 determines the result the dependence $\Delta L_i = L_{i+1} - L_i$. The result of the calculation in comparison device 29 ΔL_i is transmitted to the input of relay element 30 that has a logical output with a nonlinear static characteristic of the function of ΔL_i, $L = f\left(\Delta L_i\right)$. That is, the signal L takes discrete values 0 or 1 in cases where $\Delta L_i < \delta$ and $\Delta L_i \geq \delta$, respectively, where δ is a characteristic of the minimum value of the signal at which relay control element 30 is triggered. The value of δ is set as necessary and sufficient for identification of the presence in the chuck of objects with appropriate diameter for clamping with the nominal characteristics in a certain type of CM. A discrete logic level signal is generated at the output of relay element 30, indicating the presence (absence) of the object for clamping in the chuck and the presence (absence) of gaps between the clamping jaws and the object. This determines the operation of control system unit 27 in relation to the algorithm for switching on electromagnetic windings 3 and 5 (Fig. 1) of the electric drive CM. Completion of the process of the gaps elimination between the object for clamping and the clamping jaws is marked by stopping the movement of probe 19 and, consequently, reaching the state of $\Delta L_i < \delta$. In this state, the positioning and holding of the object with the possibility of its position correction and removal with little effort are ensured. Simultaneously with the command for unclamping the object, the values of the signal recorded in the two-level storage device 28 is reset.

Conclusions

The proposed design of the CM allows to implement the concept of a two-stage process of clamping objects in the spindle units of technological equipment and achieve adaptability of the first stage of fixation with a predetermined amount of clamping force required. The design also provides for more control and adjustment of the clamping force. This improves the ability to set more optimal conditions for certain work characteristics of the CM operation. The design of the proposed mechanism does not contain movable elements in the radial direction, which determines the possibility of its high-precision balancing and operation as part of high-speed spindle assemblies. The supply of input energy of the CM is provided in a non-contact way due to electromagnetic interaction. This allows control of the CM operation when the spindle rotates and reduces the possibility of disturbing effects on the stability of spindle positioning.

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Мехатронний пристрій для двохетапного затиску циліндричних об'єктів у шпиндельних вузлах верстата

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Представлено конструкцію електромеханічного пристрою для закріплення циліндричних предметів у шпиндельних вузлах технологічного обладнання. Розроблено нову двоступеневу концепцію затискного процесу з відокремленою першою стадією. Конструкція представленого механізму забезпечує розширені можливості управління та регулювання його робочих характеристик. Запропонована система управління з можливістю проведення першого етапу затиску в автоматичному режимі та без підключення до системи управління верхнього рівня в технологічній машині. Залучення електричних пристроїв для перетворення та передачі енергії замість їх механічних аналогів використовується як один із перспективних способів підвищення ефективності роботи машинних агрегатів. Це допомагає спростити та розширити можливості управління, а також зменшити втрати енергії під час проміжних перетворень. Відсутність механічних перетворювачів енергії у запропонованій структурі сприяє зменшенню втрат енергії на проміжні перетворення. Простота конструкції розширює можливості інтеграції запропонованого затискного механізму в структуру як нових, так і існуючих технологічних машин з метою його модернізації. Це дозволяє досягти технічних результатів, таких як розширення функціональних можливостей металообробних верстатів, підвищення рівня автоматизації процесу затиску та точності затискання предметів у шпиндельних вузлах. Завдання досягається оснащенням затискного елементазатискного патрона спеціальним механізмом для *виявлення присутності предмета для затиску. Для цієї мети затискний елемент обладнаний зондом, який здатний одночасно взаємодіяти з предметом для затиску та плунжером. Плунжер жорстко прикріплений до магнітного елемента, магнітне поле якого має можливість взаємодії з датчиком магнітного поля. Датчик передає свої електричні сигнали в систему управління приладом. Результати дослідження спрямовані на задоволення вимог до ефективного управління затискними механізмами з можливістю автоматичної роботи за заданим алгоритмом для підтримки оптимальних характеристик процесу затискання та широкого діапазону вибіркових налаштувань.*

Ключові слова:двоступеневий затиск, цанговий патрон, система управління, електропривод, шпиндельний вузол

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Мехатронное устройство для двухэтапного зажима цилиндрических объектов в шпиндельных узлах станка

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Представлена конструкция электромеханического устройства для закрепления цилиндрических предметов в шпиндельных узлах технологического оборудования. Разработана новая двухэтапная концепция процесса зажима с отдельной первой стадией. Конструкция представленного механизма обеспечивает расширенные возможности контроля и регулирования его рабочих характеристик. Предлагается система управления с возможностью проведения первого этапа зажима в автоматическом режиме и без подключения к системе управления верхнего уровня в технологической машине. Использование электрических устройств для преобразования и передачи энергии вместо их механических аналогов используется как один из перспективных способов повышения эффективности работы агрегатов машин. Это помогает упростить и расширить возможности управления, а также снизить потери энергии при промежуточных преобразованиях. Отсутствие в предлагаемой конструкции преобразователей механической энергии позволяет снизить потери энергии на промежуточные превращения. Простота конструкции расширяет возможности интеграции предлагаемого зажимного механизма в конструкцию как новых, так и существующих технологических станков с целью его модернизации. Это позволяет достичь технических результатов, таких как расширение функциональных возможностей металлообрабатывающих станков, повышение уровня автоматизации процесса зажима и точности закрепления предметов в шпиндельных узлах. Задача достигается за счет оснащения губки зажимного патрона специальным механизмом для определения наличия объекта зажима. Для этого зажимная губка оснащена зондом, способным осуществлять одновременное силовое взаимодействие с объектом и плунжером. Плунжер жестко прикреплен к магнитному элементу, магнитное поле которого имеет возможность взаимодействовать с датчиком магнитного поля. Датчик передает свои электрические сигналы в систему управления устройством. Результаты исследований направлены на удовлетворение требований к эффективному управлению зажимными механизмами с возможностью автоматической работы по заданному алгоритму для поддержания оптимальных характеристик процесса зажима и широким набором дополнительных настроек.

Ключевые слова: двухступенчатый зажим, цанговый патрон, система управления, электропривод, шпиндельный узел

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