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Investigation of the Dynamics of the Spindle of Metal-Cutting Machines by Different Methods

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ABSTRACT: With the development of mechanical engineering in the Republic, new methods of machining are being developed, which take place at increased cutting conditions, which affects the elastic deformations arising in the machine tool nodes, which in turn affect the accuracy of processing parts.

The increase in productivity is very often limited by the vibration that occurs in the machine-tool system. The type of cutting operation and the tool used determine which part of the system will be excited and which will vibrate with the greatest amplitude. The performance analysis of a machine tool spindle system based on finite element analysis software includes the following steps: creating a finite element model, determining constraints and loads, solving the model, and analyzing the output. For finite element analysis, the appropriate unit type should be selected for different models, analysis types, and analysis methods. It is necessary to take into account both the accuracy of the calculation and the cost, as well as the calculation time.

KEYWORDS: spectrum, oscillations, machine tools, dynamics, rigidity, vibrations, diagnostics, metal-cutting machines, spindle, frequency, mathematical modelling.

I. INTRODUCTION

Spindle assemblies are designed for precise rotation of the tool or workpiece. They are included in the bearing system of the machine and largely determine its rigidity and vibration resistance.

The spindle unit of the machine consists of a spindle, its supports, and a drive element. In the spindle, the front end and the inter-support section are distinguished. The spindle is subjected to loads caused by cutting forces, forces in the drive, as well as centrifugal forces arising from the imbalance of the rotating parts of the spindle assembly itself. The design of the unit includes: selection of the type of drive, supports, devices for their lubrication and protection from contamination; determination of the spindle diameter, the distance between the supports and the development of the design of all elements.

II. GEO SCATTERED TYPE BIG DATA IN APPLICATION

The following requirements are imposed on the spindle units of machine tools:

1. Precision of rotation, measured by the beating at the front end of the spindle in the radial or axial directions; Deviations from ideal rotation are one of the main causes of machining errors on many machines. The permissible runout of the spindle of universal machines must comply with national standards. The runout of the spindle of special machines should not exceed 1/3 of the tolerance for the limiting size of the part machined on the machine.
2. Rigidity of the spindle assembly, determined by the elastic displacements of the front end of the spindle, due to the flexibility of the spindle itself and its supports; the radial and axial rigidity of the spindle assembly significantly affects the machining accuracy. The permissible minimum stiffness of the front end of the spindle of production machines is 20 N / µm, for precision machines - 400 N / µm. The permissible angle of rotation of the spindle in the front support, accompanied by an uneven distribution of the load between the bodies of rotation of the bearings, is taken equal to 0.0001 ... 0.00015 rad. The angle of rotation of the spindle under the drive gear is allowed 0.00008 ... 0.0001 rad, and the deflection in this place should not exceed 0.01m (m is the module of the gear).

III. SYSTEM ANALYSIS

Spindle stiffness requirements can be expressed in another way. To ensure the operability of spindle bearings, the following ratio is required between the diameter d of the spindle and the center distance l:

$$d \geq \sqrt[4]{(0.05 \dots 0.1) l^3} \tag{1}$$

The permissible radial movement of the front end of the spindle under the action of the load should not exceed 1/3 of the tolerance on the size of the part machined on the machine.

3. Vibration resistance of the spindle assembly, which significantly affects the overall stability of the supporting system and the entire machine; the damping properties of the supports and the amplitude-frequency characteristics of the spindle assembly affect the surface roughness and the maximum permissible processing modes (resonance phenomena can be dangerous for high-speed machine tool spindles).
4. The durability of the spindle units, which is related to the durability of the spindle bearings in the sense of maintaining the original rotation accuracy; this requirement is of particular importance for spindle bearings.
5. Fast and reliable fastening of the tool, fixture or part, ensuring their accurate centering and, accordingly, accurate rotation; in modern machine tools, the requirements for the automation of clamping a tool, fixture or workpiece are increasing.
6. Limitation of heat generation and temperature deformations of the spindle assembly, which greatly affect the accuracy of processing; spindle supports at high rotational speeds are an intense source of heat generation in the immediate vicinity of the processing area.

The design of the spindles depends on how the tool or workpiece is attached to its front end. The front ends of the spindles are standardized for most types of machine tools. Centering is provided by taper mating of the Morse taper type with a relatively rare manual tool change (Table 1), 7/24 tapers with automatic tool change in programmed machines (Table 2) and 1/3 tapers in grinding machines for centering an abrasive tool.

