CURRENT STATUS AND DEVELOPMENT PROSPECTS OF MOTOR-SPINDLES FOR MACHINE TOOLS

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Abstract
The materials of the article show the global trend for high-speed processing on machine tools, which consists in the transition from multi-link drives of the main rotary movement to a single-link drive, where the spindle unit of the machine tool is made in the form of a motor-spindle, the stator of which is the body of the spindle unit, and the rotor is the spindle. Currently, self-acting motor-spindles that perform rotational and longitudinal forming movements are not manufactured. It was possible to combine these movements in the motor-spindle design thanks to the universal genetic crossing operator, which made it possible to move to hybrid systems, which became the object of this research.

Keywords: patent search, genetic data bank, structural and genetic analysis, motor-spindle.

INTRODUCTION

One of the main units of machine tools, which provides form-forming movements in the process of cutting on lathes, drilling, milling, assembly, grinding and other machines with rotary movement of the part or tool, has always been the spindle unit, as the main movement drive. Over time, during the evolution of spindle unit, the kinematic chain from the energy source to the output link (part or tool) was shortened and turned into a single node that unites the energy source, energy converters, transmission-amplifying circuits and the executive body - a spindle with a clamping device for the part or instrument as a whole. These are electric spindles, which have recently been called motor-spindles (M-S). M-S is considered as one of the main elements [7] representing the machine and becomes a key object on the way to the transition to smart production, where intelligent machines, systems and networks are able to independently exchange information and respond to it, manage industrial production processes. Scientists and industrialists faced the challenges of the fourth industrial revolution "Industry 4.0" [9] and the fifth "Industry 5.0", which is already approaching. The *purpose of the research* is to determine the macrogenetic program of structure formation of the M-S functional class for machine tools systems, experimental confirmation and development of a strategy for the practical use of its innovative potential.

EXPOSITION

The current state was assessed based on the results of information search [8] and analysis of open access information resources (patents, catalogs, prospectuses of international specialized exhibitions, information digests, etc.). The database contains organized information about leading European research institutions, companies and manufacturers of modern motor-spindles (Germany, Switzerland, Italy, as well as developers and manufacturers of Japan, China and Taiwan), the products of which are intended for CNC machine tools, machining centers and special purpose machine tools.

According to the results of the search, it can be stated that M-S are being researched and developed in many countries, but most of all in Germany, Italy, the USA, China, Ukraine and Russia. In Ukraine, the development and research of high-speed SHV and M-S have been engaged in since the 80s of the last century, and a candidate's dissertation was prepared on self-acting M-S using a system-morphological and genetic approach [10-12].

It should be noted that China became interested in and began to engage in M-S much later than other countries with a high intensity of development, research, acquisition of rights to them and their commercialization with the advantage of technology transfer to other countries of the Eurasian and American continents. About 10 years ago, intelligent M-S [7] became the object of research due to improved sensor sensors and executive mechanisms, development of data processing algorithms, artificial intelligence technologies, management, strategies for monitoring the state of the machine tool and the cutting process, as well as maintenance. Thanks to the use and integration of intelligent M-S, it became possible for developers, and this is already predicted by scientists, to combine them into supersystems at the level of an intelligent machine tool of the "Smart Machine Tool" type on a modular basis, and then to combine the machine tools into an intelligent "Smart Zavod". This is evidenced by the latest information on the Internet and the catalogs of leading manufacturers of M-S.

Based on the results of the patent information search, an information database (control sample) was formed, which consists of 104 objects (power of the control sample of evolutionary events of the N_{PK} = 104). The geography of patent holder countries within the control sample is represented by 9 countries (Fig. 1).

The leading manufacturers of modern M-Sh are such countries as: Japan (JP), Germany (DE), France (FR), China (CN), Italy (IT), Russia (RU). The most famous manufacturers in these countries are: DMU, ELTE, Franz Kessler, Weiss, Diebold, Antecs, Cytec, Henninger, IMT, NSK, FANUC, KITAGAWA, HOWA, SUDA, SIEMENS, SAUTER, GRUNDFOS, DUPLOMATIC, SMW AUTOBLOC and others.

It has been established that there are more than 300 manufacturing companies operating in Germany, which manufacture up to 400 names of M-S for various machines (milling, turning, grinding, multi-purpose, woodworking and special purpose). A typical structure of M-S is shown in Fig. 2.

