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GENETIC SYNTHESIS OF HYBRID ELECTRO-MECHANICAL SYSTEMS FOR MOTOR-SPINDLE UNITS WITH ADAPTIVE SPATIAL STRUCTURE

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ABSTRACT

The results of fundamental research carried out at the Department of Electromechanics of KPI named after Igor Sikorsky, it was established that the structural organization and evolution of arbitrary classes of technical systems that function on the principles of electromechanical energy conversion is determined by the principles and laws of genetically organized systems. Motor-spindles (M-Ш) also belong to the category of such systems. The energy and genetic core of technical systems with electromechanical energy converters is the active zone of the energy converter, which is a physical and information carrier of genetic information and the corresponding genetic code. The trend of creating multi-coordinate motor-spindle units with a spatially adaptive structure, designed to function as part of metalworking centers and machines with digital control systems, is analyzed. In genetically organized systems, the processes of structuring objects of any level of complexity are implemented on the basis of the elemental information base of genetic programs using genetic synthesis operators. From the point of view of the theory of genetic structure formation, spatial adaptation is the result of chromosomal transformations using the principles of hybridization, mutation, replication, and isomerism. The problem of synthesizing a hybrid multifunctional EM structure for motor-spindle units with a spatially adaptive modular structure was formulated and solved. A generalized genetic model of chromosomal synthesis of hybrid electromechanical modules of motor-spindle units according to a given function has been developed. The structural formulas of hybrid electromagnetic chromosomes, which determine the population structure of original technical solutions, have been determined. Based on the simulation results, the structures of spatially adaptive motor-spindle units with two-, three-, and four-coordinate movement of the working body were synthesized. Based on the results of the research, a genetic catalog was created, which serves as a system basis for the development of original technical solutions for motor-spindle units.

1. INTRODUCTION

Multi-coordinate processing using motor-spindles plays an important role in modern technologies for the production of complex and knowledge-intensive products, the volumes and scope of which are constantly growing. Compared to classic motor-spindles, multi-coordinate machining is becoming more and more popular and popular. The ability to change the orientation of the tool in the process of processing during one installation provides a significant benefit. The volume of interoperational change and transportation of parts is reduced, since more operations are performed simultaneously. The number of items and the complexity of machine tools, as well as the time of the technological process, are reduced. These trends determine the relevance of the problem of synthesis of electromechanical systems (EM-systems) for a new generation of motor-spindle units (MSU) with an adaptive spatial structure.

2. RELEVANCE OF THE WORK

The analysis of modern trends in the evolution of motor-spindles (M-S) shows that one of the promising directions for their improvement is the creation of multi-coordinate motor-spindle units designed to function as part of metalworking centers and machine tools with digital control systems [1]. Multi-coordinate processing is considered the elite of metalworking processes. Leading manufacturers of modern M-S create a wide range of innovative high-tech products to meet the highest requirements of digital automated production. Recently, motor-spindle units with a spatially adaptive structure of drive EM systems, which implement complex multi-coordinate movements of the working body, have become widely used. Such units are used for specialized, universal and general processing of complex parts and assemblies. From the point of view of the theory of genetic structuring, multicoordination is the result of chromosomal transformations using the principles of hybridization,

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mutation, replication, and isomerism [2-5]. The discovery of the law of hybridization creates fundamentally new opportunities for structural prediction, system analysis, and synthesis of new classes and types of complex hybrid EM structures. Synthesis using the technology of genetic prediction is accompanied by a guaranteed innovative effect. Therefore, the methodology of innovative synthesis is a key element in the concept of creating knowledge and transforming it into material values that are consumed by society. The possibility of identifying the structure and information of the genetic core of an arbitrary representative of M-Sh opens up the possibility of determining their genetic programs of structure formation according to the methodology of genetic analysis of electromechanical systems. The purpose of the study is to develop and test the methodology of multi-level genetic synthesis of hybrid motor-spindle units with a spatially adaptive modular structure, which provide multi-coordinate movement of the working body.

3. MATERIAL AND RESEARCH RESULTS

Principles of structuring EM objects of multi-coordinate motion. In genetically organized systems, the processes of structure formation of objects of any level of complexity are implemented on the basis of elementary information base of genetic programs using genetic synthesis operators. In the concept of genetic evolution, the historically created diversity of electromechanical objects is considered as the result of hereditary structure formation on a finite set of elemental basis, which is ordered by the periodic structure of the genetic classification (GC) of the primary sources of the electromagnetic field. Genetic models of structural synthesis belong to the class of nature-like models that reproduce optimal synthesis trajectories of electromechanical structures (EM-structures) according to a given synthesis function. The synthesis methodology at the chromosomal level significantly simplifies the search procedures, ensures the localization of the search space, operates with prognostic information and guarantees the completeness of the synthesized structures with the corresponding emergent effect.

