

Evolution of spindle assemblies of machines based on motor-spindle

Yurii Kuznietsov, Kateryna Oliinyk

National Technical University of Ukraine "Igor Sikorsky Kyiv Politechnic Institute"

Abstract. Solving the problems caused by the growth of M-S diversity belongs to the latest current scientific field of research in modern mechanics and electromechanics, which is generalized to the concept of structural and systems research with models of microevolution and macroevolution. If genetic synthesis allows to find new structures of M-S and spindle nodes on their basis, then for the synthesis of schemes and structures it is advisable to use a system-morphological approach. To develop a morphological model, functional (morphological) features are selected, which are divided into three groups in accordance with the modular principle: the modules of the rotational motion of the spindle, the drive feed -translational motion and the clamp-expansion.

KEY WORDS: MACHINE, MAIN DRIVE, MOTOR-SPINDLE, INTELLIGENT SPINDLE, EVOLUTIONARY SYNTHESIS, GENETIC OPERATORS, MORPHOLOGICAL MODEL

1. Current trends and restraining factors of high-speed metalworking.

In the context of the challenges of "Industry 4.0" and the approach of "Industry 5.0", one of the relevant topics in modern engineering technology is High Speed Cutting, High Production Cutting and High Precision Cutting [2]. Fast, high-quality and cheap - these are the advantages of advanced processing, which is widely implemented in enterprises of mechanical engineering, automotive, aircraft and others using advanced cutting tools that can increase many times (10-15 times) the speed of cutting and feeding on CNC machines. Already today there is a need to use lathes with a spindle speed (for workpieces) up to 20 thousand rpm., Drilling and milling up to 200 thousand rpm. and more. At such speeds (centrifugal forces increase squarely depending on the speed) dynamic loads reach catastrophic values, which requires changing the priorities of the requirements for spindle assemblies, clamping mechanisms of the workpieces, the clamping chuck in terms of reliability, accuracy and safety. High-speed machining requires the creation of new designs of spindle assemblies, high-speed clamping chucks with compensation of centrifugal forces), the use of new high-strength and vibration-resistant materials for body parts, balancing and mechatronic devices and more. In the drive of the main movement of high-speed lathes with $n_{max} > 10$ thousand rpm. it is almost impossible to use electric motors with mechanical reduction. Therefore, machines designed for high-speed machining are equipped with new aggregate-modular designs of spindles with special supports (bearings) and built-in electric motors such as motor-spindle (M-S) [3,8,9].

One of the main indicators of technical and economic efficiency of metalworking is the cost, which has such an important characteristic as the productivity of the cutting process [1,10]. Depending on the approach to the evaluation of the cutting process, the productivity of turning can be expressed by different values and, in particular, through the volume productivity, m^3 / min , it is seen that the increase in machining productivity is influenced by the speed (speed of rotation of the part), feed and depth of cut. Accuracy of manufacturing of details which is provided at finishing operations, is also one of the most important characteristics of quality and is characterized by stability of the sizes, deviations of a geometrical form, undulation and roughness of a surface. If, for example, we talk about the roughness of the surface of the part during turning, the significant influence is exerted by the cutting speed (v_c), feed and geometry of the cutter. Height of irregularities depending on giving and radius of rounding of the cutter: (2) Thus, on the one hand, to increase the technical and economic performance of machines on finishing operations, it is necessary to increase the cutting speed (speed of the part n) and reduce the feed, while increasing the productivity and quality of the treated surface. At the same time normal conditions of processing from the point of view of observance of safety measures have to be provided. Improving the speed of SW lathes is constrained by a number of factors, among which are the following (Fig. 1):

