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DESIGN VARIANTS MODELING OF THE SMALL-SIZED GANTRY-TYPE MILLING MACHINE

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ABSTRACT

Desktop CNC machines are designed for small-scale details manufacturing and form the perspective direction of specialists training at design, research, development and operation of machine-tool equipment of new generation. The research objective is to construct genetic models and programs for directed synthesis of desktop milling machines without mechanical transmissions. Evolution theory bases of electromechanical energy converters and genetic synthesis method of the complex combined electromechanical structures, based on the genetic operators are used here. The analysis of various approaches to kinematics of forming movements, to kinematic chains record and modeling, and configurations of traditional performance machines and mechanisms of parallel structure is made. New approach of genetic modeling on the example of the gantry-type milling machine with linear electric motors is offered. There are first-ever created the genetic synthesis models of small-sized milling machines without mechanical transmissions and discovered their genetic programs, on which basis the original samples of desktop milling machines that can be used successfully in production and educational process, are synthesized. This study is original in use of innovative genetic approach to solving the tasks of desktop milling machines synthesis. The offered approach can be used for synthesis of machines, robots and robotic systems of different function.

1. INTRODUCTION

Today it is very difficult or it is even impossible to overestimate relevance of desktop machines with computer numerical control (CNC). They can process the majority of materials: various metals, plastic, wood, stones, granite, etc. Concerning processing accuracy, CNCs are second to no one, as their executive bodies' step width reaches one micrometer. CNCs' application field deals with aviation, automotive industry, engraving, production of promotional products, processing of jewelry, tools manufacturing etc.

Desktop machines also gained such relevance due to their availability and simplicity. In comparison with classical CNC machines, desktop ones are several times cheaper, less in weight, have simpler design, and less noise. So far as concerns small-size details processing in small series or CNC use in higher education institutions at quite limited financing, these machines are no worse than the full-rate CNCs. Of course, they will not replace big machines at the enterprises where the large-size details of serial or mass production are manufactured.

2. EARLIER STUDIES

Problems of coding and modeling of form-building movements and also modular approach were engaged by experts of the different countries [1.2,5-9.14,15.20,22]. Granovsky G.I. [8] offered digital coding of cutting kinematics, which was further used by Vragov Yu. [6], Averyanov O.I. [1], Homyakov B.C. [15] and others for writing down the structural formulas of configurations at the different instantiation levels according to the modular approach and taking into account the forming coordinate movements from the work-piece to the tool.

Concerning machines of new generation with the mechanisms of parallel structure (MPS), the works of Dmitriyev D.A. and Kuznetsov Y.M. [9, 14] are representing that symbolical record of formulas for a coordinate and basic configurations of machines with MPS only partially represents their design in the analysis. For the stationary block description it is offered to use coding of seated connections and the stationary block's framework, in the form of the binary relations of two matrixes, and the matrixes size n is equal to number of points on each coordinate axis of the machine all along the configuration dimensions.

The following impetus to the modeling configurations of machines and other processing equipment of new generation was given by the Genetic Electromecanics [16, 17, 21], based on the periodic table of primary sources of the electromagnetic field, discovered by Shinkarenko V. F. [16].

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3. THE EXISTING SMALL-SIZED MILLING MACHINES ANALYSIS

These machines got great popularity quite recently, and trends of their development are based on the following main requirements: reduction in metal consumption of the bearing system without decrease in qualitative characteristics of the machine; processing accuracy increase, and frame stiffening; processing efficiency and machine's modularity degree increase. Today there are known small-sized milling machines of several various configurations, among which: console (Fig. 1, a) and portal (Fig. 1, b, c), and is rarer frame ones (Fig. 2).

a) *b)* *c)*

Fig. 1. Small-sized milling machines: a console type (a), traveling gantry machine, (b) machine with a moving table (c)

Fig. 2. 3D-model of the machine of frame configuration with MPS

Fig. 3. Table milling machine «CNC 3030» (Ukraine)

CNC machine of the CNC 3030 series (Fig. 3) is intended for processing wood, plastic, organic glass, acryl, stone, non-ferrous metals and even steel.