Hybridization is one of the most productive mechanisms of structure formation in the evolution of genetically organized systems of natural and anthropogenic origin. The genetic nature of hybrid structures is determined by the invariant properties of the primary sources of the electromagnetic field (electromagnetic chromosomes, isomorphic to the concept of biological chromosomes), which perform the function of the elemental information base in the periodic structure of the GC. The theoretical basis of the structure formation of hybrid EM - structures is the law of hybridization of electromagnetic chromosomes [2]. The principles of chromosomal crossovers are determined by the structure of the universal genetic codes of electromagnetic chromosomes and their location in the periodic structure of the GC. The mathematical basis of crossings is determined by the rules of combinatorics, taking into account the type and number of components of genetic information to be crossed. The reliability of genetic principles and models of hybrid structure formation and their correspondence to the real processes of technical evolution of electromechanical objects are confirmed by the results of numerous evolutionary experiments. The methods of genetic analysis identified and confirmed the presence of structural representatives of all seven legally defined hybrid classes of electromechanical objects in the technical evolution, which testify that the technical evolution of electromechanical objects is carried out in strict accordance with the genetic principles of structural and informational hybridization. Experiments show that the structural evolution of hybrid electromechanical objects is still at the initial level, where structural representatives of only 5% of the species allowed by law are involved. The basis of the structuring of multispindle units of the modular type is the replication and isomerism operators, which, in combination with the crossover and structural mutation operators, determine a wide range of their spatial compositions in modern machine tool construction. Multi-spindle units can have different layout schemes in the three-dimensional space R^3, which determine the spatial orientation and functional capabilities of the working heads of the spindles.

Synthesis of the genetic model. The main task of the exploratory design stage is to determine the microgenetic program based on a given integral function synthesis of F_S. The initial information for the formulation of the task of innovative synthesis of hybrid MSU is the results of the analysis of the space of admissible crossings for the class of geometric hybrids G and the class of GTE polyhybrids (Fig. 1). According to the results of previous studies based on the law of hybridization and evolutionary experiments, it was established that the genetically permissible variety of hybrid structures of the class of geometric monohybrids is limited to a chromosomal set of 90 hybrid chromosomes, and of the class of polyhybrids to 210 chromosomes. The vast majority of species - descendants of the specified classes belong to the implicit category (genetically determined, but not yet involved in the technical evolution of machine tool construction). We specify the task of synthesizing a hybrid multifunctional EM structure using the example of creating aggregate-module motor-spindles.

We specify the task of synthesizing a hybrid multifunctional EM - structure using the example of creating aggregate-module motor-spindles type that combines the functions of a rotary table and a high-speed spindle. The integral function of F_S synthesis of hybrid structures must take into account the following set of partial requirements: 1. Provision of the main high-speed traffic MSU (ω_{OZ}). 2. Provision of controlled orthogonal turning movement MSU (ω_{OX}). 3. The possibility of implementing the managed *OX* reciprocating motion MSU ($\pm V_{OX}$). 4. The possibility of implementing additional controlled *OZ*-progressive MSU movement ($\pm V_{OZ}$). 5. Aggregate-modular principle of technical implementation (K_{AM}). 6. Ensuring the dynamic stiffness of the MSU structural composition ($k \to max$). 7. Implementation of the modular principle of construction of the main components of the unit ($\sum M$).

In order to reduce the dimensionality of the search space, we will impose the following restrictions on the search area R^n: the search is carried out in the subject area of the primary elements of the first major period of the generative system *GC*; only the electromechanical principles of implementation of given spatial movements are considered; the search space R^n is limited by macrogenetic programs of hybrid classes *G* and *GTE*. Taking into account the specified requirements and restrictions, the integral function of the synthesis in the multidimensional search space R^n of the subject area of the *GC* takes the following form:

$$F_S = (\omega_{OZ};\omega_{OX};\pm V_{OX};\pm V_{OZ};K_{AM};k \to max;\sum M) \subset Rn \quad (1)$$

One of the essential advantages of the theory of chromosomal structure formation is that the researcher operates with the information of a finite set of genetically determined elementary structures, which is endowed with a prognostic function. The given set of partial F_S requirements makes it possible to localize the search space within the informational and structural basis of genetic classification (Table 1).

