GENETIC MODELING AND STRUCTURAL SYNTHESIS OF CNC MULTI-SPINDLE AUTOMATIC MACHINES OF NEW GENERATION

ГЕНЕТИЧЕСКОЕ МОДЕЛИРОВАНИЕ И СТРУКТУРНЫЙ СИНТЕЗ МНОГОШПИНДЕЛЬНЫХ ТОКАРНЫХ АВТОМАТОВ С ЧПУ НОВОГО ПОКОЛЕНИЯ

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Abstract: *Global trends on the key technical and economic indicators in development of multiple-spindle automatic machines (MSAMs) with various control systems and the hybrid MSAMs with consecutive reduction and complete elimination of mechanical kinematic chains, developed with the use of electromechanical structures (EM-structures) in I. Sikorsky KPI, are given in this paper. Genetic synthesis of MSAM EM-structures by the defined search function using genetic synthesis models and genetic operators of crossing, replication and a mutation have been made here.*

KEY WORDS: MULTIPLE-SPINDLE AUTOMATIC MACHINE, ELECTROMAGNETIC CHROMOSOME, HYBRID, COMBINED SYSTEM, GENETIC MODEL, SYNTHESI

1. Global trends on the key technical and economic indicators in MSAMs development

With a global trend in development of flexible automated agile manufacturing, increasing the specific weight of small-scale manufacturing, there are such products and individual parts which are produced in thousands and millions of pieces (accessories, fixtures, bearings, plumbing fixtures, etc.). Similar products and parts are produced in high-volume and mass production on high-performance machines, which MSAMs belong to. Such machines are processing is the rod, and pipe stocks, and chuck work-pieces (Fig. 1) [2, 8-10, 14, 15].

The first rod-stock MSAM with the rotary spindle drum (SD) has been released by National Acme Co., Cleveland, the USA on the basis of the American patent No. 530180 in 1894 [13]. A. Schuette's 'Gildemeyster and Co.' manufactured Acme-system MSAMs. The next was Gridley system with the 4-pindle automatic machine, manufactured by 'K. Hasse & Wrede' (Berlin). Further development was in Davenport systems with five working spindles, 6-spindle machines of New Briten systems, 3-spindle machines of Lister system (made by 'Davies Seving's and Co., Dighton, the USA). Prentice-system MTA had been made with dual-side ('Prentice & Co.', New Hoven, the USA) and single-side performance ('K. Hasse & Wrede', 'New Britain'). Vanner-system is distinctly different from other vertical configuration systems in having 8 spindles, placed around core (that MSAM first appeared on World exhibition in Brussels, but there was nothing more to be heard about it). The same principal was used in Bullard-system MSAMs for big work-pieces.

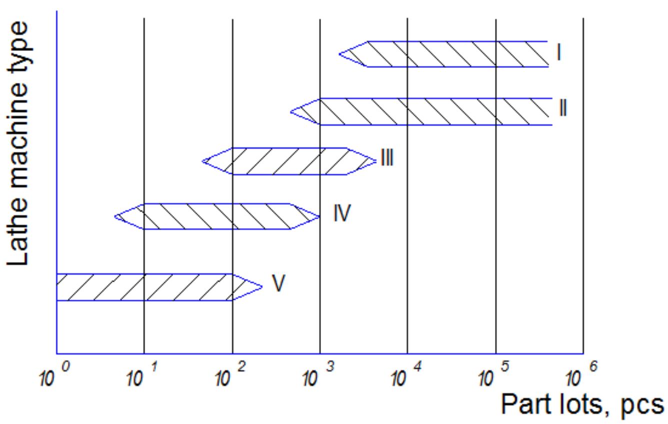

Fig. 1. *Applications of various lathe machines under a variety of part lots: 1 - drum (rotor) automatic machine; 2 - multiple-spindle automatic machine; 3 - single-spindle automatic lathe; 4 - capstan lathe; 5 - CNC lathe*