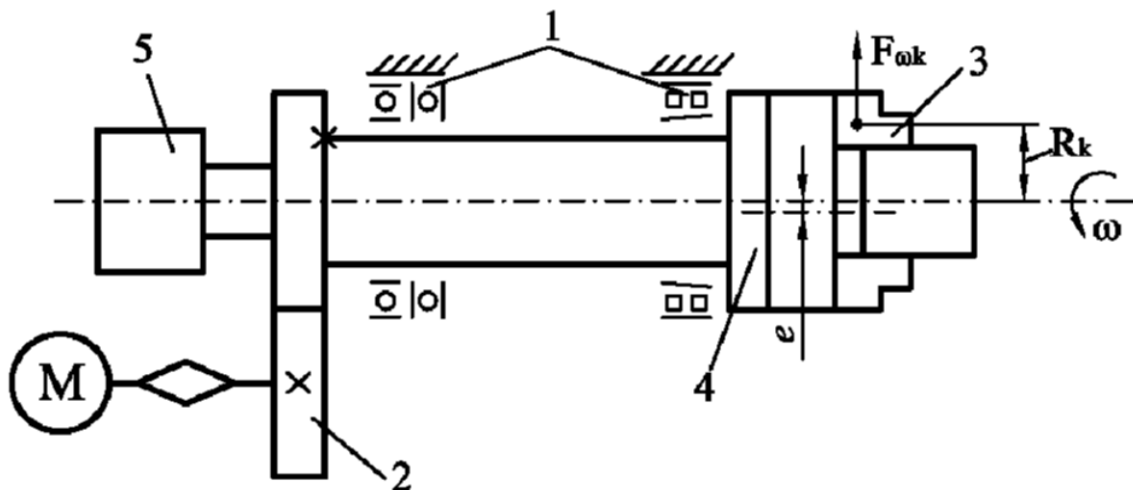


Fig. 1. Spindle assembly of the lathe with designation of sources-places of restriction of frequency of rotation: 1 - support; 2 - transfer of turns on a spindle from the engine; 3 - clamping chuck with radius R_k of unbalanced clamping elements; 4 - system "spindle-chuck-part" with eccentricity (imbalance) e ; 5 - clamp drive

1) spindle supports, characterized by speed (n - maximum spindle speed, rpm; d - average diameter of spindle necks for bearings, mm); according to this indicator, all spindle units on the rolling bearings are divided into low-speed, medium-speed and high-speed [1,4];

2) step and stepless torque transmission from the electric motor M (drive) to the spindle; for example, for gears, the limiting circumferential speeds are limited by the requirements for noise (acoustic) characteristics, and for belt drives by slipping, etc. ;

3) clamping chucks for rod and artificial workpieces, in which the drop in clamping force is associated with the influence of centrifugal forces of unbalanced elements (mainly clamping cams). Even with the introduction of centrifugal force compensation [2,8], the maximum speed is limited by the strength of the elements of the cartridge and, in particular, its body, which can explode like a bomb;

4) imbalance of the spindle with clamping chuck, which can lead to vibration and destruction of its parts, and in the drilling and milling machines of the fixed cutting tool due to the occurrence of unbalanced loads - forces $F_g = m_{ch} \omega^2 e$, where m_{ch} is the mass of the cartridge and e is the eccentricity of the shift of

2. Evolution of the development of the drive of the main movement of metal-cutting machines

The whole history of the development of machines, from the Stone Age to modern times, is associated with the evolution of its individual mechanisms, components, assemblies, control systems. According to the laws of development of technical systems (TS), the life cycle is described by an S-shaped curve, where in the coordinate system (important characteristic - time), its individual parts develop unevenly, which is influenced by human achievements in science and technology. This also applies to the main movement, which has gone through various stages of use of energy sources and its converters, namely: - biological (human from the hands and feet, with the involvement of animals such as horses); - natural (water wheel, air - windmills); - steam engine; - electric motors; - alternative sources (solar, chemical, biofuels, hydrogen, etc.). And only with the discovery in the 18th century of electric current in all spheres of human life there were significant changes, which were also reflected in metal-cutting, woodworking, stone processing machines and other technological equipment not only in drive systems but also in control systems. control and information. Without electricity, it is now impossible

