ИЗВЕСТИЯ
на Технически университет
Габрово

Journal of the Technical University of Gabrovo, Vol. 48’2014 (15-19)

## Раздел 2
## МАШИНОСТРОЕНЕ

## Section 2
## APPLIED MECHANICS

# GENETIC PROGRAM OF STRUCTURAL EVOLUTION AND SYNTHESIS OF SPINDLE-MOTOR HYBRID ELECTROMECHANICAL SYSTEMS

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Revised 04 July 2014, Accepted 05 September 2014

Annotation

*The paper studies the matters of genetic models, which determine algorithms for structural synthesis of hybrid electromechanical converters of "spindle-motor" class. According to the analysis of the space admissible crosses, authors determine the genetic structurisation programs of the investigated spindle-motor class as the diversity of genetically admissible classes of spindle-motors hybrid structures. On the basis of genetic models the structural foresight was realized and there were defined the species of spindle-motors, which are promising at this stage of technical evolution and are the subject to technical implementation.*

**Key words:** evolution, electromagnetic chromosome, genetic program, crossing, hybrid electromechanical energy converter, spindle-motor, spindle unit.

## 1. INTRODUCTION

The concept of genetic programs was applied only to living organisms, until today. The genetic programs of living organisms are coded in their genome structure. They contain information about the structure of the organism, its functioning and adaptation to external conditions.

The last achieved results of fundamental and experimental research in the field of Genetic Electromechanics [1-3] has shown that the genetic structurisation programs are the fundamental property of all genetically organized developing systems, including systems of anthropogenic origin [1].

Structural-system research, conducted by authors in the field of decoding of the genetic programs of hybrid classes of electromechanical energy converters (EMEC) [3] has opened the possibility of the structural prediction problems formulation and solving, related to the practical use of EMEC structural potential, which is not involved at the actual technical evolution stage [4].

The subject of the actual research is the class of hybrid EMEC of "spindle-motor" type. This type of EMEC is widely used in metal-working machines and other technological equipment [5].

The main goals of the research are decoding of the genetic structurisation program, e.g. the definition of genetically admissible diversity of species of hybrid classes of electromechanical systems of "spindle-motor" type, which are able to implement independent movement by two coordinates (rotational and return-but-progressive for CNC metal-cutting machines of new generation [5]), and the definition, on the basis of the decoded program, of the region of existence of competitive varieties of spindle-motors, including spindle-motors with controlled movement in longitudinal coordinate of the clamped object during treatment.

## 2. THE MATTER OF RESEARCH

As it is known from the Genetic evolution theory of Electromechanical systems [1], the task of the genetic program decoding can be solved by determining of the genome structure of the class. Genome is the genetically defined set of generating electromagnetic chromosomes, which determines the species diversity of the EMEC class.

Resulting from information analysis of certain projects and technical requirements to determine the limits of the synthesis objective function $F_S$, let us highlight the following significant features. The required EM-structure should provide:

1) the combination of the functions of Electromechanical drive and spindle ($S_E \times S_M$) in a single structural unit;

2) realization of independently operated rotational movement of the spindle, including reverse ($\pm\omega$)

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*ISSN 1310-6686© 2014 Известия на Технически университет Габрово*

3) realization of independently operated reciprocating motion of the spindle ($\pm V_{OX}$);

4) the alignment of the application moments and forces acting on the spindle $(M_\omega \times F_V)_{OX}$, where OX is the symmetry axis of the spindle;

5) the increased specific indicators of the main drive with limited dimensions of a unit ($S_A \rightarrow max$)

6) the competitiveness of the synthesized structure > ($K_S > K_A$), where $K_A$ is the set of essential features of the closest analogue (prototype);

**The synthesis objective function.** The synthesis objective function $F_S$ is possible to define a number of requirements and is represented as a sequence of partial functions. Proceeding from the aforementioned requirements, the integral objective function of synthesis is as follows:

$$F_S = [(S_E \times S_M), \pm\omega, \pm V_{OX}, (M\omega \times F_V)_{OX}, S_A \rightarrow \rightarrow max, (K_S > K_A)]$$

Using method of expert evaluations, we define weighting factors for partial functions as follows (Table 1).