The main technical-and-economic index for MSAM, defining its progressive development, is a performance rate, which is significantly influenced by the main movement drive, mainly, spindle rotation speed. The technical forecasting up to 2000 for MSAMs in line of their performance rate with certain degree of probability was made in the paper [5] using patent information in MSAM special design bureau (SDBMA) at M. Gorkiy Kiev automatic lathe plant. The other technical-and-economic index for technology equipment and machines of various purpose is the relation between its weight G and installed capacity N of the main drive. This ratio characterizes the metal intensity of MSAM and also defines its progressive development, especially under the metal scarcity conditions (the entrails of the earth are depleting at catastrophically warp speed):

$$M = \frac{G}{N} \quad (1)$$

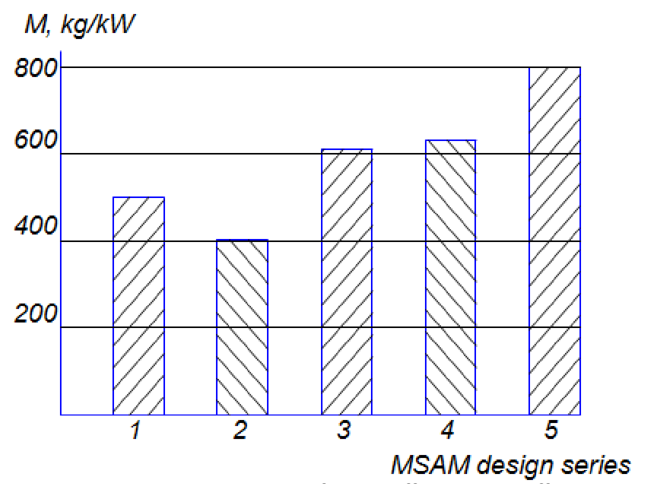

Fig. 2. *Comparative diagram of metal efficiency in different design series of multiple-spindle automatic machines: 1 – 123; 2 – 1240-6; 3 – Wickmman MSAM; 4 – Gildemeister AG MSAM; 5 – KON MSAM*

In the mid-20th century according to the data in [2], this index for 6-spindle MSAM with countershaft sequence-type control ranged within 400 to 800 kg/kW (Fig. 2).

By the late 1970s Ukrainian MASMs with countershaft sequence-type control [9] had lower M-index in the range of 387…769 kg/kW. It should be mentioned, that according to [2, 9], due to long kinematic chains as mechanical transmissions (tooth and belt gears), Ukrainian light and medium manufacturing MSAM with 15…42 kW cutting power had 5.7…10.8 kW losses, while main drive efficiency was 0,6…0,8, and even less (in some cases it was 0,3). Japan enterprises were buying MSAMs, made in Kiev, and used them on full load, increasing cutting speeds and decreasing no-load time, due to countershaft rotation speed increase.

After their utilization, Kiev MSAMs were recycled, and Japan enterprises were manufacturing 3 own MSAMs using metal of 2 utilized Ukrainian ones. Further using widespread introduction of the CNC systems and high-speed spindle units with short kinematic chains, Japanese enterprises were succeeded to produce two MSAMs utilizing the metal of one Kiev MSAM. It means, the indicator of metal intensity has decreased at first by 1,5 times (to the limits of 258…513 kg/kW), and then twice (193…385 kg/kW).

Such tendency of the metal intensity indicator decrease is observed also in other enterprises which have begun to use CNC modern systems and short kinematic chains, excepting mechanical transmissions and applying high-speed spindle units of the stepless control CNC (i.e., spindle-motors [3, 4, 16, 18]). As an example, the Multiswiss-seria MSAM of Swiss company Tornos with 6 operating spindles and one backwork spindle has the metal intensity index M=208 kg/kW. Such level of M-index is also achieved by the other Eastern-Europe and West companies, which approach was modular design of MSAM providing maintenance and repair.

But the achieved levels of M-index are not the final results, and could be decreased more due to implementation of electromechanical systems (EM-systems), mechatronics, new forms of cage and shell frames, and new non-metallic materials, specifically composite [16,17].

Solving the problems of MSAM efficiency increase and metal-intensity decrease it is reasonable to use the approaches of the evolutionary and genetic synthesis [1, 6, 11 ,12, 16], based on the evolution laws and cross-discipline sciences. Among these is genetics, which is the cross-discipline field of knowledge, exploring the laws of heredity and structural variability in evolving natural and anthropogenic systems. Application of CNC systems in MSAM changed the kinematic chains, and the mechanical chains were replaced by the electromechanical ones. That was the beginning of new MSAM generations, taking into account the evolution of main drive, spindle drum turning devices and position-holding mechanisms.

