MAGNET'IC CONDUCTORDIMENSIONS AFFECTINGOUTPUT PARAMETERSOF SPINDLE UNIT WITH GAS-MAGNETIC SUPPORT

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Methodology of calculation of output descriptions of high speed spindle unit is considered with front gas-magnetic bearing strength of which is condi-tioned by the united action of gas forces and forces of the electromagnetic field. A construction over of such bearing is brought. With the purpose of verification of authenticity of theoretical results of calculations their comparison over is brought with experimental data. Analyzed influence of the length magnetic conductor of double-pole gas-magnetic bearing on operational characteristics of spindle unit. On the basis of the executed researches the industrial construction of high-speed spindle unit the tests of which were shown on high quality and exactness of the processed surfaces is made.

Keywords: spindle unit, gas-and-magnetic support, load carrying ability, lubricating layer hardness

Considered is the output parameters design procedure of the high speed spindle unit with the front gas-magnetic support, its load carrying ability conditioned by the coaction of the forces of gas and the electromagnetic field. Given is a construction of such a bearing. Compared are the theoretical results of the computations with the experimental data to prove the irreliability. Analyzed is the influence of the magnetic conductor length of the bipolar gas-magnetic bearing on the spindle unit output parameters. Produced on the basis of the research is the industrial standard of the high-speed spindle unit which tests have shown the high quality and accuracy of the processed surfaces.

The development of modern industry makes increased demands for productivity and accuracy of the process equipment. By way of example the grinding machines can be cited used in finishing operations for precision and super-precision machining. The accuracy and productivity of such machines depend basically on the spindle unit (SU) precision.

High-speed SU of the grinding machines should provide high speed, hardness on the grinding wheel and sufficient cutting force to increase the productivity and working accuracy.

The high speed of the SU is attained with the help of noncontact gas or magnetic supports. However, such bearings have rather a low load carrying ability [5] which restricts the cutting force of the grinding wheel and results in productivity slowdown, particularly by the rough stock and semi-finished allowances removal.

One of the ways to raise the performance specifications of the noncontact SU supports consists in application of combined bearings, particularly gas-and-magnetic supports. The coaction of gas-film lubrication and magnetic field pressure forces provides the load-carrying ability of these bearings [4].

Let's consider the design procedure of the SU output parameters with the front gas-and-magnetic and the back gas-static supports. The front support has two magnetic poles. Gas is supplied to the bearing clearance through the porous inserts situated in the gastight inlay. Fig. 1 shows the typical SU scheme to mount the grinding wheel on the spindle bracket.

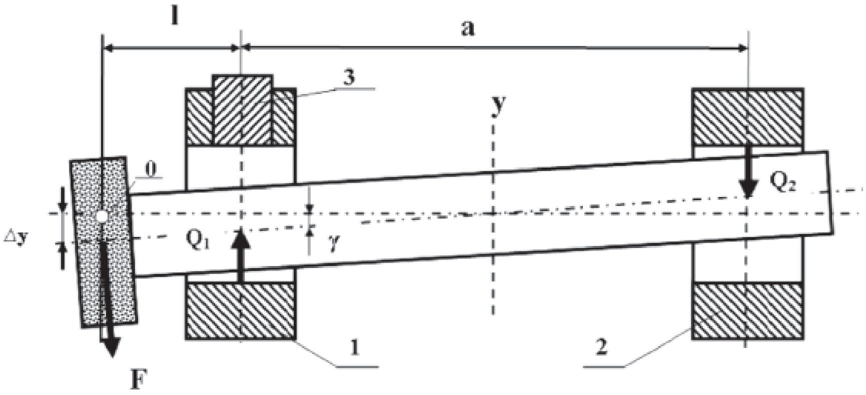

Fig. 1. The SU scheme to mount the grinding wheel on the spindle bracket:
1 – frontgas-and-magneticsupport; 2 – back gas-static support; 3 –magnetic conductor

The load on the grinding wheel is found from the two equations of statics: the sum of projections of forces on axis *Y*:

$$F = Q_1 - Q_2$$

and the moment equation about point *O*:

$$Q_1 l = Q_2 \left(a + l\right) + M,$$

where Q_1 and Q_2 is the load carrying ability of the front and the back support respectively, M is the restoring moment from the misalignment of the front and the back supports.