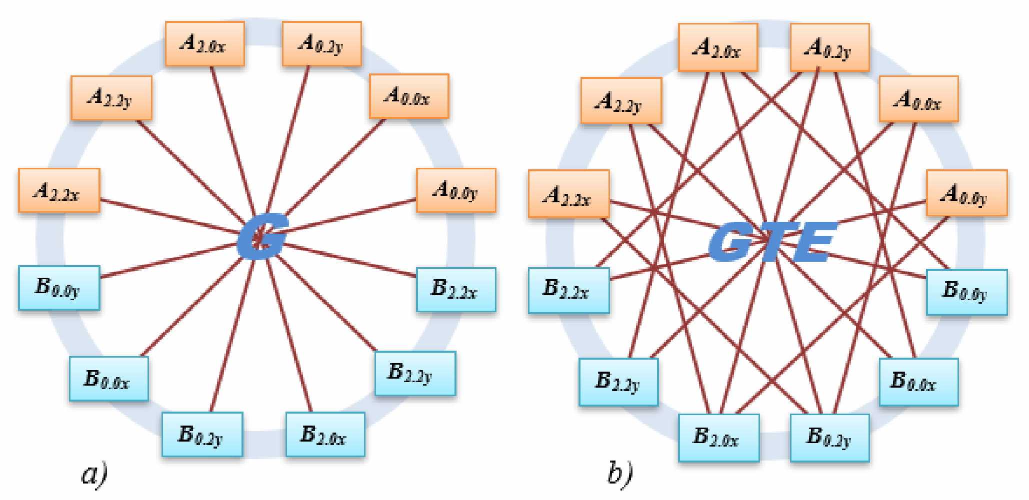


Fig. 1. The space of genetically permissible crossings of electromagnetic chromosomes: a) for the structures of geometric monohybrids of the class G; b) for the polyhybrid structures of the class GTE

Since the area of synthesis is limited to hybrid classes *G* and *GTE*, as well as taking into account partial requirements 4–7, the procedure of synthesis of the genetic model is carried out using parental chromosomes with the maximum genetic predisposition to F_S requirements: *CL 0.2y* – for the implementation of the main movement motor-spindle module and for the synthesis of the *OZ* module - submissions; *TP 0.2y* – for the synthesis of the rotary module; *CL 2.0x* – for the synthesis of the *OX* supply module.

Taking into account the specified limitations, the given integral function F_S is matched to the generalized genetic model of chromosomal hybridization (Fig. 2).

Analysis of simulation results. The generalized genetic model visualizes the multi-level trajectory of the gradual complication of the genetic information of the original parental chromosomes, according to the principle "from simple to complex", in the F_S search space, using the genetic operators of crossover, mutation and replication. Chromosomes of each subsequent level store the information of previous levels, which are supplemented with new ones.

Synthesized chromosomes perform the function of generating technical solutions for the relevant populations: P_{01} – monohybrid 2-coordinate EM-structures; P_{02} – populations of technical solutions with polyhybrid 3-coordinate MSA; P_{03} – populations of technical solutions from monohy - by boring 3-coordinate MSU; P_{04} – populations of technical solutions with polyhybrid 4-coordinate MSU. The results of genetic analysis of chromosome synthesis procedures are summarized in Table 1.

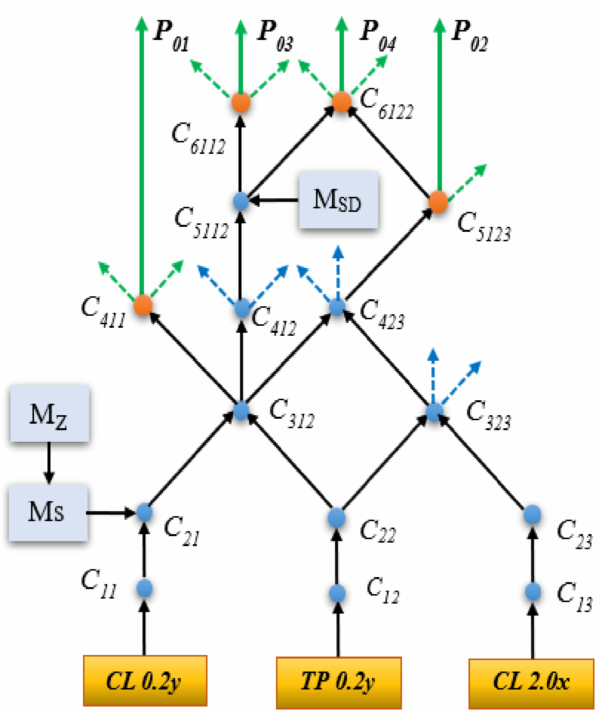


Fig. 2. Generalized genetic model of the synthesis of hybrid EM - structures of a multi-coordinate motor-spindle unit according to a given F_S: CL 0.2y, TP 0.2y, CL 2.0x – parental electromagnetic chromosomes; C_{11}, C_{12}, ..., C_{6123} – chromosomal set of the microgenetic program; Ms – module of the spindle assembly; Mz – module of the clamping device; M_{SD} – screw transmission module; C_{412}, C_{5123}, C_{6112} and C_{6122} – generative chromosomes of the respective populations of technical solutions P_{01}, P_{02}, P_{03}, P_{04}

