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SYNTHESIS OF STRUCTURES OF SPINDLE UNITS WITH ELECTROMECHANICAL ACTUATORS OF CLAMPING MECHANISMS AS COMPLEX COMBINED AXISYMMETRIC SYSTEM

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ABSTRACT

A new approach to creation spindle units with electromechanical drivers of clamping mechanism for machine tool by using the genetic-morphological approach is proposed. Certain provisions of the theory of genetic structural-schematic synthesis of spindle units according to objective search function are highlighted. The motor spindle with an electromechanical clamping mechanism is considered as a combined system that creates a spatial composition of two structures where each performs its function. The model of formatting technical units like "motor-spindle" as a complex combined system with possibility of its description at different levels of structural complexity is presented. The features of developing new technical system as a process of its evolution with transferring individual information from one generation to another are taken into account. Based on new principle, a combination of new and well-known technical solutions in the design of a new technical object is made. This approach opens up the possibility of formulating fundamentally new system-level tasks related to the identification principles of structural organization and the laws of development objects and systems of technological equipment.

1. INTRODUCTION

The process of identifying new structures of spindle units (SU) with clamping mechanisms (CM) is mainly informal, since the elements of this system and the connections among them are not fully formalized. It makes it impossible for us to describe them, for example, in forms of codes that can be used to make up the data banks. Automation designing process of SU as complicated systems and their subsystems such as CM, clamping chuck (CC), electromechanical clamping actuator (ECA), etc. would help to reduce the complexity and design time while at the same time improving the quality of design work.

There are several studies [1,3] representing the current level of engineering design as a process that takes into account the features of development of technical systems (TS), that is, the process of their evolution is considered as the transfer of individual information from one generation to another. Based on this principle, a combination of new and well-known technical solutions is carried out in the design of a new technical object. Such an approach opens up the possibility of formulating fundamentally new system-level tasks related to the identification of the principles of structural organization and the laws of development of objects and systems of technological equipment.

The tasks of this level include the tasks of prediction of the structures as genetically permissible variety of TS with the subsequent selection and directed synthesis of the necessary construction according to the given objective function [5]. Organization and development research in this sphere gives the possibility for transition from the existing fragmentary-object level of system representation to a systematic and scientifically predicted level of knowledge. The developed theory uses the information both in relation to a known variety and in relation to potential classes of TS that are not yet available at this stage of their evolution [1].

2. METHODS AND MATERIALS

The modelling by using structural (genetic and morphological) formulas for describing SU which contain a motor and CM with ECA allows creating data banks for further prediction of new structures, schemes and construction. It helps to create new generation machine tool units, including those with wireframe systems and mechanisms of parallel structure.

Hybrid electromechanical structures are characterized by mixed genetic information therefore, their functional properties are determined by the corresponding functions that are inherent in generative types [4]. The synthesis of hybrid species is based on genetic processes of crossing, which determine the complexity of structures and the expansion of their functional properties as well. The basis of the combined structures is the principles of the spatial

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combination of two or more electromechanical structures, which can relate to different basic types.

Systems of the motor-spindle (M-S) type are complex combined electromechanical structures that include mechanical and electromagnetic parts (Fig. 1). The spindle belongs to the mechanical part and windings belong to the electromagnetic part because they are the source of the electromagnetic field.

The combined electromechanical system is a structure in space which contains at least two elementary structures, each of which performs its function in the system. Therefore, in such a combined system, the spatial shape and the number of moving and stationary parts, air gaps, power and control systems is determined by a specific objective function, the corresponding spatial geometry and the number of combined elementary EM structures.

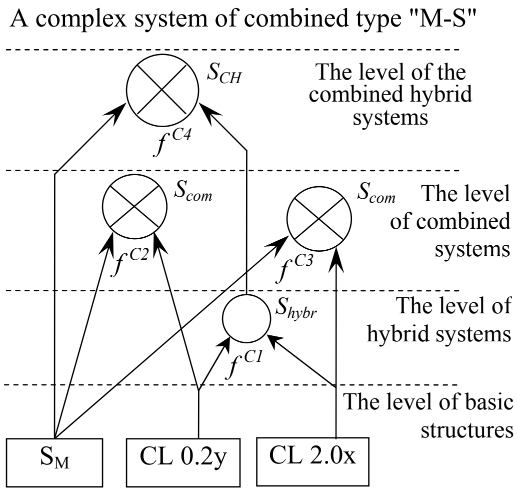

Fig. 1. A model of forming a complex combined system like "motor-spindle" type with an electromechanical actuator of a clamping mechanism