To definition of the weighting factor. Table 1

| Function | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | $S_E \times S_M$ | $\pm\omega$ | $\pm V_{OX}$ | $(M_\omega \times F_V)_{OX}$ | $S_A \rightarrow max$ | $K_S > K_A$ |
| Weighting factor | 0,25 | 0,15 | 0,15 | 0,15 | 0,2 | 0,1 |

Particular requirements 1-3 of the objective function $F_S$ hold that the required structure belongs to the class of hybrid EM-objects, providing the rotational and translational motion of the spindle.

The requirements of the independently operated rotational and translational spindle motion realization (requirements 2 and 3) point out the necessity of ensuring the following condition:

$$L2 = (La\omega + LaV + Lx), \qquad (1)$$

where: $L_2$ is the total length of the active part of the spindle; $L_{aV}$ is the rotor active length of the main drive; $L_{aV}$ is the secondary element active length of the axial drive; $L_x$ is the axial drive stroke length.

The coaxiality requirement of the forces and moments application (4) limits the scope of the search to considering only those generating chromosomes that have axial symmetry.

To meet the requirement of increased specific indicators at the chromosomal level we select chromosomes that have the predisposition for maximum use of the active surface.

The requirement of competitiveness is confirmed at the final stage of structural synthesis by obtaining the protective document.

**Genetic synthesis model.** The requirements (2, 3 and 4) to the system of the electric drive are most met by the parental chromosomes $^3CL\ 0.2y$ (isotope) and $CL\ 2.0x$. The results of the synthesis made on the basis of these chromosomes are presented in the Fig. 1:

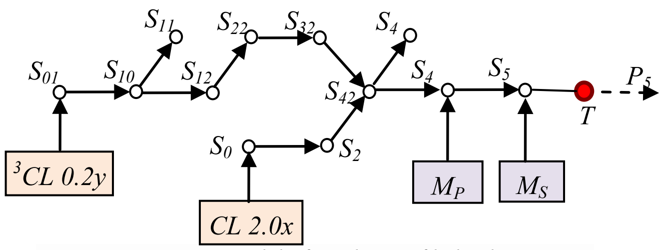


***Figure 1** - Genetic model of synthesis of hybrid structures $T_S$*

The model in the Fig. 1 is a graphical representation of the genetic program of the required EM-object. Its structure is defined by the combined chromosome $S_{54}$ of fifth generation.

The results of decoding of the synthesized hybrid structure genetic program. Table 2.

| The chromosome cipher | The structural formula | The status of chromosome | Coefficient of matching |
|---|---|---|---|
| $^3CL\ 0.2y$ | $^3CL\ 0.2y$ | Parental (isotope) | 0,15 |
| $S_{01}$ | $(^3CL\ 0.2y)_1 \times (CL\ 0.2y)_2$ | Generating (steam room) | - |
| $S_{10}$ | $(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R]_2$ | Informational (replicated $S_{01}$) | |
| $S_{11}$ | $(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R_{OX}]_2$ | Informational (axial isomer) | |
| $S_{12}$ | $(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R_r]_2$ | Informational (radial isomer) | |
| $S_{22}$ | $(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:}M\ (r_2>r_1)]_2$ | Informational (mutated isomer) | |
| $S_{32}$ | $(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:}M(r_2>r_1){:}I_{OX}]_2$ | Generating (space-inverse) | |
| $CL\ 2.0x$ | $CL\ 2.0x$ | Parental | 0,13 |
| $S_{02}$ | $(CL\ 2.0x)_1 \times (CL\ 2.0x)_2$ | Generating (paired) | |
| $S_{20}$ | $(CL\ 2.0x)_1 \times [(CL\ 2.0x){:}M(L_2>L_1)]_2$ | Generating (mutated) | |
| $S_{42}$ | $\{(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:}M(r_2>r_1){:}I_{OX}]_2\} \times \times \{(CL\ 2.0x)_1 \times [(CL\ 2.0x){:}M(L_2>L_1)]_2\}$ | Informational (hybrid) | |
| $S_{43}$ | $\{(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:} M(r_2>r_1){:}I_{OX}]_2\} \times \{(CL\ 2.0x)_1 \times [(CL\ 2.0x){:}M(L_2>L_1)]_2\}{:}\ I_R$ | Informational (hybrid isomer - radial) | |
| $S_{44}$ | $\{(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:} M(r_2>r_1){:}I_{OX}]_2\} \times \{(CL\ 2.0x)_1 \times [(CL\ 2.0x){:}M(L_2>L_1) : I_L]_2\} \times (M_P)$ | Generating (axial isomer, combined with a quill $M_P$) | |
| $S_{54}$ | $\{(^3CL\ 0.2y)_1 \times [2(CL\ 0.2y){:}R{:}M(r_2>r_1){:}I_{OX}]_2\} \times \{(CL\ 2.0x)_1 \times [(CL\ 2.0x){:}M(L_2>L_1){:}I_L]_2\} \times (M_P, M_S) \rightarrow T_S$ | Generating ($S_{44}$, combined with spindle $M_S$) | 0,9 |