The stiffness of the tapered connection of the spindles to the fixture mandrel or tool shank has a significant impact on the overall rigidity of the carrier system. Elastic displacement of the mandrel under the action of force P applied at some distance L from the end of the conical connection can be represented as

$$y = \delta + \theta L \,, \tag{2}$$

where δ - displacement at the edge of the conical connection as a result of contact compliance;
θ - angle of rotation in conical connection.

Without taking into account errors in the conical connection, elastic displacement δ and angle of rotation θ can be determined by the formulas:

$$\delta = \frac{4P\beta C}{\pi D}(\beta L C_1 + C_2) \tag{3}$$

$$\theta = \frac{4P\beta^2 C}{\pi D}(\beta L C_1 + C_2) \,, \tag{4}$$

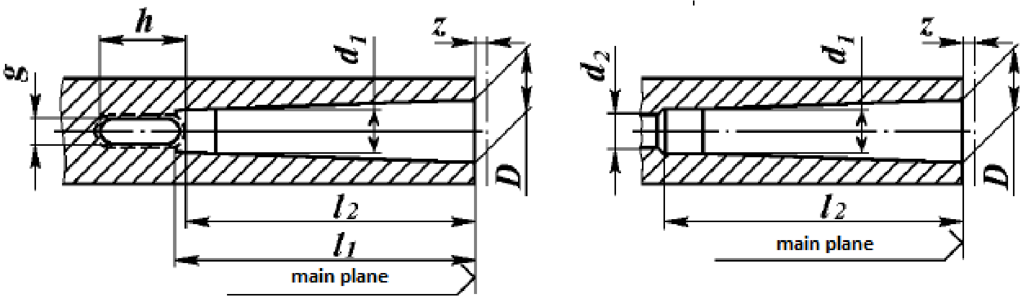
Where

$$\beta = \sqrt[4]{\frac{1}{13CD}}$$

C - coefficient of contact compliance (for Morse cones C = 0.03 ... 0.06, and for 7/24 cones C = 0.02; C1, C2, C3 - coefficients that take into account the change in diameter along the length of the conical connection (for Morse cones C1, C2, C3 = 1, and for 7/24 cones C1 C2 = 1.35 and C3 = 1); D - mandrel diameter.

Table 1

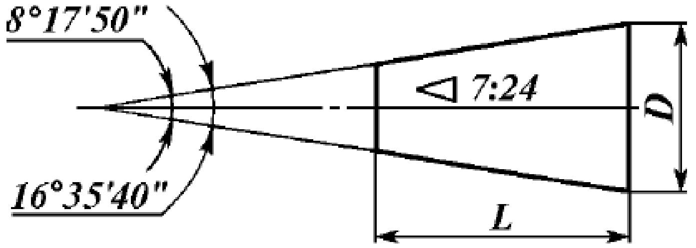
Dimensions of tool cones Morse and metric (according to ST SEV 147-75), mm



case designation	D	d_1	d_2	$l_{1\,min}$	l_2	g	h	z
morse								
0	9,045	6,7	-	52	49	3,9	15	1
1	12,065	9,7	7	56	5	5,2	19	1
2	17,78	14,9	11,5	67	62	6,3	22	1
3	23,825	20,2	14	84	78	7,9	27	1
4	31,267	26,5	18	107	98	11,9	32	1,5
5	44,399	38,2	23	135	125	15,9	38	1,5
6	63,348	54,6	27	188	177	19	47	2
metric								
4	4	3	-	25	21	2,2	8	0,5
6	6	4,6	-	34	29	3,2	12	0,5
80	80	71,5	33	202	186	26	52	2
100	100	90	39	240	220	32	60	2

Table 2

Dimensions of inner and outer cones with a taper of 7:24 (according to GOST 15945-82), mm



case designation	D	L	case designation	D	L
10	15,87	21,8	50	69,85	103,7
15	19,05	26,9	55	88,90	132
25	25,4	39,8	60	107,95	163,7
35	38,1	57,2	70	165,1	247,5
40	44,45	65,6	75	203,2	305,8
45	57,15	84,8	80	254	390,8

To transfer torque to the spindle, a gear or belt drive is used, as well as a clutch located at the rear cantilever end of the spindle. The type of the drive element is selected depending on the spindle speed, the torque transmitted to it, the layout of the machine, the requirements for the smoothness of the spindle rotation.

The gear transmission is capable of transmitting large torque, is simple in design, and is compact. But transmission errors reduce the smoothness of the spindle rotation and cause additional dynamic loads in the drive. Gear transmission is usually used when the spindle speed does not exceed 2000 ... 3000 rpm. But with precise manufacturing and installation of the gear, it can be used for high speeds.