Deviation from spindle drum, which axis is in line with geometrical axis of lathe machine [3, 10], allows to realize as high as possible the modular design [4], and, using the system-and-morphological approach [6], to create the big number of CNC MSAMs increasing the number of spindles aiming to productivity improvement. Starting from the MSAMs evolution analysis, there can be predicted 2 ways of their improvements:

1.with spindle drum and EM-systems of main drive, tool carrier and feeding heads axial drives, form-locked clamp drive in load-unload position, bar feed and stop drive, spindle drum turning device drive and position-holding mechanism drive;

2.without spindle drum and EM-systems of main drive, with integrated in one module spindle-motor, automatic clamp, without tool carrier and feeding heads axial drives, bar feed and stop drive.

In both cases the combined and hybrid systems of mechanisms' and units' electric drives, as well as frame supporting systems with wide usage of non-metallic materials. The most advanced is the 2-nd way without turning spindle drum, which realizes the parallel and parallel-series cut-map, from the point of high productivity and machining quality with the highest level of modular design approach and lowest material and energy consumption. Though, in this paper it is considered the 1-st level of MSAM evolution.

*2. New MSAM Design*Design description

The principal design of such MSAM is shown at Fig. 3. This MSAM contains a frame 1 (Fig. 3a) with the lower carriages 2, a traverse 3 with upper carriages 4, the installed on the frame 1 case 5 with spindle drum turning mechanism 6, which is in line with the axis 7 of the drum.

The drum turning mechanism 6 is designed as a step-motor, which rotor 8 is rigidly connected with the axis 7, and its stator 9 is

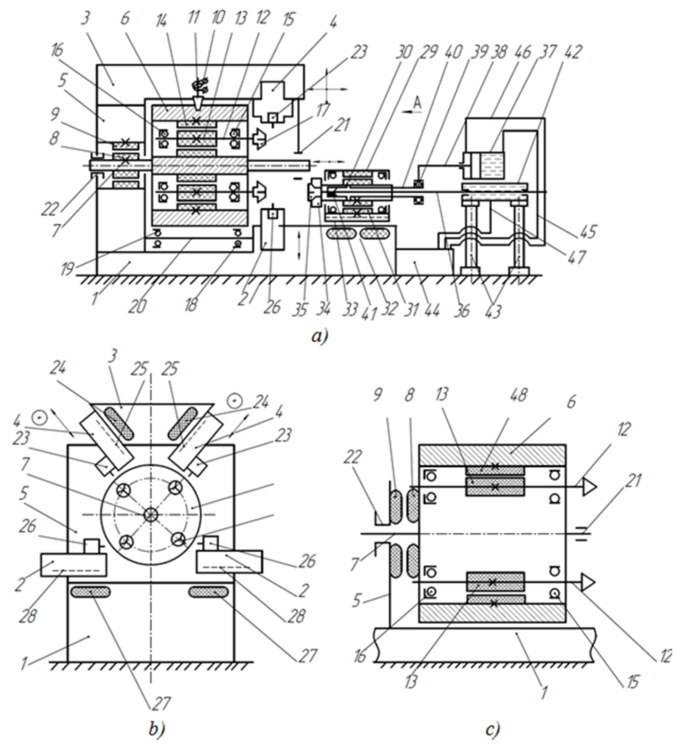

***Fig. 3**. The principal design of multiple-spindle automatic machine: a) spindle drum with a cylindrical-shape motor drive; b) view by arrow A; c) variant of spindle drum with a planar-toroid-shape motor drive*

hard-mounted in the case 5. The drum position-holding mechanism is equipped with the electromagnet 10 and a wedgelock 11. The spindle drum 6 contains operating spindle-motors, which cylindrical rotors 13 are hard-mounted in the spindles 12, and their stators 14 are hard-mounted in the hole of spindle drum 6.

The operating spindles 12 are mounted on the front 15 and tail 16 rolling contact bearings and equipped with the clamping chucks 17 with the clamping drives (are not shown here). The spindle drum 6 is mounted on the rolling bearings 18 and 19, placed on the fixed axis 20. The spindle drum axis 7 is mounted on the bearings 21, 22. The upper, for example 2-coordinate, carriages 4 are placed from the both sides of the traverse 3 (Fig. 3b).