The synthesized chromosome $S_{54}$ 90% meets the specified $F_S$. The exception is the requirement of competitiveness ($K_S > K_A$), which is determined at the stage of development of technical solutions and patenting.

The structural formula determines the level of the genetic complexity of hybrid object $T_S$.:

$$S54 = \{(3CL0.2y)1 \times [2(CL0.2y): R: M(r2 > r1): IOX]2\} \times \times \{(CL2.0x)1 \times [(CL2.0x): M(L2 > L1): IL]2\} \times (MP, MS) \subset TS \qquad (2).$$

One of variants of technical realization of the structure of chromosomes S54 presented in Figure 2.

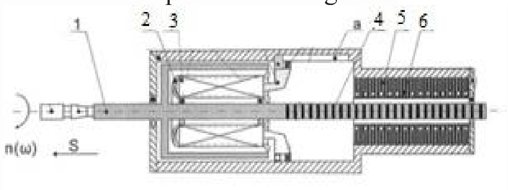


***Figure 2****-Option competitive solutions, developed on the basis of structural formulas (2)*

When winding 2 of a rotary motion inductor 3 is supplied by voltage, a magnetic field is induced, interacting with a bilateral surface of a spindle 1 and thus forces a spindle 1 to rotate with a necessary frequency n (ω). In order to ensure reciprocating motion of a spindle, the electricity is supplied on a winding 6 of the linear field inductor 5, which electromagnetic field interacts with a secondary element with permanent magnets 4 moves and provides the required reciprocating motion S.

Similarly, with use of genetic approach was constructed the genetic model of synthesis (Fig. 3) of the combined electromechanical structures of spindle-motors, which back and forth motion is realized due to the use of screw-nut system.