According to the above expressions, to determine the load on the grinding wheel one must know the load carrying ability of the supports and the restoring moment from the spindle misalignment. It should be noted as well, that the latter valueis on the order of magnitude less than the moments of forces Q_1 and Q_2 as the calculations show.

The design of the partly porous gas-static SU bearings is developed full enough in paper [2].

Let's consider the performance specifications design procedure of the gas-and-magnetic support with two magnetic suspensions represented on Fig. 2

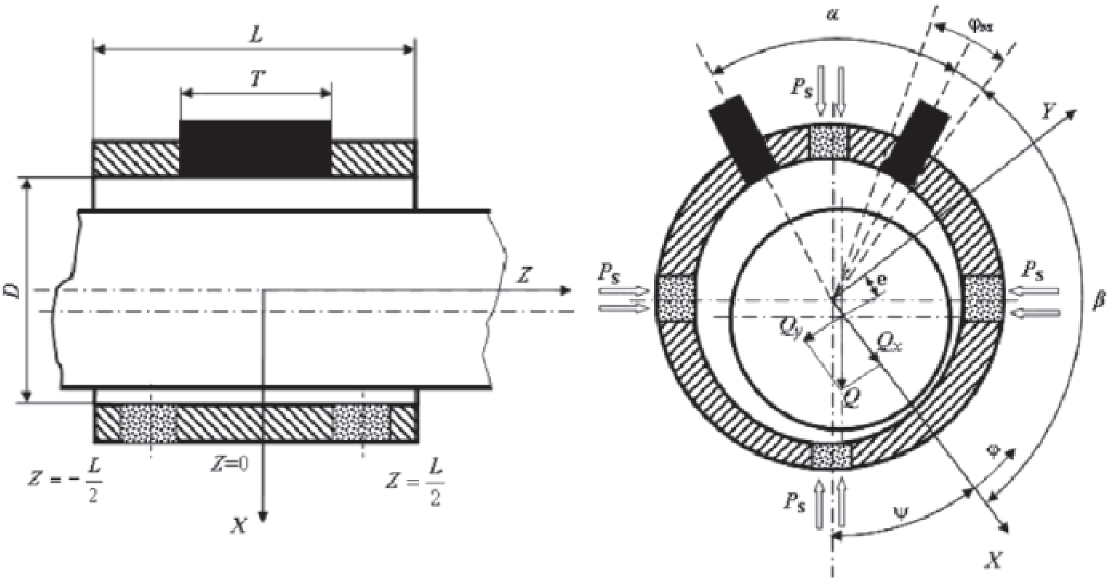

Fig. 2. The scheme of the gas-static support with two magnetic suspensions

The design procedure of the gas-and-magnetic support is based on the fact that the pressure field of gas-film lubrication differs from the magnetic field and that they render almost no influence on each other. Thus, the load carrying ability of the support can be represented as the resultant vector of two vectors of force: the magnetic force and the force of gas pressure. In the scalar form the expression to define the load carrying ability of the gas-and-magnetic support looks like this:

$$Q = \sqrt{Q_x^2 + Q_y^2},$$

where Q_x and Q_y are the projections of the load on axes *X* and *Y* respectively. Each of these projections equals:

$$Q_x = Q_{xg} + F_{xm},$$

$$Q_y = Q_{yg} + F_{ym},$$

where Q_{xg} and Q_{yg} are the projections on axes X and Y of the gas component of the load carrying ability, F_{xm} and F_{ym} are the projections on axes *X* and *Y* of the magnetic component of the load carrying ability.

According to paper [3] the projections on the coordinate axis of the gas component of the load equal:

$$Q_{xg} = R \int_{-\frac{L}{2}}^{\frac{L}{2}} \int_{0}^{2\pi} p \cos\varphi \, d\varphi \, dz;$$

$$Q_{yg} = R \int_{-\frac{L}{2}}^{\frac{L}{2}} \int_{0}^{2\pi} p \sin\varphi \, d\varphi \, dz.$$

where *R* is the inlay radius, *L* is the bearing length, *p* is the pressure in the gaseous layer, φ is the coordinate in the circumferential direction of the bearing, *z* is the coordinate in the axis direction of the bearing.

The magnetic component of the load carrying ability of the support equals in magnitude to the tractive force of solenoids. Its elementary value is known to be found in this formula:

$$dF_m = \frac{B^2}{2\mu_0}dS, \qquad (1)$$

where B is the magnetic induction, S is the area of the ferromagnetic solid, is the space permeability.