The cutting tool holders 23 or tool turrets could be mounted on the carriages 4. The carriages 4 electric drives are represented as EM-systems with planar movements, for example planar electric motors with stators 24 hard-mounted on the traverse 3, and rotors 25, mounted in the carriages 4. The lower, for example single-coordinate, carriages 2 are placed from the both sides of the frame 1. The cutting tool holders 26 or tool turrets could be mounted on the carriages 2. The carriages 2 electric drives are represented as planar EM-systems with linear movements, for example linear electric motors with stators 27 hard-mounted on the frame 1, and rotors 28, mounted in the carriages 2.

The additional spindle workhead 29 with spindle-motor (rotor 30, stator 31) is mounted on the frame 1. The workhead 29 linear movement is realized by the linear electric motor with stator 32, which is hard-mounted on the frame 1, and secondary element 33, which is mounted with the workhead 29. The additional spindle 34 has a collet clamp 35 and a collet bar feed 36 with hydraulic drive with hydraulic cylinder 37 and piston-rod 38 on the axis 15. The piston 38 is connected by the bearing 39 with the supply pipe 40, which end is the feed collet 41 placed on. The bar feed mechanism has a cylindrical pipe 42, filled with oil, and mounted on the columns 43. The hydraulic pump assembly 44 with the pipe-lines 45, 46, 47 are mounted behind the frame 1.

The spindle drum 6 (Fig. 3, c) can have other variant of design, which is represented by planar-toroidal-shape EM-system (rotor 8, stator 9). Its operating spindles 12 have separated hard-mounted rotors 13, and the rotating electromagnetic torque is obtained due to the interaction with the electromagnetic field of the stator 48, mounted inside the hollow spindle drum 6 (that also reduces the weight of the lathe machine).

2.2. Operating principal

The MSAM operates in the following way. The bar 26 (Fig. 3a) is supplied on the defined length and clamped by the collet chuck. The preliminary machining is made then in the collet 17 of the operating spindle 12, which is opposite to the spindle 34. The preliminary machining is made by the lower carriage 2 (Fig. 3b) with the linear movements of the workhead 29. After that the processed end of the bar is supplied to the collet chuck 17 in the spindle 12 and clamped. The cutting instrument in the cutting tool holder 26 of the left carriage 2 is cutting the part, and the spindle drum 6 is turning into one position, due to the electric current supply into the electrical winding of the stator 9, and fixed by the wedgelock 11 (Fig. 3a). The spindle 34 unclamps the ready-made part, which is off-loaded then. The cycle begins to repeat.

3. *Genetic Synthesis Of MSAMs*

In reliance on the Genetic evolution theory of EM-systems [1, 6, 11, 12, 16], allowing to obtain the results with the guaranteed completeness [12, 18, 20, 21], it is necessary to identify the search function F_{TP} 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 system S_{TP} :

1) modular design (*Mod*);
2) use of EM-systems for all type of movements (M_{EM});
3) cylindrical shape of spindles stator and rotor active surfaces $(CL_{1,2})_S$
4) several operating spindles (S_{Num})
5) fast change of spindle unit (S_{ch})

Taking into account the specified above requirements, the integral search function could be represented as a vector F_{TP} in multidimensional space R^n:

$$F_{TP} = [Mod;\ M_{EM};\ CL_{1.2};\ S_{Num}\ ;\ S_{ch}] \in R_n \qquad (2)$$

The genetic synthesis model, described on Fig. 4, corresponds to the defined F_{TP}.

This genetic model represents the search trajectories for EM-structures, which satisfies the F_{TP}. 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_{TP}:

$$k_c = P_C / F_{TP} \leq 1_n \qquad (3)$$

The electromagnetic chromosome, which satisfies the F_{TP}, has a certain genetic complexity level, which is estimated from the results of genetic analysis (Table 1).