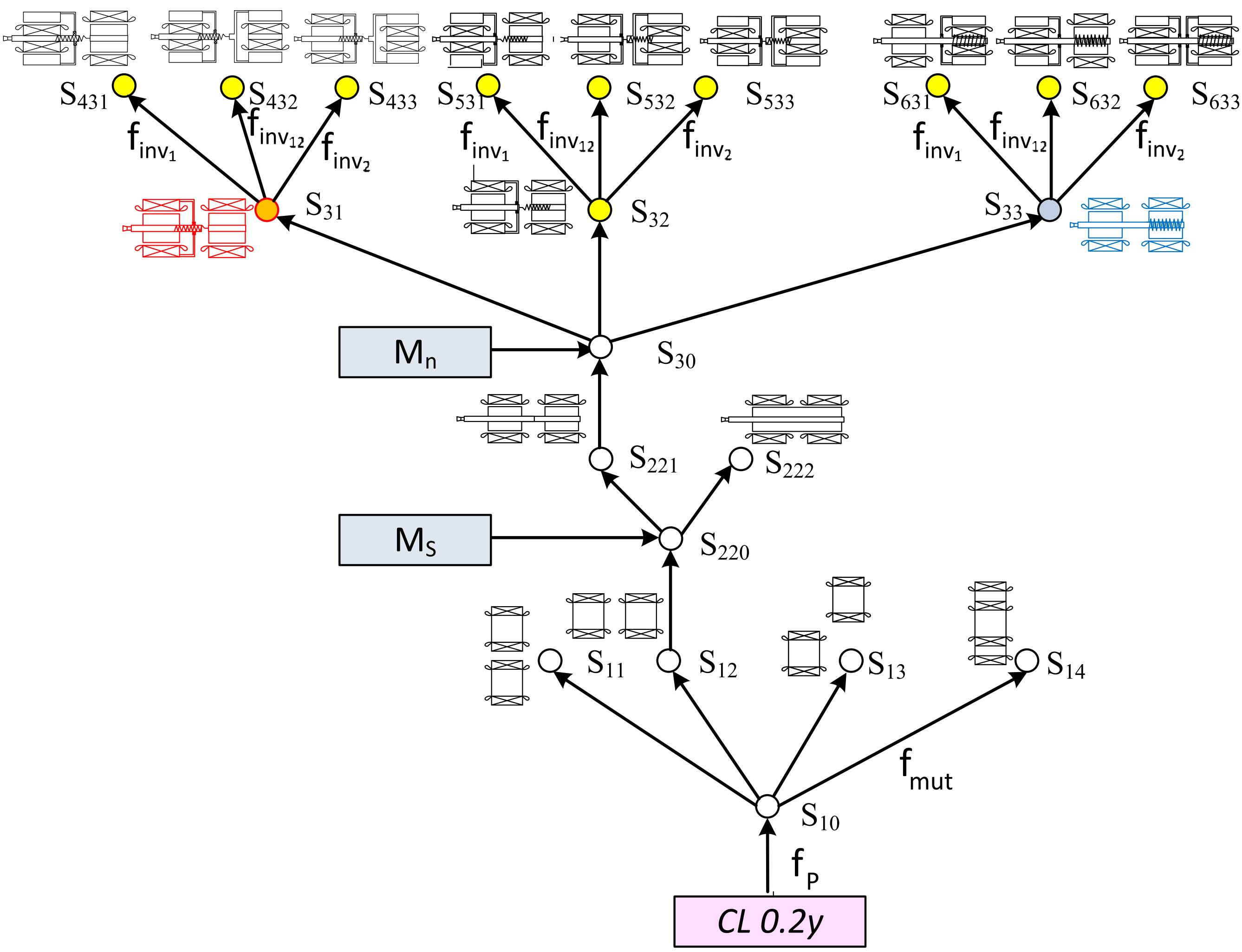


***Figure 3 -*** *Genetic synthesis model of combined electromechanical structures of spindle-motors with “screw-nut”*

One of the variants of technical realization of the synthesized chromosome $S_{31}$ is presented in Fig. 4 [6].

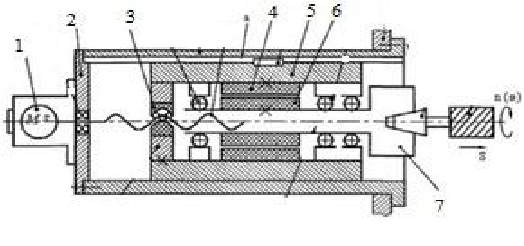


***Figure 4*** *- Longitudinal section of the spindle-motor assembly*

In this spindle-motor unit the magnetic field appears when voltage is applied to the stator winding 4. This magnetic field interacts with double layer active surface of the rotor 6 and causes the spindle 7 rotate with the necessary speed n (ω).

In order to ensure reciprocating motion of a spindle, the electric motor 1 is supplied with the voltage. The turns of the electric motor 1 are transformed means of CNC system and through screw-and-nut couple 2, 3 into the necessary linear motion S of moving sleeve 5.

Variants of the technical implementation of the synthesized chromosome $S_{33}$ are presented in Fig. (5-7).

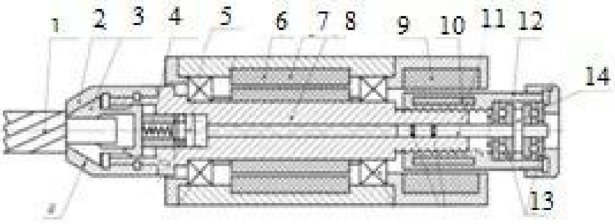


***Figure 5*** *- Longitudinal section of the spindle-motor assembly*

When the spindle 8 is fixed and the collet 3 is uncompressed, the clamp-on object 1 is placed in the internal seating of the collet. When electric current flows in winding 2 of stator 9 the electromagnetic field is induced and it interacts with the active surface of the rotor 10 connected rigidly with a nut 12. That is why appears the torque, which rotates a rotor 10 with the nut 12, moved along a spindle 8.

The torque creates the axial force operating through axial bearings 13 and coaxially located plunger 11. The pressure appears in the closed hydraulic system, acting on an output plunger 5 with bigger diameter. Thanks to its bigger diameter the initial axial force becomes more than input force.

After clamping, the stator winding 7 is fed by electricity and the electromagnetic field appears, interacting with a rotor winding 6 and therefore makes the spindle 1 to rotate with a necessary frequency. Control of spindle-motor unit with the clamping mechanism is performed by CNC system.