It is used for manufacturing art panels for finishing buildings interiors and facades, logos, promotional products of wood and metal.

The next one machine worthy of attention of is "CNC 3020 mini" (Fig. 4) on which it is possible to make wooden models, panels, badges, souvenirs, aircraft models and other wooden products.

Fig. 4. Table milling machine «CNC 3020 mini» (Ukraine)

One more representative of milling mini-machines, considered here, is from the Japanese manufacturer "Roland" (Fig. 5).

Fig. 5. Milling mini-machine «Roland SRM-20»

4. OBJECT OF RESEARCH

In Igor Sikorsky Kyiv Polytechnic Institute at the Department of design of machine tools and machines there are created desktop milling machines [11, 12, 13], including "CNC 500" (Fig. 6), intended for milling processing of such materials as: bronze, duralumin, textile laminate, various plastics, wood, wax, etc. This CNC can be used in many fields, in particular instrument making, jewelry production, manufacturing of PCB, chips, souvenirs, unique signs and labels, etc.

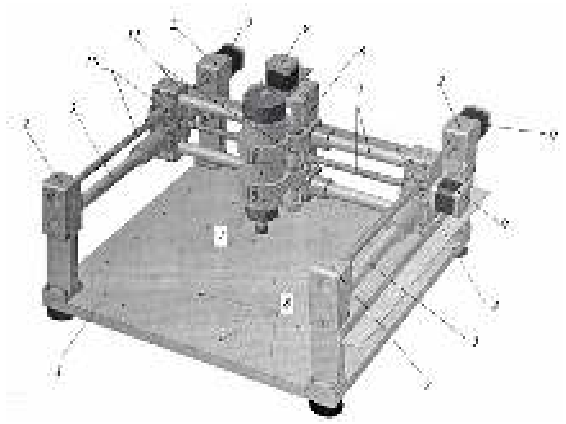

Fig. 6. Table traveling gantry milling machine «CNC 500»: 1-carrier plate; 2-vertical rod; 3-slideway; 4- gantry; 5-two slideways; 6-carriage; 7- spindle-motor; 8-threaded holes; 9-stepping motor; 10- ball-and-screw unit; 11- inductive proximity switch

5. RESEARCH RESULTS

The first version of the upgraded machine (Fig. 7) is the most similar to the prototype (Fig. 6) on their design and configuration.

The main difference and advantage of this machine is use of linear electric motors [3, 18, 23-27] instead of step electric motors that worked with ball-and-screw unit. The chosen flat linear motor LMTA-4 is perfectly suitable for this machine due to the small overall dimensions, convenient fastening and high dynamic characteristics. There is enough accuracy of the electric motor positioning in 0,01 mm for processing the most responsible details with increased requirements on accuracy and qualities. For movement on Y-axis the secondary element of cylindrical linear electric motor 7 is fixed in the modernized rods 3 which are placed at every corner of the machine base 1. For movement on X-axis similar electric motors 6 which are fixed in special rigid fixing brackets 4 are used. The fixing brackets 4, in turn, are fixed directly to the case of sideways motors 7, forming the so-called moving gantry.

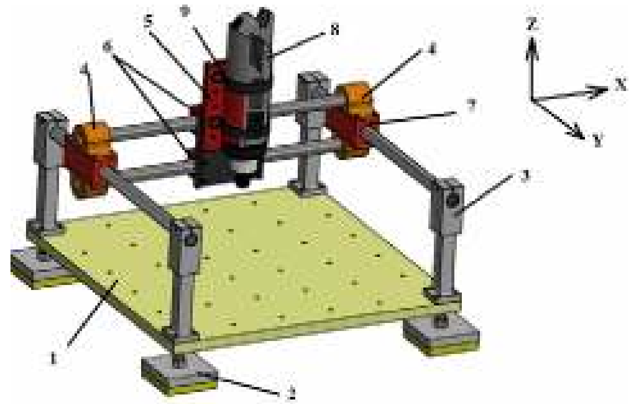

Fig. 7. 3D model of the upgraded machine with moving beam: 1-carrier plate; 2- vibration mount; 3-vertical rod; 4- fixing bracket; 5-flat linear electric motor; 6, 7-cylindrical linear electric motors; 8-spindle-motor; 9- fixing bracket for the spindle-motor