3. Areas of research of the Kiev school in the field of spindle nodes and MS

Scientists of Donbass Machine-Building Academy (Kramatorsk) for heavy-duty machines, Chernihiv Polytechnic for universal lathes and circular grinders [6], Igor Sikorsky Kyiv Politechnic Institute for lathes, drills, drills including parallel kinematics, and new generation mobile machines without mechanical transmissions [1-3,5,8,9]. Research in Ukraine and abroad has recently focused on the widespread use of M-W, which provides only the main rotational motion, where there are no mechanical transmissions, and torque is transmitted by electromagnetic field between the stator mounted in the spindle head housing and the rotor, which is made in the form of a spindle with a clamping mechanism, which may have a mechanized clamp drive, and in its absence - a clamping chuck with a manual clamp, mainly collet. Some M-S designs use air and electromagnetic bearings. The main advantages of such spindles on magnetic bearings: lack of mechanical contacts and, as a consequence, wear; the possibility of using higher (compared to traditional designs) speeds; minimal vibration, no friction and reduced heat loss; the ability to change the stiffness and damping characteristics of the system; ability to work in vacuum and harmful environments; ecological purity. The rapid development of technology encourages the development of new and more advanced types of M-S [9,10]. Problems of structural synthesis of electromechanical objects and systems belong to the category of the most complex search problems, which are set in the absence of clear input information. Traditionally, solving this type of problem involves the use of heuristic search methods or the professional intuition of the researcher. The Igor Sikorsky Kyiv Politechnic Institute at the Department of Machine and Machine Design (Mechanical and Mechanical Engineering Institute) in cooperation with the Department of Electromechanics (Faculty of Electroautomatics) drilling and milling machines with mechanisms of parallel structure, built on the modular principle. The genetic approach is based on the principles developed at the

4. Using the theory of evolution to build models of M-S

The evolution of EM systems is accompanied by an intensively growing variety of functional classes and structural varieties, the complexity of their structural organization,

the mass of the cartridge and the moments $M_g = F_g e = m_{ch} \omega^2 e^2$;

5) the clamp drive, which creates the initial force of the clamp when, and on the occasion of automatic control, compensates for the loss, for example by increasing the pressure when using the hydraulic drive; in the presence of unbalanced elements in the clamp drive, for example, with a geometric circuit, centrifugal forces acting on unbalanced elements (levers, rollers, balls) can reduce or increase energy loss on the clamp-clamp, disrupt reliable operation of the drive, and therefore the entire clamp mechanism [4].

to imagine human life on earth and beyond. Therefore, the future of the new generation of machines can not be imagined without the use of electromagnetic energy. The evolution of spindle assemblies can be traced using spindle supports, which significantly affect the performance and, in particular, to ensure speed [1]. Modern designs of spindle assemblies use rolling bearings, hydrostatic, hydrodynamic, gas-static (aerostatic), gas-dynamic (aerodynamic), magnetic bearings and their combinations (hybrids), such as gas-magnetic (gas-bearing bearings with magnetic suspension) [5,6]. The increase in the speed of spindle assemblies using the energy of electromagnetic forces was facilitated by the consistent reduction of the kinematic circuit from the power source to the workpiece or tool: first, a group electric drive for several machines; then common to one machine with stepped gears; then individual with stepped gearbox; finally individual coaxial through couplings, and then high-speed pneumatic spindles and electric spindles. The latter were called "Motor Spindle" (MS).