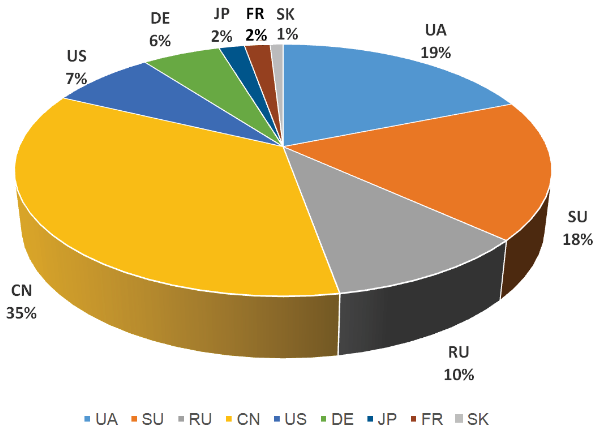

Fig. 1. Proportion of patent holder countries within the control sample

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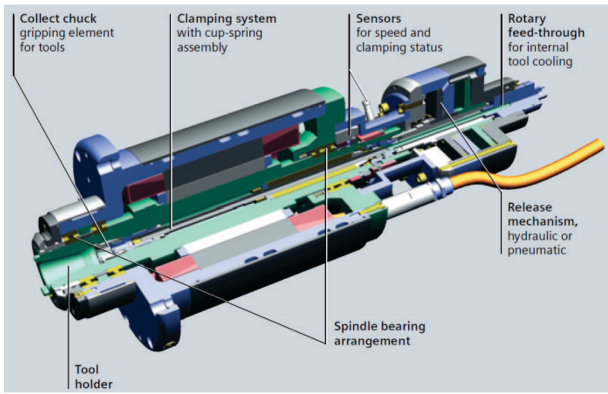

Fig. 2. Typical structure of SIEMENS motor-spindles

Chinese state structures, scientists and industrialists with the involvement of specialists from other countries of the world, in particular from Europe and the USA, pay great attention to the design, research and production of M-S, including intellectual ones (Fig. 3) [7].

In the intelligent M-S, its technical and economic efficiency is optimized taking into account the rate of tool wear, the stability of the cutting process, thermal deformations, the service life of the bearings, etc. Thus, intelligent M-S are characterized by a transition from independent state control and control systems to a single control system that surpasses a single controller from the point of view of processing productivity, quality of parts and reliability of operation.

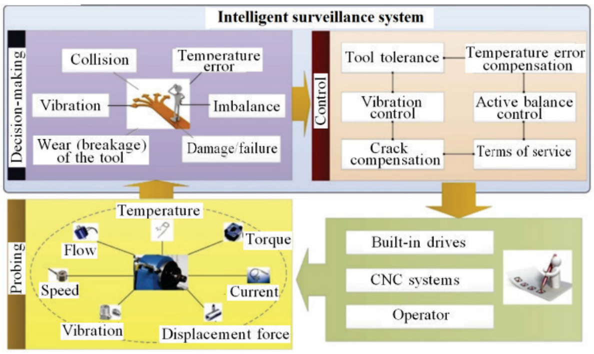

Fig. 3. *System architecture and work processes of intelligent spindles*

Development prospects. The results of previous studies have 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 (GOS) [1]. The genetic and energy core of such systems is the active zone of the electromechanical energy converter (electric motor, generator), which is the physical carrier of genetic information and genetic code. The possibility of identifying the structure and information of the genetic core of an arbitrary representative of M-S opens up the possibility of determining their genetic programs of structure formation according to the methodology of genetic analysis of electromechanical systems [2, 3].

The results of structural and genetic analysis show that the current level of technical implementation of M-S characterizes them as a complex electromechanical system that integrates components of different physical and genetic nature (Fig. 4).