The specified F_{TP} is satisfied by genetically higher combined hybrid chromosomes S_{7112} and S_{7223}. Their complexity degree, as well as the complexity degree of the related populations of technical solutions P_{7112} and P_{7223} , can be expressed by the following structural formulas respectively:

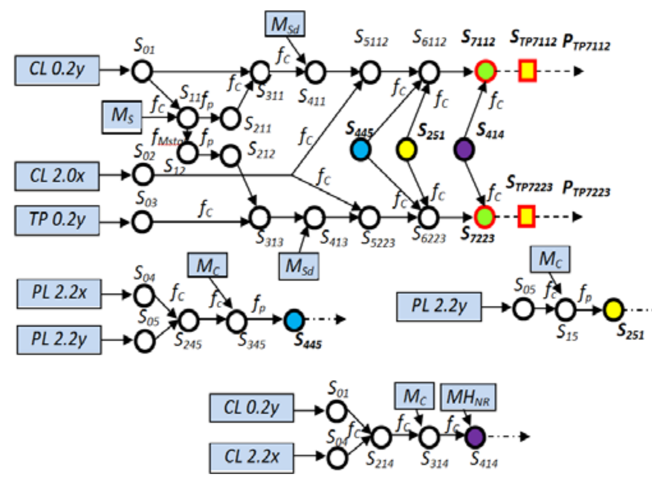

Fig. 4. *Genetic model of multiple-spindle automatic machineEM-structure synthesis using defined search function F_S(2): f_C – genetic crossing operator; S_{01} , S_{02} ,…, S_{7112}, S_{7223} – synthesized structures of electromagnetic chromosomes; S_{TP7112}, S_{TP7223} – technical solutions; P_{7112}, P_{7223} – populations of technical solutions*

$$\begin{bmatrix} (CL0.2y_1 \times CL0.2y_2)\times 4\left[(CL0.2y_1 \times CL0.2y_2)_{(R:A)} \times M_S\right]\times \\ M_{Sd}\times (CL0.2y_1 \times CL0.2y_2)_{(\beta:OZ)}\times 2\left[\left(PL2.2(x\times y)_1 \times PL2.2(x\times y)_2\right)_{(ZY)}\times M_C\right]\times \\ 2\left[(PL2.2y_1 \times PL2.2y_2)\times M_C\right]_{(R:OY)} \end{bmatrix}\times$$
$$\times\left[(PL2.2x_1 \times PL2.2x_2)\times (CL0.2y_1 \times CL0.2y_2)\times M_S \times MH_{NR}\right] \qquad (4)$$

$$\begin{bmatrix} (TP0.2y_1 \times TP0.2y_2)\times\left[(CL0.2y_1 : f_{Mstat})\times 4(CL0.2y_2 \times M_S)_{(R:A)}\right]\times \\ M_{Sd}\times (CL0.2y_1 \times CL0.2y_2)_{(\beta:OZ)}\times 2\left[\left(PL2.2(x\times y)_1 \times PL2.2(x\times y)_2\right)_{(ZY)}\times M_C\right]\times \\ 2\left[(PL2.2y_1 \times PL2.2y_2)\times M_C\right]_{(R:OY)} \end{bmatrix}\times$$
$$\times\left[(PL2.2x_1 \times PL2.2x_2)\times (CL0.2y_1 \times CL0.2y_2)\times M_S \times MH_{NR}\right] \qquad (5)$$

where:

- $CL0.2y_1$ is a genetic code of the cylindrical-shape rotating-wave primary source of electromagnetic field (stator inductor systems of spindle drum turning device and spindle-motors);
- $CL0.2y_2$ is a genetic code of the cylindrical-shape rotating-wave secondary source of electromagnetic field (rotor inductor systems of spindle drum turning device and spindle-motors);