***Table 1** Results of deciphering the microgenetic program of hybrid EM systems for multifunctional motor-spindle units*

Chromosome	Structural formula of the synthesized chromosome	Electromagnetic chromosome status
C_{01}	$(CL\ 0.2y)_1$	Parental, primary
C_{02}	$(TP\ 0.2y)_1$	Parental, primary
C_{03}	$(CL\ 2.0x)_1$	Parental, primary
C_{11}	$(CL\ 0.2y)_2$	Secondary, informative
C_{12}	$(TP\ 0.2y)_2$	Secondary, informative
C_{13}	$(CL\ 2.0x)_2{:}M_{OX}$	Secondary, mutated, informative
C_{21}	$(CL0.2y)_1{:}(CL0.2y)_2{\times}M_S{\times}M_Z$	Even, combined with M_S and M_Z, informative
C_{22}	$(TP\ 0.2y)_1{:}(TP\ 0.2y)_2$	Paired, informative
C_{23}	$(CL\ 2.0x)_1{:}(CL\ 2.0x)_2{:}M_{OX}$	Paired, mutated, informative
C_{312}	$[(CL0.2y)_1{:}(CL0.2y)_2{\times}M_S{\times}M_Z]{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]$	Monohybrid (isomer), informative
C_{411}	$[(CL0.2y)_1{:}(CL0.2y)_2{\times}M_S{\times}M_Z]_{OX}{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]_{OZ}$	Monohybrid (class ***G***), reproductive
C_{412}	$[2(CL0.2y)_1{:}(CL0.2y)_2{:}R_{OZ}{\times}M_S{\times}M_Z]{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]$	Replicated (isomer), informative
C_{423}	$[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]{\times}[(CL\ 2.0x)_1{:}(CL\ 2.0x)_2{:}M_{OX}]$	Polyhybrid (isomer), informative
C_{5112}	$[2(CL0.2y)_1{:}(CL0.2y)_2{:}R_{OZ}{\times}M_S{\times}M_Z{\times}M_{ZD}]{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]$	Monohybrid, combined with M_{ZD}, informative
C_{5123}	$[(CL0.2y)_1{:}(CL0.2y)_2{\times}M_S{\times}M_Z]_{OX}{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2{\times}(CL\ 2.0x)_2{:}M_{OX}]_{OX}$	Polyhybrid (class ***GTE***), reproductive
C_{6112}	$[2(CL0.2y)_1{:}(CL0.2y)_2{:}R_{OZ}{\times}M_S{\times}M_Z{\times}M_{ZD}]{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2]$	Monohybrid (class ***G***), reproductive
C_{6122}	$[2(CL0.2y)_1{:}(CL0.2y)_2{:}R_{OZ}{\times}M_S{\times}M_Z{\times}M_{ZD}]{\times}[(TP\ 0.2y)_1{:}(TP\ 0.2y)_2{\times}(CL\ 2.0x)_2{:}M_{OX}]_{OX}$	Polyhybrid (class ***GTE***), reproductive

Analysis of synthesis results. The technical implementation of the hybrid modular MSU makes it possible to realize its following advantages: – provision of two-, three- and four-coordinate functioning of MSU; - main rotational movement relative to the OZ axis with the possibility of changing the angular position of the spindle relative to the OX axis based on a toroidal flat motor *TP 0.2y*; – the implementation of the modular principle of layout using the main movement modules M_1, the module OX- rotation M_2, the OX - feed modules M_3 and the OZ - feed M_4; – provision of increased rigidity modular unit. Synthesized structural diagrams of multi-coordinate motor-spindle units, which are represented by synthesized structures of populations P_{01}, P_{02}, P_{03} and P_{04}, serve as intellectual prompts for the synthesis of their possible technical implementations.

According to the simulation results, the structural formulas of hybrid chromosomes (C_{411}, C_{5123}, C_{6112}, C_{6122}), with the status of generative ones were determined, which satisfy the integral function of synthesis and determine the directions of structure formation of the corresponding populations of technical solutions. One of the variants of the technical implementation of the synthesized structure of the MSU (chromosome C_{5123}) is presented in Fig. 3.