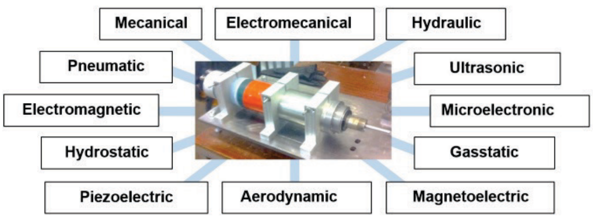

Fig. 4. *The main subsystems involved in the structuring of the functional class of motor-spindles for machine tools*

Taking into account the results of genetic analysis to determine the genetic predisposition of electromagnetic chromosomes to the implementation of given partial functions, the structure of the macrogenetic program of functional class M-S can be represented by the following horizontal homologous series of parental electromagnetic chromosomes:

$P_{MS} = (H_{00y}, H_{00x}, H_{02y}, H_{20x}, H_{22y}, H_{22x})$,

where:

H_{00y} = (*CL0.0y*, *KN0.0y*, *PL0.0y*, *TP0.0y*, *SF0.0y*, *TC0.0y*);

H_{00x} = (*CL0.0x*, *KN0.0x*, *PL0.0x*, *SF0.0x*);

H_{02y} = (*CL0.2y*, *KN0.2y*, *PL0.2y*, *TP0.2y*, *SF0.2y*, *TC0.2y*);

H_{20x} = (*CL2.0x*, *KN2.0x*, *SF2.0x*);

H_{22y} = (*CL2.2y*, *KN2.2y*, *PL2.2y*, *TP2.2y*, *SF2.2y*, *TC2.2y*);

H_{22x} = (*CL2.2x*, *KN2.2x*, *PL2.2x*, *SF2.2x*).

Taking into account the genetic equivalence of the components of the genetic information of the parental chromosomes of group 2.2 (*PL2.2y* = *PL2.2x*, i *SF2.2y* = *SF2.2x*), the finite set of generative structures of the functional class of M-S in the macrogenetic program is represented by 27 electromagnetic chromosomes of the basic level.

Genetic programs are system carriers of prognostic information [4]. The element-informational basis of the macrogenetic program for the structure formation of the functional class M-S determines the finite set of genetically admissible generative structures (electromagnetic chromosomes) C_G, which contains information about the historically involved structures - descendants (Species) of C_H and prognostic information about the structures of latent C_F Species that are not yet available currently the evolution of the class. The following relation holds true for a macrogenetic program of an arbitrary functional class: $C_G = C_H + C_F$.

If C_G is unambiguously determined by methods of genetic analysis based on the element-informational basis of the periodic system of electromagnetic elements, the function of which is performed by the genetic classification of primary sources of the electromagnetic field, then the determination of the C_H component is carried out according to the data of a patent-information search, the results of which are equivalent to the statement of evolutionary experiments and are drawn up in the form of genetic data bank (GDB) (Fig. 5) [5]. The presence of C_G and C_H components is sufficient to determine the prognostic potential of the C_F component.

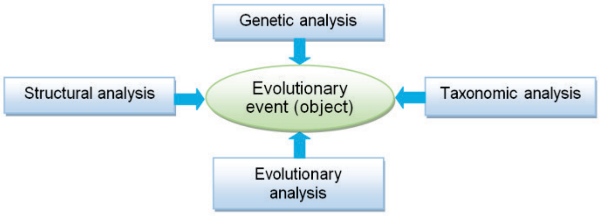

Fig. 5. *Components of the structural and system methodology for the analysis of objects presented in the GDB structure*

According to the results of the information analysis, patents were selected from the general array of patent information, which were selected to form a control sample of objects. The selection criteria were: originality of technical solutions; maximum coverage of the historical period of M-S evolution; taxonomic completeness of the sample; availability of innovative solutions; maximum coverage of the population diversity of the research object.

According to the data of the structural analysis, the following were determined: the structure of the object; the structure of the drive motor as a carrier of genetic information (geometry and topology of the active surface, the number and type of windings, the presence of auxiliary electromagnetic and electromechanical systems); type and kinematics of spatial movement (rotational, translational, reciprocating, helical, etc.); physical nature and function of auxiliary nodes and subsystems M-S, availability of innovative technical solutions; emergent effect.

Genetic analysis methods for each evolutionary event were used to determine: components of genetic information of drive and auxiliary electric motors (spatial geometry of the active surface; group of electromagnetic symmetry and topology of the generative electromagnetic chromosome); the universal code of the electromagnetic chromosome, which identifies the genetic structure of the drive motor; the presence and type of genetic synthesis operators (replication, crossover, inversion, crossing over and mutation), the totality of which determines the level of genetic complexity of the object's functional structure; the genetic status of the object, which determines its belonging to the corresponding genetically determined classes - intersystem hybrids, monohybrids, dihybrids, polyhybrids, twin objects, etc.; the genetic formula of the structure of the object, which includes the genetic code of the electromagnetic chromosome, operators of chromosomal adaptation, as well as components of subsystems of a different genetic nature.