To describe the structure SU with a CM of the milling machine at the chromosomal level it is proposed to use elementary power streams. This is realized by introducing various types of power flows into the description of the structure and combining them according to the type and quantity, depending on the task, characteristics of the clamping object (CO) and the location of the processing area in relation to CO. The description depends on the technological capabilities of the machine tool unit, the design of its elements and the availability of additional devices on the spindle [7,9].

3. RESULTS AND DISCUSSING

The commonality of the structural and informational basis of electromechanical and mechanical objects opens up the possibility of using generalized genetic models of structure formation for solving problems of analysis and synthesis of their structures. The studied structures of a multi-rotor electric motor and bearing can be represented by a generalized genetic model (Fig. 2) [5].

The number of power flows to clamp a cylindrical object (tool shank) in one single place is determined from the morphological matrix. The matrix describes the options for inputs and outputs:

$$M_{C\Pi} = \begin{vmatrix} F_{x1} \\ \overline{F_{x1}} \\ F_{y1} \\ M_{x1} \\ \overline{M_{x1}} \\ M_{y1} \\ \overline{M_{y1}} \end{vmatrix} \wedge \begin{vmatrix} F_{x2} \\ F_{y2} \end{vmatrix}, \quad (1)$$

which gives options $N_{C\Pi} = 7 \cdot 2 = 14$.

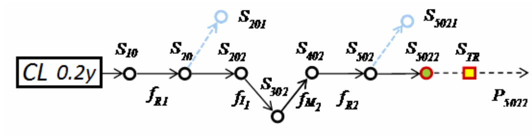

Fig. 2. A generalized genetic model of axisymmetric electromechanical TS: CL0.2y – parent chromosome; S_{10}, S_{20}, …, S_{5021} – are paired chromosomes; S_{201}, S_{5021} – chromosomes-isomers; S_{5022} – is the generating chromosome of object S_{TR}; P_{5022} – a population of descendant objects.

During rotation of a CO clamped by using the outer surface and due to the action of centrifugal forces $F\omega$ from unbalanced parts of the clamping elements (CE), the output clamping force Fy_2 decreases to the value $Fy_{2\omega}$, which depends on many factors [2,4].

For the case when we don't take into account directions of forces and torques on the input link of mechanism, in a result of using the principle of symmetry [4], the number of options for description at the chromosomal level will be reduced, that is $N_{C\Pi} = 8$ the number of options:

$$M'_{C\Pi} = \begin{vmatrix} F_{x1} \\ F_{y1} \\ M_{x1} \\ M_{y1} \end{vmatrix} \wedge \begin{vmatrix} F_{x2} \\ F_{y2} \end{vmatrix}, \quad (2)$$

Modelling and synthesis SU with CM for a milling machine provides for a solution to the problem of directional searching of the combined structure "M-S" and CM according to the synthesis function $F\omega$, which can be determined by the following minimum set of basic initial requirements:

– implementation of an independent controlled rotational movement of the spindle, including reverse ($\pm\omega$);

– ensuring the coaxiality of the CM electric motor with the axis of symmetry of the spindle (S_{OX}) for achieving coaxiality of the moments and forces which are acting in the spindle unit;

– the ability to control kinematic links in CM (K);

– combination of a spindle with CM (S_{CM}).

To ensure the correctness of the synthesis results, we impose the following restrictions on the search area:

– only the electromechanical principle of the implementation of rotational motion is considered;

– only primary sources of an electromagnetic field with axial symmetry are considered.

The integral function of synthesis F_S is determined by the set of requirements and is presented as a sequence of individual functions. Based on these requirements, the integral objective function of synthesis takes the form

$$F_{\omega} = \left[\pm\,\omega; S_{OX}; K; S_{CM}\right] \subseteq R^{n} \,. \tag{3}$$

So, the desired version of the structure T_{ω} that satisfies the given F_{ω} should contain the following set of basic nodes: spindle coaxial with the rotor of the electric motor of a clamping mechanism, support units with bearings. In the next stage, a given set of characteristics must be associated with the genetic model. For the presented set of requirements for the electric drive system the next parental chromosomes *CL 0.2y* and *CL 2.0x* are the most suitable. The result of synthesis based on these chromosomes is presented in the form of a genetic model of Fig. 3.