Table 1.
Genetic analysis results of MSAM structure-creation model

Electromechanical chromosome	StructurAL formula	Chromosome status	k_c
$CL0.2y$	$CL0.2y$	Parental	-
S_{01}	$CL0.2y_1 \times CL0.2y_2$	Electromagnetic pair	-
$CL2.0x$	$CL2.0x$	Parental	-
S_{02}	$CL2.0x_1 \times CL2.0x_2$	Electromagnetic pair	-
$PL2.2y$	$PL2.2y$	Parental	-
$TP0.2y$	$TP0.2y$	Parental	-
S_{03}	$TP0.2y_1 \times TP0.2y_2$	Electromagnetic pair	-
S_{04}	$PL2.2x_1 \times PL2.2x_2$	Electromagnetic pair	-
$PL2.2x$	$PL2.2x$	Parental	-
S_{05}	$PL2.2y_1 \times PL2.2y_2$	Electromagnetic pair	-
S_{11}	$(CL0.2y_1 \times CL0.2y_2) \times M_C$	Informational	-
S_{12}	$(CL0.2y_1 : f_{Mstat}) \times (CL0.2y_2 \times M_S)$	Informational	
S_{15}	$(PL2.2y_1 \times PL2.2y_2) \times M_C$	Informational	-
S_{211}	$4[(CL0.2y_1 \times CL0.2y_2) \times M_C]_{(R:A)}$	Informational, replicated, isomer	-
S_{212}	$(CL0.2y_1 : f_{Mstat}) \times 4(CL0.2y_2 \times M_S)_{(R:A)}$	Informational, replicated, isomer	-
S_{214}	$(PL2.2x_1 \times PL2.2x_2) \times (CL0.2y_1 \times CL0.2y_2)$	Informational, hybrid, isomer	-
S_{245}	$(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(\beta: ZY)}$	Hybrid, isomer (β≠90°),	-
S_{251}	$2[(PL2.2y_1 \times PL2.2y_2) \times M_C]_{(R:OY)}$	Informational, replicated, isomer	-
S_{311}	$(CL0.2y_1 \times CL0.2y_2) \times 4[(CL0.2y_1 \times CL0.2y_2)_{(R:OX)} \times M_S]$	Informational	-
S_{313}	$(TP0.2y_1 \times TP0.2y_2) \times [(CL0.2y_1 : f_{Mstat}) \times \times 4(CL0.2y_2 \times M_S)_{(R:A)}]$	Informational	-
S_{314}	$(PL2.2x_1 \times PL2.2x_2) \times (CL0.2y_1 \times CL0.2y_2) \times M_S$	Informational	-
S_{345}	$(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C$	Informational	-
S_{411}	$(CL0.2y_1 \times CL0.2y_2) \times 4[(CL0.2y_1 \times CL0.2y_2)_{(R:OX)} \times M_S] \times M_{Sd}$	Informational	-
S_{413}	$(TP0.2y_1 \times TP0.2y_2) \times [(CL0.2y_1 : f_{Mstat}) \times \times 4(CL0.2y_2 \times M_S)_{(R:A)}] \times M_{Sd}$	Informational	-
S_{414}	$(PL2.2x_1 \times PL2.2x_2) \times (CL0.2y_1 \times CL0.2y_2) \times M_S \times MH_{NR}$	Informational	-
S_{445}	$2[(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C]_{(R:ZY)}$	Informational	-
S_{5112}	$(CL0.2y_1 \times CL0.2y_2) \times 4[(CL0.2y_1 \times CL0.2y_2)_{(R:OX)} \times M_S] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ)}$	Generating, isomer (β=90°)	0,6
S_{5223}	$(TP0.2y_1 \times TP0.2y_2) \times [(CL0.2y_1 : f_{Mstat}) \times 4(CL0.2y_2 \times \times M_S)_{(R:A)}] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ)}$	Generating, isomer (β=90°)	0,6
S_{6112}	$(CL0.2y_1 \times CL0.2y_2) \times 4[(CL0.2y_1 \times CL0.2y_2)_{(R:OX)} \times M_S] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ)} \times \times 2[(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C]_{(R:ZY)} \times 2[(PL2.2y_1 \times PL2.2y_2) \times M_C]_{(R:OY)}$	Generating	0,8
S_{6223}	$(TP0.2y_1 \times TP0.2y_2) \times [(CL0.2y_1 : f_{Mstat}) \times 4(CL0.2y_2 \times \times M_S)_{(R:A)}] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ)} \times 2[(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C]_{(R:ZY)} \times 2[(PL2.2y_1 \times PL2.2y_2) \times M_C]_{(R:OY)}$	Generating	0,8
S_{7112}	$(CL0.2y_1 \times CL0.2y_2) \times 4[(CL0.2y_1 \times CL0.2y_2)_{(R:OX)} \times M_S] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ} \times 2[(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C]_{(R:ZY)} \times 2[(PL2.2y_1 \times PL2.2y_2) \times M_C]_{(R:OY)} \times [(PL2.2x_1 \times PL2.2x_2) \times (CL0.2y_1 \times CL0.2y_2) \times M_S \times MH_{NR}]$	Generating	1,0
S_{7223}	$(TP0.2y_1 \times TP0.2y_2) \times [(CL0.2y_1 : f_{Mstat}) \times 4(CL0.2y_2 \times \times M_S)_{(R:A)}] \times M_{Sd} \times (CL2.0x_1 \times CL2.0x_2)_{(\beta:OZ)} \times 2[(PL2.2(x \times y)_1 \times PL2.2(x \times y)_2)_{(ZY)} \times M_C]_{(R:ZY)} \times 2[(PL2.2y_1 \times PL2.2y_2) \times M_C]_{(R:OY)} \times [(PL2.2x_1 \times PL2.2x_2) \times (CL0.2y_1 \times CL0.2y_2) \times M_S \times MH_{NR}]$	Generating	1,0