The genetic formula determines the level of genetic complexity of the structure of the object, the combinatorics of genetic operators, which form the basis for the further development of chromosome theory and the development of algorithms for directed genetic synthesis; belonging to the corresponding period, group and subgroup in the periodic structure of the genetic code (GC), which allows the identification of other genetically and functionally related objects.

Based on the results of the ***evolutionary analysis***, the following were determined: the priority date of the corresponding evolutionary event; object evolution time; belonging of the object to the relevant population. Based on the results of the ***taxonomic analysis***, the main systematic units of genosystematics of the studied class M-S were determined, which identify the EM object's belonging to the corresponding Genus, Species and horizontal homologous series of the periodic structure of the genetic code, as well as belonging to a specific structural population of the corresponding Species.

Based on the results of the GDB analysis, it was established that the technical evolution of the M-S class is carried out in accordance with their genetic programs. Currently, structural populations of 8 species of the basic level (29.6%) with 27 genetically admissible by the genetic program are involved in the evolution of the class (Fig. 6). The majority of genetically admissible species (70.4%) have the status of implicit, i.e., not yet present in the M-S class of evolution.

GDB belong to a fundamentally new type of intellectual products, analogues of which currently do not exist in the field of technical sciences. The GDB of the M-S functional class contains the results of the genetic, structural, taxonomic and evolutionary analysis of each evolutionary event (within the control sample), systematized in chronological order, with an indication of the priority, the source of information and a graphic representation of the object (Fig. 7) [6] . The structure of GBD is open for expansion of the research object, clarification and updating of data.

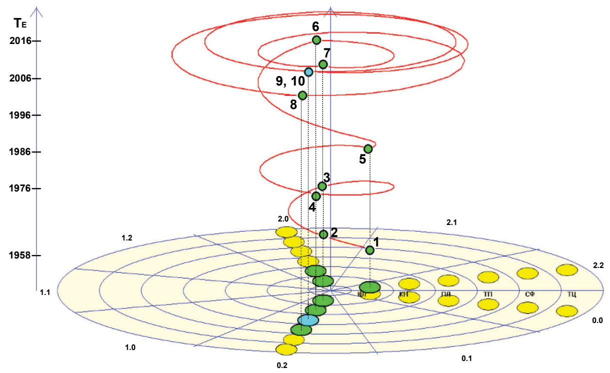

Fig. 6. *Model of macroevolution of motor spindles at the Species level (TE = 64 years)*

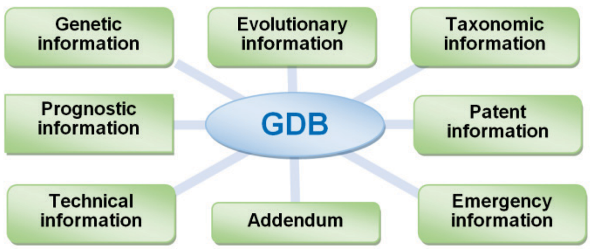

Fig. 7. *Components of the information arrays of the genetic data bank M-S for machine tools*

Such information systems are designed for the accumulation, storage and analysis of genetic information about the structural diversity of objects that have already been used within a certain historically determined period of their technical evolution. The information arrays of the GDB, supplemented by the analysis of genetic programs, open the possibility of implementing the technology of genetic prediction and innovative synthesis at the level of new Species, populations, or individual objects of this class.