The stop of a spindle 1 is realized due to power dump of the stator winding 6, and the object 14 declamping is realized due to the change of poles on the stator winding 13, which forces the rotor 10 and the nut 12 to rotate in the opposite direction, moving a nut 12 in initial position and decreasing the liquid pressure in the closed hydraulic system. By means of a spring 4 the plunger 5 moves back and the plunger 11 moves back to a starting position. Self-unclamping of the gripping collet 3 is carried out due to elasticity of the clamping blades.

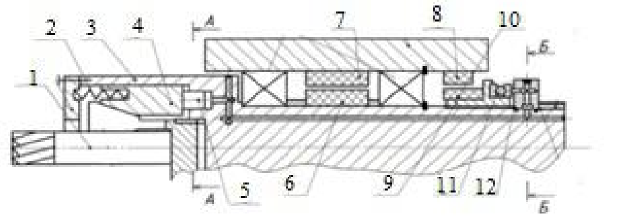


***Figure 6*** *- Longitudinal section of the spindle-motor assembly, containing the main motion drive, helical gear and collet chuck*

When electric current flows in winding of stator 8, the electromagnetic field occurs, interacting with windings of the rotor 10 connected rigidly with a nut 6. That is why appears the torque *M*, which rotates the rotor 10 with a nut 9, moved along a spindle 3 on a thread with diameter *dp*. The torque creates the axial force operating through the axial bearing 11 on coaxially located plungers 12.

After clamping, the stator winding 7 is fed by electricity and the electromagnetic field appears, interacting with a rotor winding 6 and therefore makes the spindle 3 to rotate with a necessary frequency. Control of spindle-motor unit with the clamping mechanism is performed by CNC system.

The stop of a spindle 3 is realized due to power dump of the stator winding 5, and the object 1 declamping is realized due to the change of poles on the stator winding 8, which forces the rotor 10 and the nut 9 to rotate in the opposite direction, moving a nut 9 into the initial position and decreasing the liquid pressure in the closed hydraulic system. By means of a spring 2 the flared sleeve 4, the plungers 5 and 12 move back to the initial position.

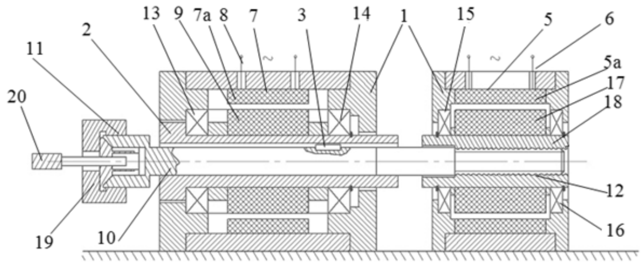


***Figure 7*** *- Longitudinal section of the spindle-motor assembly*

When control current is supplied from a control system 23 through the terminals 6 and 8 on windings 5a and 7a, the induced magnetic fields interact with rotors 9 and 17 respectively and rotate the rotors 9 and 17 connected to a spindle 10, which is mounted on radial-thrust bearings 13 and 14, and the nut mounted on radial-thrust bearings 15 and 16 respectively. At this time the moving sleeve 2 is kept from turning by a pin 3 that contacts to the rectilinear directing groove 4 made on the case 1.

At that time the magnetic field of the inductor 7 provides creation of torque M1 on the rotor 9 and, on the spindle 10. The torque M1 through the flange end 11 acts on the clamping mechanism 19, and on the tool 20. The magnetic field of the inductor 5 creates torque M2, which is necessary to overcome the motion resistance force and to support the relative position of the spindle 10 and nut 18, at which there is no mismatch between moments M1 and M2 and the angle $\delta=\varphi_2-\varphi_1$ is equal to 0. The corresponding angles of rotation of the spindle 10 ($\varphi_1$) and the nut 18 ($\varphi_2$) are controlled by the sensors 21 and 22, respectively, connected with the control system 23.