- $CL0.2y_1 \times CL0.2y_2$ is a pair electromagnetic chromosome of cylindrical-shape rotating-wave electromechanical energy converters (EME-converters) (drum turning device and spindle-motors); M_S is a spindle mechanical chromosome;
- M_{Sd} is a spindle drum mechanical chromosome;
- $CL2.0x_1$ is a genetic code of the cylindrical-shape forward-wave primary source of electromagnetic field of solenoid electromagnet;
- $CL2.0x_2$ is a genetic code of the cylindrical-shape forward-wave secondary source of electromagnetic field of solenoid electromagnet;
- $Cl2.0x_1 \times CL2.0x_2$ is a pair electromagnetic chromosome of cylindrical-shape forward-wave solenoid electromagnet; M_C is a planar carriage mechanical chromosome;
- $PL2.2(x \times y)_1$ is a genetic formula of plane-shape plane-parallel-wave hybrid primary source of electromagnetic field (inductors of planar carriage and spindle-motor headstocks);
- $PL2.2(x \times y)_2$ is a genetic formula of plane-shape plane-parallel-wave hybrid secondary source of electromagnetic field (inductors of planar carriage and spindle-motor headstocks);
- $PL2.2(x \times y)_1 \times PL2.2(x \times y)_2$ is a pair hybrid electromagnetic chromosome of plane-shape plane-parallel-wave EME-converters (inductors of planar carriage and spindle-motor headstocks);
- $TP0.2y_1$ is a genetic code of the planar-toroidal-shape rotating-wave primary source of electromagnetic field (stator inductor systems of toroid-shaped spindle drum turning device);
- $TP0.2y_2$ is a genetic code of the planar-toroidal-shape rotating-wave secondary source of electromagnetic field (stator inductor systems of toroid-shaped spindle drum turning device);
- $TP0.2y_1 \times TP0.2y_2$ is a pair electromagnetic chromosome of planar-toroidal-shape rotating-wave EME-converters (toroid-shaped spindle drum turning device);
- f_{Mstat} is a genetic operator of mutation concerning stator (increase of stator inner diameter comparing to outer diameter of rotor);
- MH_{NR} is a mechanical-and-hydraulic chromosome of noise reduction system.

One of the technical realization variants of the synthesized structure $\boldsymbol{S_{7112}}$ of MSAM is represented on Fig. 3a, 3b. One of the technical realization variants of the synthesized structure $\boldsymbol{S_{7223}}$ of MSAM is represented on Fig. 3c.

4. Conclusion

Consequently, the directed synthesis of innovative MSAM variants using innovative synthesis methods of hybrid EM-structures, based on the EM-systems Evolution Theory, is realized in this paper. The structural synthesis from the level of elementary sources of electromagnetic field to the level of complex combined hybrid EM-structures is done in correspondence with the defined search function. The specific variants of the technical realization are proposed for two competitive MSAM structures, obtained as a result of structural synthesis.

5. Literature

[1] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics*, 2nd ed., vol. 3, J. Peters, Ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15–64.

[2] E.P. Balashov, *Evolyutsionnyiy sintez system*, Moscow, USSR: Radio i svyaz, 1985.

[3] B.L. Boguslavskiy, *Tokarnyie avtomatyi. Osnovyi raschota, proektirovaniya i ekspluatatsii*, Moscow, USSR: Mashgiz, 1958.

[4] Y.N. Kuznetsov, L.N. Sribnyiy, *Povyishenie effektivnosti tokarnyih avtomatov*, Kiev, Ukraine: Tehnika, 1989.