The other option of modernization became a machine with moving table and stationary frame (Fig. 8).

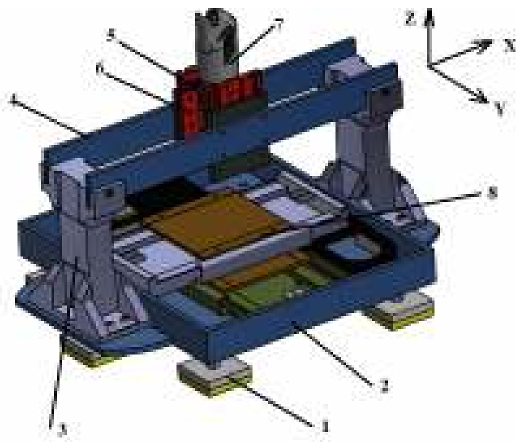

Fig. 8. 3D-model of the upgraded machine with moving table: 1-vibration mount; 2-base; 3-vertical rod; 4-double fixing bracket; 5-adjustable fixing bracket; 6-flat linear motor, 7-spindle-motor; 8-crossed motion linear table «LMX2E-CB5CB8-XXX-YYY-G20» [25]

The design of this machine significantly differs from the initial version (Fig. 6). The main lack of machines with a moving table are increased dimensions, and the main advantage are high rigidity and low location of the mass center.

In reliance on the Genetic evolution theory of EM-systems [14, 15, 18], it is necessary to identify the technical solution search function F_{TS} in order to conduct the directed synthesis. The search function is defined from the corresponding number of requirements and limitations. Let us formulate the main particular requirements for the searched systems S_{TS} and S'_{TS}:

1) table-sized design (D_{TS});
2) use of EM-systems for all type of movements (M_{EM});
3) 3-coordinate movement of spindle ($S_{X,Y,Z}$)
4) moving beam ($B_{X,Y}$) – for S_{TS}; or moving table ($T_{X,Y}$) – for S'_{TS}.