Based on the results of the synthesis, a genetic catalog of structural variants of multi-coordinate spindle units with a spatially adaptive structure was developed, which serves as a system basis for the development of competitive technical solutions (Table 2).

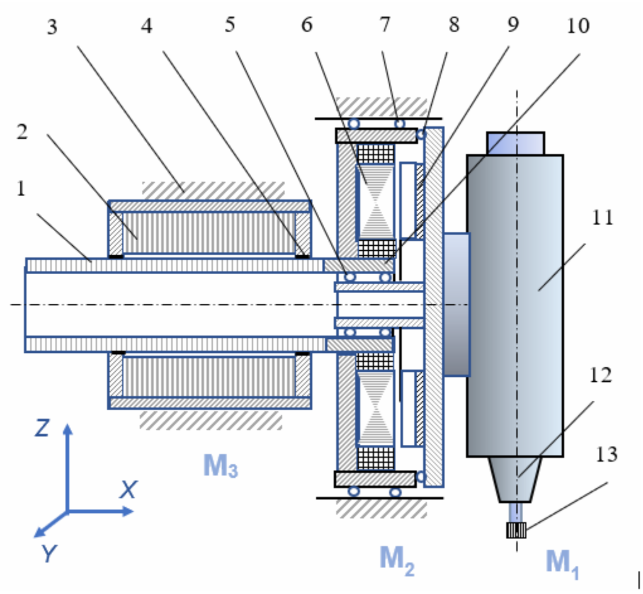
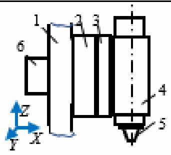
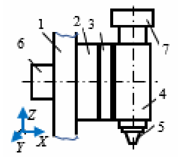
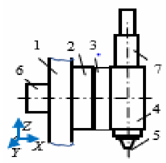
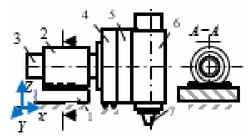
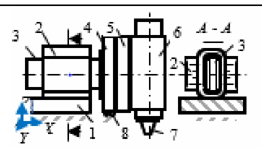
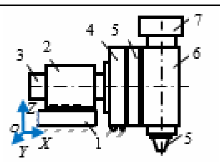
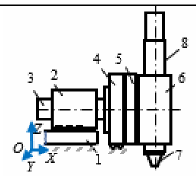
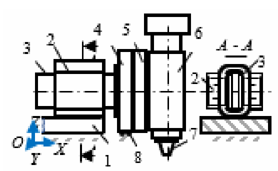


Fig. 3. A variant of the genetically synthesized three-coordinate MSA with an adaptive spatial structure

***Table 2** Genetic catalog of synthesized structures of multi-coordinate motor-spindle units with an adaptive spatial structure (fragment of the catalog)*

	A combination of modules	A type of spatial movement	Spatially adaptive structure	Hybrid EM-system status
Two-coordinate movement units				
P_{01}	M_1, M_2	$(\omega_{OZ}; \pm\omega_{OX})$		Geometric monohybrid ***G*** class
Units of three-coordinate movement				
P_{03}	M_1, M_2, M_4	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OZ})$		Geometric monohybrid ***G*** class
P_{031}	M_1, M_2, M_5	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OZ})$		Geometric monohybrid ***G*** class
P_{02}	M_1, M_2, M_3	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OZ})$		Intergeneric polyhybrid ***GTE*** class
P_{021}	M_1, M_2, M_6	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OZ})$		Intergeneric polyhybrid ***GTE*** class
Four-coordinate movement units				
P_{04}	M_1, M_2, M_3, M_4	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OX}; \pm V_{OZ})$		Intergeneric polyhybrid ***GTE*** class
P_{041}	M_1, M_2, M_3, M_5	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OX}; \pm V_{OZ})$		Intergeneric polyhybrid ***GTE*** class
P_{042}	M_1, M_2, M_4, M_6	$(\omega_{OZ}; \pm\omega_{OX}; \pm V_{OX}; \pm V_{OZ})$		Intergeneric polyhybrid ***GTE*** class

4. CONCLUSIONS

According to the research results, the methodology of multi-level genetic synthesis of hybrid electromechanical structures was developed and tested, and their structural schemes were developed using the example of multi-coordinate motor-spindle units with an adaptive spatial structure, which are intended to function as part of intelligent metalworking centers. The developed genetic catalog of multi-coordinate spindle assemblies with a spatially adaptive structure performs the function of a system.

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