[5] Y.N. Kuznetsov, “Povyishenie effektivnosti mnogoshpindelnyih tokarnyih avtomatov,” *Stanki i instrument*, no. 2, pp. 4-6, 1988.
[6] Y.M. Kuznetsov, R.A. Sklyarov, *Prognozuvannya rozvitku tehnichnih sistem: Navch. posibnik*, Y.M. Kuznetsov Ed., Kyiv, Uktraine: TOV «ZMOK» - PP «GNOZIS», 2004.
[7] Y.N. Kuznetsov, Gerra Zh.A. Hamuyela, T.O. Hamuyela, *Morfologicheskiy sintez stankov i ih mehanizmov*, Y.N. Kuznetsov Ed., Kiev, Ukraine: OOO «GNOZIS», 2012.
[8] Y.N. Kuznetsov, V.F. Shinkarenko, “Geneticheskiy podhod – klyuch k sozdaniyu slozhnyih tehnicheskih system,” *Tehnologichni kompleksy*, no. 1,2 (5,6), pp. 15 – 27, Lutsk, Ukraine, 2013.
[9] *Spravochnik po tehnologii rezanya materialov*, G. Shpur and T. Shteffle eds. Book 1, Y.M. Solomentsev ed. transl., Moscow, USSR: Mashinostroenie, 1985.
[10] *Tokarnyie mnogoshpindelnyie avtomatyi*, V.I. Chergikalo, O.I. Gurov, B.P. Davyidovich *et al.*, Moscow, USSR: Mashinostroenie, 1978.
[11] G.A. Shaumyan, *Avtomatyi i avtomaticheskie linii*, 3-rd ed., Moscow, USSR: Mashgiz, 1961.
[12] V.F. Shinkarenko, *Osnovi teorii evolyutsii elektromehanichnyh system*, Kyiv, Ukraine: Naukova dumka, 2002.
[13] V.F. Shinkarenko, “Geneticheskoe predvidenie kak sistemnaya osnova v strategii upravleniya innovatsionnyim razvitiem tehnicheskih system,” *in Proc. Pratsi Tavriyskogo derzh. agrotehn. university*, vol. 11, Part 4, Tavria, Ukraine, 2011, pp. 3-19.
[14] G. Shlezinger *Metallorezhuschie stanki. Raschot i konstruirovanie*, N.S. Acherkana i B.L. Boguslavskogo eds. transl., Part 1, Kiev, USSR: Oborongiz, 1938.
[15] G. Spur *Mehrspindel – Drehautomatem*, Müchen, Germany: Carl Haser Verlag, 1970.
[16] G. Spur, “Greschichtlicher Rückblick anf die konstruktive Entwicklung der Mehrspindel – Drehantometen,” *Werkstatt and betrib*, no. 100, vol. 3, pp. 202-210, 1967.
[17] V. Shynkarenko, Y. Kuznetsov, “Interdisciplinary approach to modeling and synthesis of difficult technical systems,” *Journal of the Technical University Gabrovo*, vol. 52, pp. 24-28, 2016.
[18] Ibrahem Farhan Salman Alrefo, Y.N. Kuznetsov, “Evolution and genetic forecasting of multispindle automatic lathe development” *Visnyk of Kherson National Technical University*, Kherson, Ukraine, vol. 2(57), pp. 17-22, 2016.
[19] V. Shynkarenko, Y. Kuznetsov, A. Salenko, Iu. Gaidaienko, E. Oleynik, O. Chenchevaya, “Genetic program of structural evolution and synthesis of spindle-motor hybrid electromechanical systems,” *Journal of the Technical University of Gabrovo*, vol. 48, pp. 15 – 19, 2014.
[20] Mnogoshpindelnyie tokarnyie avtomatyi [Online]. Available: http:// www.tajmac-zps.cz/ru/node/542.
[21] V.F. Shinkarenko, A.A. Shimanskaya, Y.V. Gaidaienko, “Strukturnyiy sintez slozhnyih elektromashinnyih agregatov s ispolzovaniem ih geneticheskih programm,” *in Proc. of National. techn. university "HPI" : Elektrychni mashini ta elektromehanichne peretvorennya energii*, Kharkiv, Ukraine: NTU "HPI", no. 11 (1183), pp. 93-101, 2016.
[22] Shynkarenko V., Gaidaienko Iu., Ahmad N. Al-Husban, “Decoding and functionalAnalysis of genetic Programs of Hybrid Electromechanical Structures,” *Modern Applied Science*, vo.l 8, no. 2, 2014.