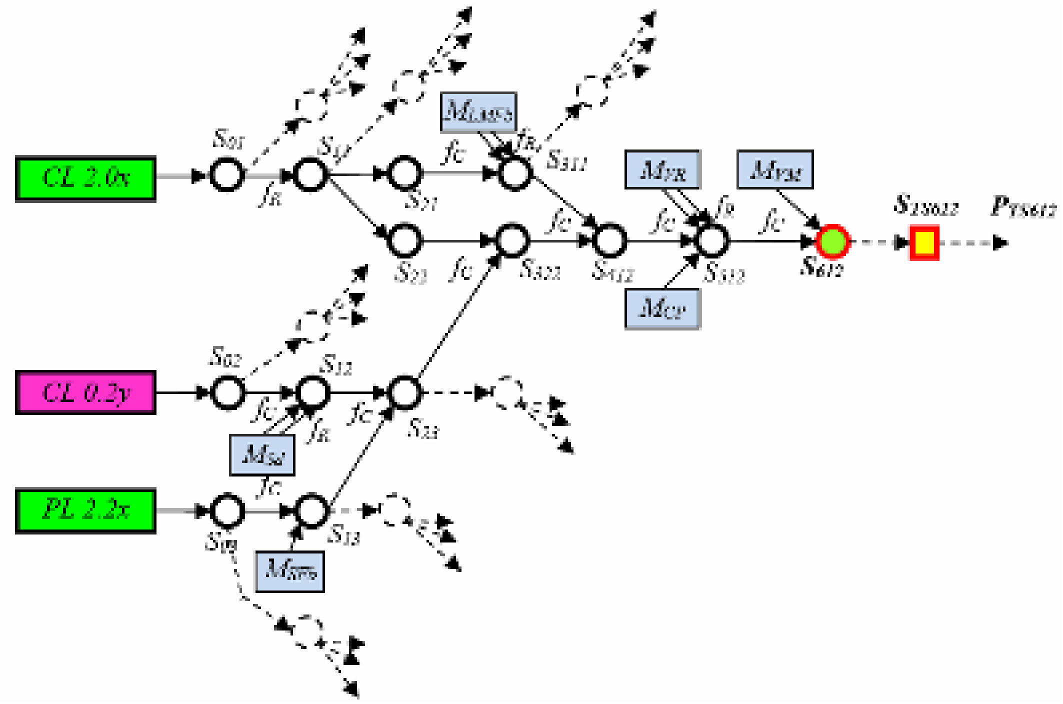

Fig. 9. Genetic model of desktop CNC-structure synthesis using defined search function F_{TS} (2): f_C – genetic operator of crossing; fR – genetic operator of replication; CL2.0x , CL0.2y , PL2.2x – primary electromagnetic chromosomes; S_{01} , S_{02} ,…, S_{612} – synthesized structures of electromagnetic chromosomes; S_{TS612} – technical solution; P_{612} – populations of technical solutions