The belt drive ensures smooth rotation of the spindle, reduction of dynamic loads in the drive of the machine, on which interrupted cutting is performed. But this transmission has a relatively large dimensions, since in order to increase the accuracy of the spindle assembly, the pulley is made unloaded.

Belt transmission is used at different speeds of the spindle, including at relatively high (6000 rpm and higher), when the circumferential speed of the belt reaches 60 ... 100 m / s.

The so-called motor spindles are used in machine tools. They include an asynchronous or frequency-controlled asynchronous electric motor, the rotor of which is fixed on a spindle between the front and rear supports. In addition, the motor-spindle includes a forced cooling system with a block of electric fans and a filter for cleaning the cooling air, a built-in temperature protection unit, and a 9th measuring transducer of the angular position of the spindle. In motor spindles designed to operate in a wide range of rotational speeds, the motor shaft can be connected to the spindle by mechanical transmissions, for example, in the form of a planetary gearbox. The motor spindle complete with an electronic frequency converter is a unified electric drive for the main movement. When developing a number of motor-spindles, they provide for the possibility of embedding them in turning, turret-lathe, multi-purpose, vertical and bed-type milling machines with CNC. The use of motor spindles reduces machine weight, energy losses, vibration levels and the spindle assembly.

In especially high-precision machines, a main drive is used with an adjustable electric motor separate from the spindle head, the shaft of which is connected to the spindle by an elastic coupling with a built-in heat-insulating element. In normal precision machines, the electric motor and the spindle are connected by an elastic coupling. To completely eliminate the transfer of disturbances from the electric motor to the spindle, a so-called inertial drive is used. The spindle is connected to a power source, accelerated to operating speed, then disconnected from the drive. The part is machined after the drive motor is turned off. To increase the stock of kinetic energy, a flywheel is sometimes mounted on the spindle. The front end of the spindle is used to locate and secure the cutting tool, workpiece or fixture. The front ends are made to national standards. Accurate centering and rigid mating of the tool or arbor with the spindle is ensured by a tapered connection (see above tables 1 and 2).

Assessment of the degree of deviation of the technical state of the mechanism from the norm by indirect signs, namely, by changes in the properties of vibration processes, depending on the nature of the interaction of its components and parts, is an important task. For metal-cutting machines, a feature of which is an increased risk of catastrophic consequences, including those related to the health or life of people due to sudden failures, as well as significant economic losses due to downtime, the need to control the vibration state is even more important.

Based on the study of Russian and foreign experience in recent years, B.L. Guericke in his monograph formulated the main tendencies of vibration diagnostics of mining machines. The main areas of application of the considered signal analysis methods for solving problems of diagnostics of mining equipment and its units are given. For early detection of mining equipment malfunctions, this work uses vibration diagnostics methods, which occupy a leading place among works on technical diagnostics of mining machines.

Vibrations are generated by dynamic processes of interaction of parts in a working mechanism, therefore, vibration signals, having a high information capacity, quickly respond to a violation of the normal nature of local interactions of mating elements during operation. Therefore, the use of this method, which allows in many cases to significantly (at least 2-3 times) reduce the likelihood of sudden failures without a noticeable increase in production costs, is a particularly promising direction. Vibration monitoring of the technical condition makes it possible to rationally use all the potentialities inherent in the machine during operation.

During operation, the technical condition of the machine is influenced by factors aimed at changing it. The change in state is a consequence of the influence of such factors as wear, fretting, corrosion, aging and many other processes, depending on the operating conditions and arising disturbing influences. Monitoring the vibration state of the machine allows you to timely determine the points of maintenance included in the operational planning of production.

The aim of the thesis is to develop methods for diagnosing and predicting parameters for assessing the current technical condition and residual life of equipment based on the integrated use of information from automated data collection devices.

IV. RESULTS

Based on this, the following tasks are posed in the dissertation work:

1. Investigate the effect of operating parameters (rotational speed and axial load), as well as the radial clearance and preload of bearing assemblies on the durability of the bearing assembly;
2. Development and analytical solution of the mathematical model of the support of the spindle assembly with a nonlinear elastic characteristic.
3. Experimental study of the dependence of the own frequency response of the spindle unit of the NT-250M machine.
4. Experimental study of the mechanism of occurrence of forced vibrations of the spindle assembly in the mode of linear increase in the spindle speed by the method of time-frequency analysis.
5. Development of a methodology for predicting the residual resource of spindle units of metal-cutting machines.

6.. selection and justification of the assessment of the technical condition of the spindle assembly by the method without collapsible control.

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