Department of Electromechanics to solve problems of directed structural synthesis of electromechanical systems (EM systems) with the completeness of their potential solutions due to the open periodic table of primary sources of electromagnetic fields [7]. This opens the possibility of implementing not only the directed synthesis and genetic prediction of electromechanical structures of arbitrary level of complexity for a given function of the target. From the point of view of genetic approach, M-S systems are complex combined genetically determined systems that can combine representatives of several types of electromechanical EM systems with components and mechanical components of other genetic nature (sensors, hydraulic systems, different types of bearings, etc.) [6,9,10]. The system-morphological approach was based on the concept developed at the Department of Machine and Machine Design, which considers the complex process of optimal design of the technical system in the form of sequential solution of multivariate, multilevel, multicyclic, multicriteria and multiextreme problems of synthesis, analysis and measurement. modular principle and modern information technology [2]. Today there is an urgent need to create M-S that can provide direct rotation of the spindle and feed movement, as well as implement complex helical spindle movement without the use of transmission mechanisms, as this allows to expand the functionality of spindle assemblies and reduce machine dimensions. Such EM-systems include, first of all, representatives of hybrid EM-objects of the twin type [8,9], however, the results of information retrieval indicate that in the studied class of combined EM-systems of the type "M-W", to date, there are no M-W, which have such properties. Thus, the task arose with the use of structural prediction technology to synthesize new structures M-W, able to directly implement the rotational movement of the spindle and the feed movement, as well as to implement complex helical movement of the spindle without the use of transmitted mechanisms.

integration with components of other systems (mechanical, electronic, hydraulic, biological, etc.), progressive volumes of accompanying information. The organization of exploratory

research, selection and justification of competitive design solutions is associated with significant costs of material and time resources, which requires the development of new methodological approaches that can reproduce complete, reliable and systematic information on structural capacity within arbitrary classes of EM systems, regardless of level their complexity and functional affiliation [7]. Solving the problems caused by the growth of M-W diversity belongs to the latest current scientific field of research in modern mechanics and electromechanics, which is generalized to the concept of structural and systems research with models of microevolution and macroevolution [6,7,9,10]. The tasks of microevolution are the search, creation and improvement of specific EM systems (creation of new structural types of EM), and macroevolution - the search for

patterns of development over species classes of systems, development of generalized genetic models, creation of information databases, construction of general EM systems [7]. Hybrid electromechanical structures are characterized by mixed genetic information, so their functional properties are determined by the corresponding functions inherent in the generative species [12]. Hybrid species include functional classes of multistage electric machines with complex spatial motion of the moving part, as well as other classes of complex EM systems, which are characterized by mixed genetic information. Systems of the type "M-W" are complex combined electromechanical structures [11,12] which include mechanical and electromagnetic parts.

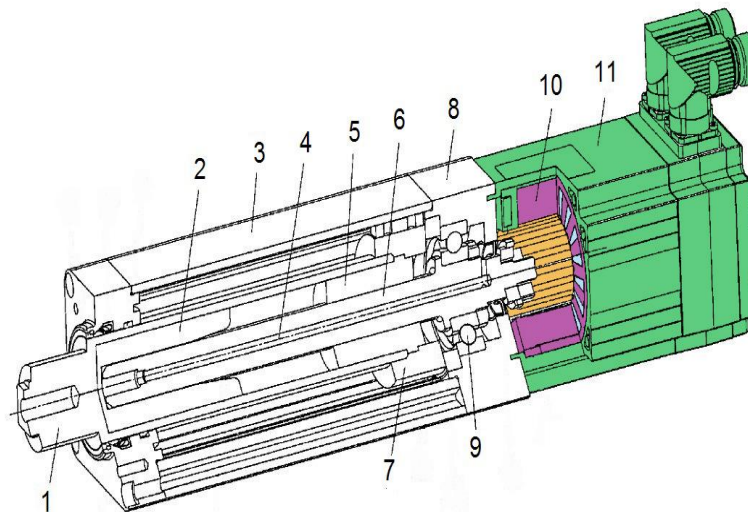


Fig. 2. Motor-spindle in section: 1 - spindle; 2-support cylinder; 3 - the body of the mechanical part of the M-W; 4 - department for oil supply; 5 - running spindle; 6 - spindle nut; 7-centering guide; 8 - casing; 9 - bearing; 10 - motor stator; 11 - engine housing