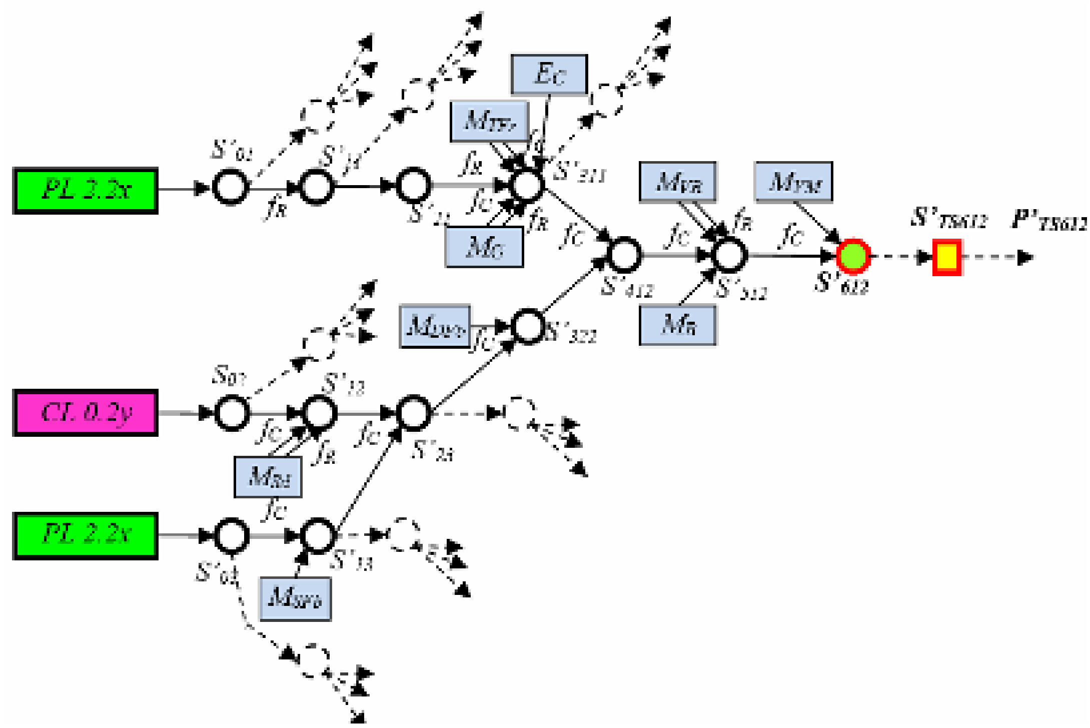

Fig. 10. Genetic model of desktop CNC-structure synthesis using defined search function F'_{TS} (3): f_C – genetic operator of crossing; f_P – genetic operator of replication; CL0.2y , PL2.2x – primary electromagnetic chromosomes; S'_{01} , S'_{02} ,…, S'_{612} – synthesized structures of electromagnetic chromosomes; S'_{TS612} – technical solution; P'_{612} – populations of technical solutions

Taking into account the specified above requirements, the integral search functions could be represented as vectors F_{TS} and F'_{TS}, respectively, in multidimensional space R^n:

$$F_{TS} = [D_{TS}; M_{EM}; S_{Z,Y,Z}; B_{X,Y};] \in R_n; \quad (2)$$

$$F'_{TS} = [D_{TS}; M_{EM}; S_{Z,Y,Z}; T_{X,Y};] \in R_n; \quad (3)$$

The genetic synthesis model, described on Fig. 9, Fig. 10 correspond to the defined F_{TS}, and F'_{TS}, respectively.

This genetic models represent the search trajectories for EM-structures, which satisfies the F_{TS} and F'_{TS} and constitute the genetic programs of directed synthesis of desktop milling machines without mechanical transmissions. To identify the final stage of synthesis procedure, there should be used the weight index of correspondence k_c, the value of which is defined by proportion of the integral genetic predisposition P_C of corresponding electromechanical chromosome to the defined integral search function F_{TS} :

$$k_C = P_C/F_{TS} \leq 1 \quad (4)$$

The electromagnetic chromosomes, which satisfy F_{TS}, and F'_{TS}, respectively, have certain genetic complexity levels, which are estimated from the results of genetic analysis (Table 1, Table 2). The specified search functions F_{TS} and F'_{TS} are satisfied by genetically higher combined hybrid chromosomes S_{612} and S'_{612}, respectively. The complexity degree of the structure S_{612}, as well as the complexity degree of the related populations of technical solutions P_{612} can be expressed by the following structural formula:

$$\left[\left[\begin{matrix}\left[2(CL2.0x_1 \times CL2.0x_2)_{(R:X)} \times M_{LMFb}\right] \times \left[2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}\right] \times \\ \left[(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}\right] \times \left[(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}\right]\end{matrix}\right] \times M_{VR} \times M_{CP}\right] \times M_{VM} \quad (5)$$

The complexity degree of the structure S'_{612}, as well as the complexity degree of the related populations of technical solutions P'_{612} can be expressed by the next structural formula as well:

$$\left[\left[\begin{matrix}\left[2(PL2.2x_1 \times PL2.2x_2)_{(R:X,Y)} \times M_{TFr} \times E_C \times M_G\right] \times \\ \left[\left[(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}\right] \times \left[(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}\right] \times M_{DFb}\right]\end{matrix}\right] \times M_{VR} \times M_B\right] \times M_{VM} \quad (6)$$

Table 1. Genetic analysis results of structure-creation model of desktop milling machine with moving beam (F_{TS})