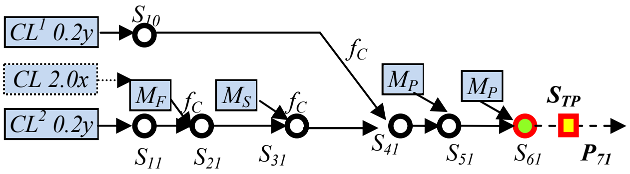

Fig. 3. A genetic model for synthesizing a SU structure with electromechanical CM according to objective function F_{TP}: f_C – genetic crossing operator; S_{10}, S_{20}, ..., S_{61} – synthesized chromosome structures; S_{TP} – technical solution; P_{71} – a population of technical solutions.

The model presented in Fig. 3 is a graphic reflection of the genetic program of the desired electromechanical object with the structure determined by the sixth-generation combined chromosome S_{61}, where:

(CL^1 0.2y) – genetic code of a motor for rotation spindle;

(CL^2 0.2y) – genetic code of a motor for rotational motion of CM rotor;

(CL 2.0x) – genetic code of the electromagnetic relay (actuator of friction clutch);

M_{SC} – mechanical chromosome of screw gearing;

M_{FR} – mechanical chromosome of a friction clutch;

M_{P} – mechanical chromosome of a plunger ram;

M_{Pl} – mechanical chromosome of a plug.

The chromosome set of model $S_{10} - S_{61}$ determines the level of genetic complexity as well as genetic program of the desired "*M–S*" structure. The presence of four crossing nodes indicates the complex hybrid nature of the T_S structure.

The presence of genetic information of an arbitrary structural representative allows determining the genetic program of the entire functional class of electromechanical objects [5]. Since the genetic codes of the main drive engine and the drive of CM are the same, the genetic program is determined for the class of rotating electric machines. The program is determined through a sequential analysis of the genetic predisposition of parental chromosomes to implementation of the F_S function. According to the type of spatial geometry of the active zone, the structural types of electric motors of SU with CM can be represented by 4 geometric classes with cylindrical, conical, toroidal-flat and toroidal-cylindrical active surfaces.

As examples of the implementation of the proposed synthesis methodology two SU constructions are protected by patents of Ukraine for inventions №116050 (Fig.4) and №120959 (Fig.5).

The work of the spindle unit for patent No.116050 is as follows. Spindle 1 is mounted on bearings 2 and 3 which are installed in the body 4. The body 4 on one side is closed by the flange 7 and on the other by a module-flange 8. When the collet 22 is unclenched CO is introduced into its hole (not shown in Fig. 4). The electromagnetic field arises around the stator windings 17 when they are supplied with current. The interaction of the electromagnetic field with the windings of the rotor 16 leads to the appearance of torque. The torque transmitted through the shaft 14, the connecting link 15 and kinematically connected coupling halves 12 and 11 to the shaft-nut 9. The couplings 12 and 11 are installed in the body 8, respectively, on bearings 13 and 10. The shaft 14 is located on the bearings 18 in the body 19 which is closed by a cover 20 on the side. The rotation of the shaft-nut 9 leads to the movement of the screw 21 to the left side as well as to the tightening of the collet 22. It leads to the clamping CO. After the clamping and opening of the kinematic connection between the coupling halves 12 and 11, a current is supplied to the stator winding 6 and an electromagnetic field appears. The electromagnetic field interacting with the windings of the rotor 5 causes the spindle 1 to rotate.

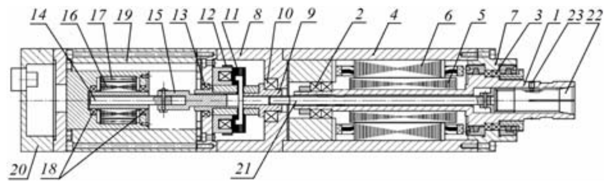

Fig. 4. The spindle unit of the machine tool for the patent of Ukraine No. 116050.