If there is a need to provide linear movement to the working instrument 20, the control system 23 changes current, which is supplied to windings 7a and 5a through the terminals 8 and 6, to provide a mismatch of the moments of M1 and M2 and the angle $\delta=\varphi_2-\varphi_1$ become different from zero. There will be thus a relative movement of the spindle 10 and the nut 18. Then the screw-end 12 will begin unscrewing from the nut 18 and to transmit the linear force to the moving sleeve 2 through the radial-thrust bearings 13, 14 and 15, 16, and causing the movement of the moving sleeve 2 from the case 1 along the axis. Thus the tool will receive linear displacement at a size L (mm) which is defined by a step of the screw T (mm), and depends on the angle δ: $L = \frac{\delta T}{2\pi}$: L, where $\delta=\varphi_2-\varphi_1$, (radian).

To return the moving sleeve 2 of the spindle 10 in the initial position the control system 23 creates a negative mismatch of moments M1 and M2. As a result, the screw-end 12 of the spindle 10 is screwing into the nut 18.

Current supply of the windings 5a and 7a and in the certain laws allow to provide not only the rotating (main) movement of the cutting tool 20, but also to provide the linear movement. This movement can be formative (when carried out smoothly in a certain distance), corrective (for example, compensation of the tool detrition and reduction of its departure) or suboperational (pulsing) to ensure chip breaking, improving work conditions, damping of dynamic instability during the spindle-motor operation.

These spindle units can find broad application as a part of multicoordinate boring-and-milling machines of new generation [5], as, for example, in pyramidal configuration of the machine without mechanical transfers (the patent of Ukraine No. 101447), fig. (8).

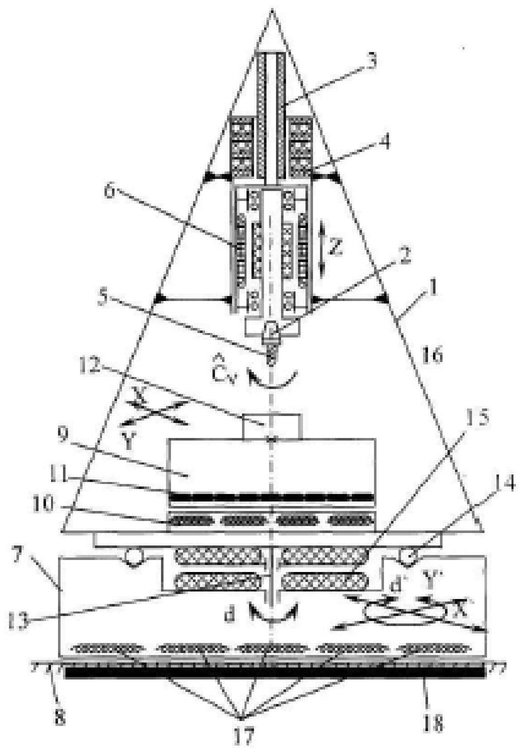


***Figure 8*** *- Pyramidal arrangement of the machine tool without mechanical transmission*

The rough workpiece 12 is placed and fixed on the table 9 by means of the handling device (is not shown on the drawing). The drive of rotation of the tool 5 ($C_V$ coordinate) turns on, and according to the program the further processing of rough workpiece 12 is carried out. The processing program is set by CNC-system (is not shown on the drawing), which gives the corresponding signals of shape-making movements to machine axis drives on *X, Y* and *Z* coordinates.

If there is a need to change the angular position of bearing system 1 the control program gives a signal to planar-and-toroid electric motor 15, which provides rotary movement on the corresponding angle (*d* coordinate) if it is provided in the flexible automated production, for example for loading of rough workpiece, unloading of the ready detail, or for solving the transporting tasks.

The positioning of the machine tool basis 7 on the surface of a floor 8, which is executed as a stator 18 of linear electric motor is provided due to the built-in electromechanical system of plane-parallel movement 17.

Difference from the known variants of the offered design consists in ensuring free orientation of the machine tool in the production working space.

## CONCLUSIONS

The results of research can be considered as a concrete example of the transition from the observed evolution to the strategy of controlled evolution of technical systems, implemented through structural technology foresight and directed synthesis on the specified objective function.

The main results of genome research can be summarized by the following provisions.

1. For the first time identified and deciphered the genetic program of a class of hybrid and combined motor-spindles, implementing independent rotational and the progressive movement.

2. According to the results of comparative analysis of genetically admissible Species diversity and real informational Species there were for the first time defined implicit Species of spindle-motors, which structural representatives are absent at the actual moment of the technical evolution.

3. To check the reliability of the practical use of genetic programs the directed synthesis and development of technical implementation variants of spindle-motors, intended for work in metal-working machines of the new generation [5] is carried out.

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