Electromechanical chromosome	***Structural formula***	***Chromosome status***	***k_c***
CL2.0x	*CL2.0x*	*Parental*	-
S_{01}	$CL2.0x_1 \times CL2.0x_2$	*Electromagnetic pair*	-
CL0.2y	*CL0.2y*	*Parental*	-
S_{02}	$CL0.2y_1 \times CL0.2y_2$	*Electromagnetic pair*	-
PL2.2x	*PL2.2x*	*Parental*	-
S_{03}	$PL2.2x_1 \times PL2.2x_2$	*Electromagnetic pair*	
S_{11}	$2(CL2.0x_1 \times CL2.0x_2)_{(R)}$	*Informational, replicated (k_R=2)*	-
S_{12}	$(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}$	*Informational, combined*	-
S_{13}	$(PL2.2x_1 \times PL2.2x_2) \times 2M_{SFb}$	*Informational, combined*	
S_{21}	$2(CL2.0x_1 \times CL2.0x_2)_{(R:X)}$	*Informational, replicated, isomer*	-
S_{22}	$2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}$	*Informational, replicated, isomer*	-
S_{23}	$[(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}] \times [(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}]$	*Informational, combined, hybrid*	-
S_{311}	$2(CL2.0x_1 \times CL2.0x_2)_{(R:X)} \times M_{LMFb}$	*Informational, combined*	-
S_{322}	$[2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}] \times [(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}] \times [(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}]$	*Generating, combined, hybrid*	0,4
S_{412}	$[2(CL2.0x_1 \times CL2.0x_2)_{(R:X)} \times M_{LMFb}] \times [2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}] \times [(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}] \times [(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}]$	*Generating, combined, hybrid*	0,6
S_{512}	$[[2(CL2.0x_1 \times CL2.0x_2)_{(R:X)} \times M_{LMFb}] \times [2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}] \times [(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}] \times [(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}]] \times M_{VR} \times M_{CP}$	*Generating, combined, hybrid*	0,8
S_{612}	$[[[2(CL2.0x_1 \times CL2.0x_2)_{(R:X)} \times M_{LMFb}] \times [2(CL2.0x_1 \times CL2.0x_2)_{(R:Z)}] \times [(CL0.2y_1 \times CL0.2y_2) \times M_{Sd}] \times [(PL2.2x_1 \times PL2.2x_2) \times M_{SFb}]] \times M_{VR} \times M_{CP}] \times M_{VM}$	*Generating, combined, hybrid*	1,0

Table 2. Genetic analysis results of structure-creation model of desktop milling machine with moving table (F'_{TS})

Electromechanical chromosome	***Structural formula***	***Chromosome status***	***k_c***
PL2.2x	*PL2.2x*	*Parental*	-
S_{01}	$PL2.2x_1 \times PL2.2x_2$	*Electromagnetic pair*	-
CL0.2y	*CL0.2y*	*Parental*	-
S_{02}	$CL0.2y_1 \times CL0.2y_2$	*Electromagnetic pair*	-
PL2.2x	*PL2.2x*	*Parental*	-

$\boldsymbol{S_{03}}$	$PL2.2x_1\times PL2.2x_2$	*Electromagnetic pair*	
$\boldsymbol{S_{11}}$	$2(PL2.2x_1\times PL2.2x_2)_{(R)}$	*Informational, replicated (k_R=2)*	-
$\boldsymbol{S_{12}}$	$(CL0.2y_1\times CL0.2y_2)\times M_{Sd}$	*Informational, combined*	-
$\boldsymbol{S_{13}}$	$(PL2.2x_1\times PL2.2x_2)\times M_{SFb}$	*Informational, combined*	
$\boldsymbol{S_{21}}$	$2(PL2.2x_1\times PL2.2x_2)_{(R:X,Y)}$	*Informational, replicated, isomer*	-
$\boldsymbol{S_{23}}$	$[(CL0.2y_1\times CL0.2y_2)\times M_{Sd}]\times[(PL2.2x_1\times PL2.2x_2)\times M_{SFb}]$	*Informational, combined, hybrid*	-
$\boldsymbol{S_{311}}$	$2(PL2.2x_1\times PL2.2x_2)_{(R:X,Y)}\times M_{TFr}\times E_C\times M_G$	*Informational, combined*	-
$\boldsymbol{S_{322}}$	$[(CL0.2y_1\times CL0.2y_2)\times M_{Sd}]\times[(PL2.2x_1\times PL2.2x_2)\times M_{SFb}]\times M_{DFb}$	*Generating, combined, hybrid*	*0,4*
$\boldsymbol{S_{412}}$	$[2(PL2.2x_1\times PL2.2x_2)_{(R:X,Y)}\times M_{TFr}\times E_C\times M_G]\times[[(CL0.2y_1\times CL0.2y_2)\times M_{Sd}]\times[(PL2.2x_1\times PL2.2x_2)\times M_{SFb}]\times M_{DFb}]$	*Generating, combined, hybrid*	*0,6*
$\boldsymbol{S_{512}}$	$[[2(PL2.2x_1\times PL2.2x_2)_{(R:X,Y)}\times M_{TFr}\times E_C\times M_G]\times[[(CL0.2y_1\times CL0.2y_2)\times M_{Sd}]\times[(PL2.2x_1\times PL2.2x_2)\times M_{SFb}]\times M_{DFb}]]\times M_{VR}\times M_{MB}$	*Generating, combined, hybrid*	*0,8*
$\boldsymbol{S_{612}}$	$[[[2(PL2.2x_1\times PL2.2x_2)_{(R:X,Y)}\times M_{TFr}\times E_C\times M_G]\times[[(CL0.2y_1\times CL0.2y_2)\times M_{Sd}]\times[(PL2.2x_1\times PL2.2x_2)\times M_{SFb}]\times M_{DFb}]]\times M_{VR}\times M_{MB}]\times M_{VM}$	*Generating, combined, hybrid*	*1,0*