CONCLUSION

1. The results of a comparative analysis of macrogenetic programs of structure formation with the data of evolutionary experiments on the functional class M-S confirm the reliability of the provisions of the theory of genetic evolution of technical systems and open the possibility of obtaining unique information about the principles of their structure formation, the directions and rates of their evolution, and the strategy of using hidden innovative potential class
2. The structural diversity of modern M-S belong to the class of genetically organized systems with a clearly expressed genetic core, which can structurally and functionally combine in various combinatorial variants subsystems and nodes of different physical and genetic nature (electromechanical, electromagnetic, mechanical, electronic, hydraulic, pneumatic, ultrasonic, optical, gas-magnetic, laser, etc.).
3. The results of genetic, evolutionary and taxonomic analysis and the data of evolutionary experiments testify to the genetic principles of structural organization and evolution of the functional class M-S and confirm the fundamental provisions of the theory of genetic evolution of technical systems.
4. For the first time, the macrogenetic program of the M-S functional class was defined, based on the results of its analysis, it was established that the genetically permissible structural diversity of M-S is limited to 5 genera and 27 species of the basic level (excluding species - twins and hybrid species).
5. According to the results of a joint analysis of the genetic program and the data of evolutionary experiments presented by the GDB, it was established that currently only 29.6% of the genetically permissible composition of their basic Species is involved in the evolution of the M-S functional class.
6. The created GDB for the motor-spindle class is a unique informational and intellectual product, as it contains the largest amount of evolutionary events and systematized genetic and prognostic information within a specific functional class of technical objects. There are currently no analogues of similar systems in technical sciences.
7. The availability of prognostic information regarding implicit Species M-S, not yet involved in evolution, is the subject of their further structural analysis and creates prerequisites for the transition to the strategy of managed innovations, based on the effective use of the hidden structural potential of their genetic programs.

REFERENCE

[1] Shynkarenko V.F. Osnovy teorii evoliutsii elektromekhanichnykh system / V.F. Shynkarenko. – K.: Naukova dumka, 2002. – 288 p.

[2] Shynkarenko V. Genetic Foresight in Science and Technology: from Genetic Code to innovative Project. 10th Anniversary International scientific Conference «Unitech'10». 19 – 20 November 2010. Gabrovo, Bulgaria.Vol.III/ p.p. 297-302.

[3] Shinkarenko V., Kuznietsov Y. Genetic Programs of Complex Evolutionary Systems (Part 1). 11th Anniversary International scientific Conference «Unitech'11», 18 – 19 November 2011. Gabrovo, Bulgaria.Vol. I. p.p. 33-43.

[4] Shynkarenko V.F. Henetycheskoe predvydenye kak systemnaia osnova v stratehyy upravlenyia ynnovatsyonnым razvytyem tekhnycheskykh system. Pratsi Tavriiskoho derzhavnoho ahrotekhnichnoho universytetu. Vyp. 11, tom 4, 2011. – S. 3 – 19.

[5] Shynkarenko V.F., Shvedchikova I.A., Kotlyarova V.V. Evolutionary Experiments in Genetic Electromechanics. 13 th Anniversary International scientific Conference «Unitech'13», 22 – 23 November 2013. Gabrovo, Bulgaria. Vol. III, 2013. – P.p. 289 – 294.

[6] Slovnyk iz strukturnoi i henetychnoi elektromekhaniky / V. F. Shynkarenko, A.A. Shymanska. – K.: NTUU «KPI», 2015. – 112 p.

[7] Hongrui Caoa, Xingwu Zhanga, Xuefeng Chenb The concept and progress of intelligent spindles: A review // International Journal of Machine Tools & Manufacture, №112, 2017.-p.p.21-52 www.elsevier.com/locate/ijmactool.

[8] https://new.siemens.com/global/en/products/drives/electric-motors/motion-control-motors/motor-spindles.html.

[9] Kuznetsov Yu.N. Vizovi chetvertoi promishlennoi revoliutsyy «Yndustryia 4.0» pered uchenimy Ukrayni //zhurnal «Vestnyk Khersonskoho natsyonalnoho tekhnycheskoho unyversyteta», №2(61), 2017.-p.67-75.

[10] Kuznietsov Yurii, Oliinyk Kateryna Evolution of spindle assemblies of machines based on motor-spindle //International Scientific Journal, "Machinens. Technologies. Materials", issue 2022.-p.p.150-154.

[11] Oliinyk K.O. Operability analysis of spindle-motor hybrid electromechanical systems //Mech. Adv. Technol. Vol.5, No.1, 2021, p.p. 89-96.

[12] Oliynyk K.O. Synthesis of spindle assemblies on the basis of motor-spindles with the use of system-morphological approach // Bulletin of the Mykhailo Ostrogradsky KrNU. Issue 5-6 / 2020 (124-125). - p.133-138.