The results of genetic analysis of known species M-S of the studied class were used to organize its identified representatives on the basis of genetic traits, as well as source information for building models of micro- and macroevolution, which, in turn, are used for targeted synthesis of new structures of class M-S. The main stages of this procedure are information-patent search in class M-S and analysis of genetic information on known types of EM, identified by the results of information search, which need to be reviewed and supplemented over time. From the point of view of genesystematics, an arbitrary functional class M-S can be represented as a corresponding set of genetically determined Species and Genus. This is the universality of the methodology of taxonomy. Another fundamental property of genesystematics is its prognostic function, ie, the ability to determine both real-information and implicit species that are not yet involved in the current evolution of the class. The source information for determining the structure and quantitative composition of the main systematic units for the studied class is the area of existence of generating electromagnetic structures and the structure of their genetic codes. The availability of such information allows to determine: -systematic units of the genus rank (according to the affiliation of generating structures to the corresponding geometric classes of genetic classification); -quantitative composition and

structure of systematic units of the rank of the species and their distribution by genus; -the ratio of real-information and implicit species, and their distribution by genus. The rank structure of genesystematics is a generalization of the results of determining the systematic units of the studied class and can be presented in graphical form.

A genetic model of synthesis of combined electromechanical structures M-S with the implementation of reciprocating motion by converting rotational motion into translational motion through the use of "screw-nut" transmission was built (Fig.3). One of the embodiments of the synthesized chromosome S31 (fig.3) is presented in fig.4. When voltage is applied to the stator winding 4, there is a magnetic field that interacts with the two-layer active surface of the rotor 6 and, thus, causes the spindle 7 to rotate with the desired speed n (ω). To ensure the supply of the spindle, the voltage is applied to the motor 1, the speed of which by means of the CNC system is converted through the screw pair 2, 3 to the translational movement of the quill 5, providing the desired supply S.