where:

- $CL2.0x_1$ is a genetic code of the cylindrical-shape primary source of running-wave electromagnetic field of linear motors;
- $CL2.0x_2$ is a genetic code of the cylindrical-shape secondary source of running wave electromagnetic field of linear motors;
- $CL2.0x_1\times CL2.0x_2$ is a pair electromagnetic chromosome of cylindrical linear motors;
- M_{LMFb} is a mechanical chromosome of linear motor fixing bracket;
- $CL0.2y_1$ is a genetic code of the cylindrical-shape rotating-wave primary source of electromagnetic field (stator inductor system of spindle-motors);
- $CL0.2y_2$ is a genetic code of the cylindrical-shape rotating-wave secondary source of electromagnetic field (stator inductor system of spindle-motor);
- $CL0.2y_1\times CL0.2y_2$ is a pair electromagnetic chromosome of cylindrical-shape rotating-wave electromechanical energy converters, i.e. EME-converters (spindle-motor);
- M_S is a spindle mechanical chromosome;
- M_{SFb} is a mechanical chromosome of spindle fixing bracket;
- $PL2.0x_1$ is a genetic code of the flat- (planar-) shape primary source of running-wave electromagnetic field of linear motors;
- $PL2.0x_2$ is a genetic code of the flat- (planar-) shape secondary source of running wave electromagnetic field of linear motors;
- $PL2.0x_1\times PL2.0x_2$ is a pair electromagnetic chromosome of flat linear motors;
- M_{VR} is a mechanical chromosome of vertical rod;
- M_{CP} is a mechanical chromosome of carrier plate;
- M_{VM} is a mechanical chromosome of vibrating mount;
- M_{TFr} is a mechanical chromosome of linear table frame;
- E_C is an electrical chromosome of electrical and electronic components of the linear table;
- M_G is a mechanical chromosome of the linear table guideways;
- M_B is a mechanical chromosome of the base of desktop milling machine;
- M_{DFb} is a mechanical chromosome of dual fixing bracket.

Some of the technical realization variants of the synthesized structure $\boldsymbol{S_{612}}$ and $\boldsymbol{S'_{612}}$ are represented on Fig. 7, Fig. 8, respectively.

CONCLUSION

With use of genetic approach there is for the first time constructed genetic models of synthesis of small-sized milling machines without mechanical transmissions. There are discovered the genetic programs on which basis for the first time from the genetic codes are synthesized 2 original samples of desktop milling machines without mechanical transmissions, which can be used successfully in production and educational process.

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