The work of the spindle unit for patent No.120959 is as follows. The clamping chuck consists of the body 1 on which a rotary cage in the form of a gear wheel 2 mounted on two needle roller bearings 3 is installed . The body 1 has a connecting conical surface for placement in the spindle 9 of the machining headstock 10. An electromechanical clamp drive is attached to the machining headstock 10 and consists of a stator 11 and the rotor 12 which is located on three rolling bearings – the rear support 13, the middle 14 and the front 15. Contact bolts 19 which can be in contact with the retracting core 20 loaded by spring in electromagnetic relay 21 are located on the body of the electromechanical drive 18. Between the retracting electromagnetic relay 21 and the lever 22, a return spring 23 is located. The lever 22 is connected to the gear 24, which drives the rotary cage in the form of gears a 2. A gasket 25 is placed in the body 1 for sealing against fluid leakage. To change the tool or workpiece, a cylindrical collet 26 is provided. Retracting the core 20 by the amount of H_1 and transmitting the movement through the lever 22 to the gear 24 leads to its movement by the amount of H_2 and engagement with a rotary cage in the form of a gear wheel 2. By connecting the end face of the core 20 with contact bolts 19, electric current is supplied through the brushes 17 to the collector plates 16, the rotor 12 is rotated and transmits the torque M_{a1} through the gear 24 to the rotary holder in form of a gear wheel 2 in one direction or another (clockwise or counterclockwise). Due to the angle α of elevation the plungers 4 are immersed in the direction to the axis of the collet, which causes compression of the fluid 5 in the working cavity A and the appearance the radial clamp force F_{r1}. As a result, radial elastic deformation of the thin-walled cylindrical shell 7 of the thin-walled cylindrical bushing 6 occurs, which compresses the cylindrical shank of, for example, a cutting tool with a radial clamping force F_{r2} [8], that is, power flow is generated from input to output $M_{a1} - F_{r1} - F_{r2}$ [2].

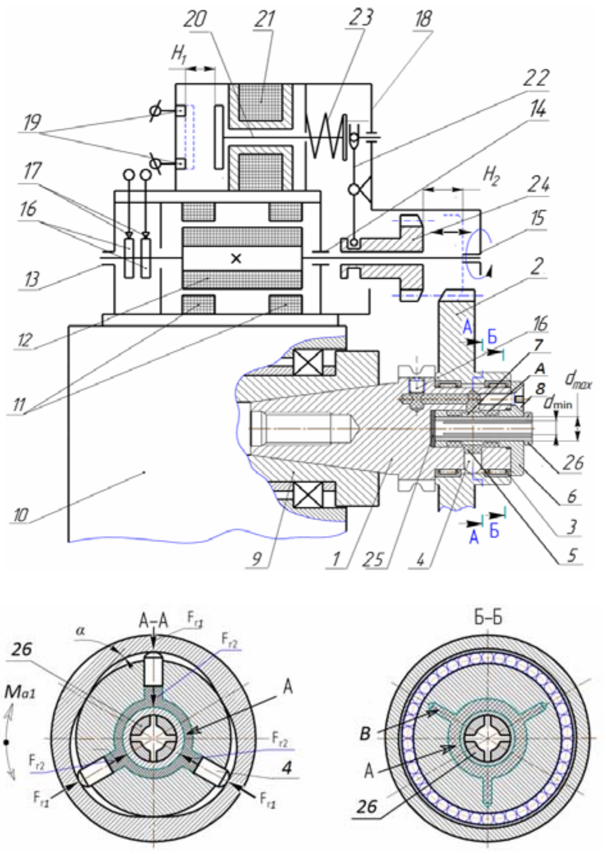

Fig. 5. The spindle unit of the machine tool for the patent of Ukraine No. 120959

4. CONCLUSION

Obtained theoretical results are prerequisite for the development of the directional synthesis theory as well as for automation design of efficient electromechanical systems like "motor-spindle" type which contain automatic mechanisms for clamping a workpiece. A search of structures should be carried out in accordance with a specific objective function at the level of elementary electromagnetic structures as well as at the level of complex combined electromechanical structures. In particular, this makes it possible to formulate the principles for creating these systems by substantiating the directions for searching new structures and identifying the features of implementation of a systematic approach to the development of structures and predicting characteristics.

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