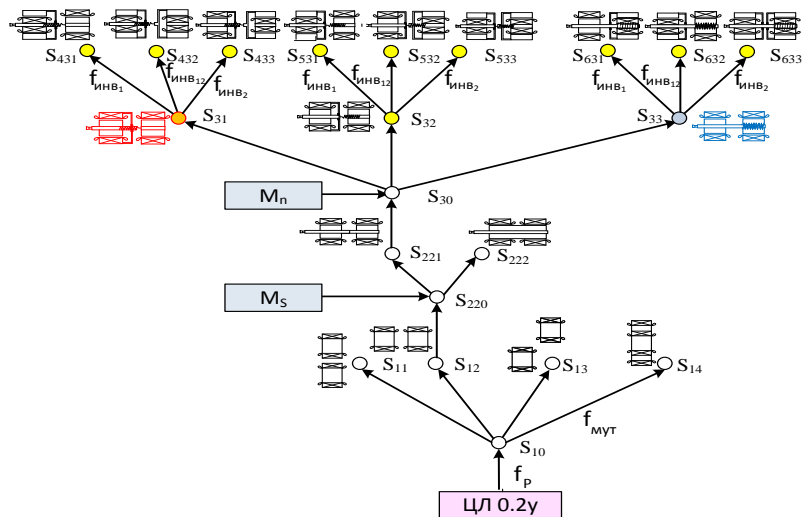


Fig.3. Genetic model of synthesis of M-S hybrid structures with screw-nut system

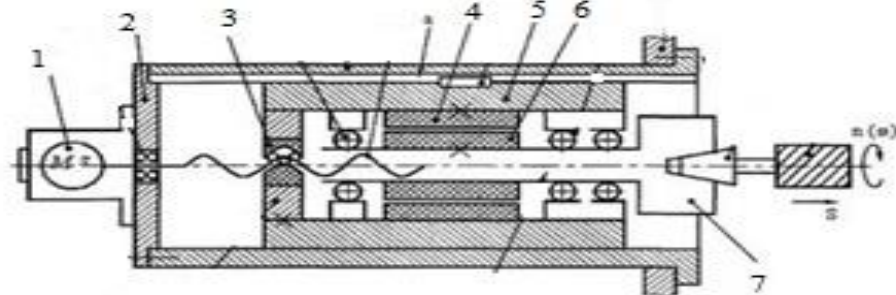


Fig.4. Schematic kinematic scheme of a spindle assembly of flange type

5. Morphological synthesis of non-self acting and self-acting M-S

If genetic synthesis allows to find new structures of M-W and spindle nodes on their basis [7,9], then for the synthesis of schemes and structures it is advisable to use a system-morphological approach [2,3]. In set-theoretic language, the morphological description contains four: $S_m = \{E, R, Str, K\}$, where $E = \{E_i\}$ and - the set of elements and their properties; element-subsystem, inside which the morphological description does not penetrate; $R = \{R_{and}\}$ and - the set of connections; Str - structure (determined by the genetic code); K - composition (arrangement in space). To develop a morphological model, functional (morphological) features are selected, which are divided into three groups in accordance with the modular principle.

For the first module of the drive of rotary main movement signs are selected: 1. Power source. 2. Primary field source. 3. The number of spindle supports. 4. Type of spindle supports. 5. Supports of radial fixing of a spindle. 6. Supports of axial fixing of a spindle. 7. Communication between spindles. 8. The connection of the spindle with the primary source of the field. 9.

Geometric axis of the spindle. 10. Relative location of spindles. 11. Execution of the spindle body.

For the second translational drive module: 12. Power source. 13. Primary field source. 14. Type of motion transducer. 15. Location of guides. 16. Execution of guides.

For the third module of the clamping mechanism: 17. Type of the clamping cartridge on the converter of movement and force. 18. Base surface of the clamping chuck for connection to the spindle. 19. Power source in the clamp-expansion drive. 20. Primary source of the field. 21. Type of energy (force) converter. The morphological model can be written with a morphological matrix in a condensed form $Mshv = Msh \wedge Mn \wedge Mz$, where Msh, Mp, Mz - morphological matrices, respectively, the modules of the rotational motion of the spindle, the drive feed -translational motion and the clamp-expansion. Experimental studies of the manufactured prototype of the synthesized self-acting M-W (fig.4,5) showed its efficiency. After improvement of a design on manufacturability and conformity to the international standards on standard sizes and connections to CNC machines of various models such self-acting M-Sh can be recommended for introduction in production.

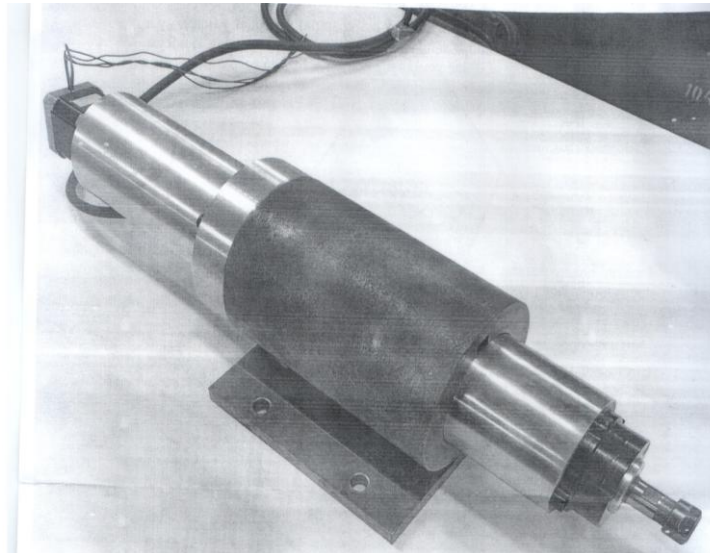


Fig.5. Modular design of self-propelled M-W with "screw-nut" transmission

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