Considering the well-known relation of the induction to the amount of clearance, we put the expression (1) down as follows:

$$dF_m = K_e h^{-2} dS, \qquad (2)$$

where $K_e = 0{,}5\mu_0 (in)^2$ is the factor allowing for the electric parameters of the solenoid; i is the solenoid current; n is the number of turns of the solenoid; h is the clearance between the spindle and the bearing in lay.

The relation (2) is referent to define the magnetic component of the load carrying ability developed by the two electromagnets.

As the clearance value is less than the linear dimensions of the pole by approximately 10^{-3}, we assume the uniformity of the magnetic field. Considering this, we can show that with the angular separation of the electromagnets α the projections of the magnetic component of the load in view of magnetic conductor length T on the coordinate axis are found in the expressions below:

$$F_{xm} = \frac{K_e RT}{c^2}\left[\cos\left(\psi - \frac{\alpha}{2}\right)\int\limits_{\beta}^{\beta+\varphi_m}\frac{d\varphi}{\bar{h}^2} + \cos\left(\psi + \frac{\alpha}{2}\right)\int\limits_{\beta+\alpha}^{\beta+\alpha+\varphi_m}\frac{d\varphi}{\bar{h}^2}\right],$$

$$F_{ym} = \frac{K_e RT}{c^2}\left[\sin\left(\psi - \frac{\alpha}{2}\right)\int\limits_{\beta}^{\beta+\varphi_m}\frac{d\varphi}{\bar{h}^2} + \sin\left(\psi + \frac{\alpha}{2}\right)\int\limits_{\beta+\alpha}^{\beta+\alpha+\varphi_m}\frac{d\varphi}{\bar{h}^2}\right],$$

where ψ is load position angle, β is the circumferential coordinate of the first pole start, φ_m is the polar angle, T is the length of the electromagnet.

It should be noted that the clearance $\bar{h}$ between the spindle and the bearing inlay is found from the following expression:

$$\bar{h} = \frac{h}{c} = 1 - \varepsilon\cos\varphi - \frac{\bar{\gamma}}{\bar{L}}\cdot\bar{z}\cos(\varphi - \psi),$$

where $\bar{\gamma} = \frac{\gamma D\bar{L}}{2c}$ is the misalignment parameter, $\bar{L} = \frac{L}{D}$ is the bearing extension, c is the average radial clearance, ε is the relative centering error, γ is the misalignment angle, D is the bearing diameter, L is the bearing length.

The hardness measured on the grinding wheel is determined by the formula:

$$J = \frac{dF}{dy},$$

where y is the displacement of the wheel axis.

The stated procedure has served as the basis for the research of the influence of the length of the magnetic conductor T, which is one of the basic elements of the gas-and-magnetic support design on the output parameters of SU.

The results of the load F and hardness J computation for the grinding wheel depending on the rotation frequency of the spindle as well as on the magnetic conductor length are given on Fig. 3 and 4 respectively. The computations are made providing that the load carrying ability of the front support is produced only due to gas pressure forces ($T = 0$). We have computed the gaseous and magnetic field coaction with the relative magnetic force $\bar{F}_m = 0{,}1$ too. The experimental data are obtained from the test bench. The designs and the principles of operation of the test bench are described in paper [3] in detail.

The relative magnetic force is determined by the following relation:

$$\bar{F}_{\text{м}} = F_{\text{м}} / DL\Delta P,$$

where $F_{\text{м}} = \sqrt{F_{x\text{м}}^2 + F_{y\text{м}}^2}$ is the absolute magnetic force, ΔP is the forced aspiration surplus pressure.

The presented relations display that the extension of the magnetic conductor makes it possible to increase the load on the grinding wheel. It should be noted that in operation of support, with the gas-and-magnetic regime, and with the constant magnetic force ($\bar{F}_{\text{м}} = \text{const}$) the spindle unit hardness is lower. This deficiency is remedied by means of the control system monitoring the spindle position.

The pilot model of the high-speed internal grinding machinespindle unit which has the front gas-and-magnetic support and the back gas-static support is designed and produced at Komsomolsk-on-Amur State Technical University.

Testing the SU while processing industrial models having 25 and 40 mm in diameter made of steel 20×13, we have obtained the following results: out-of-round of bore – up to 1,0 microns, waviness – up to 0,15 microns, surface roughness R_a up to 0,12 microns, 10–15 % better than with SU having only gas-static supports.

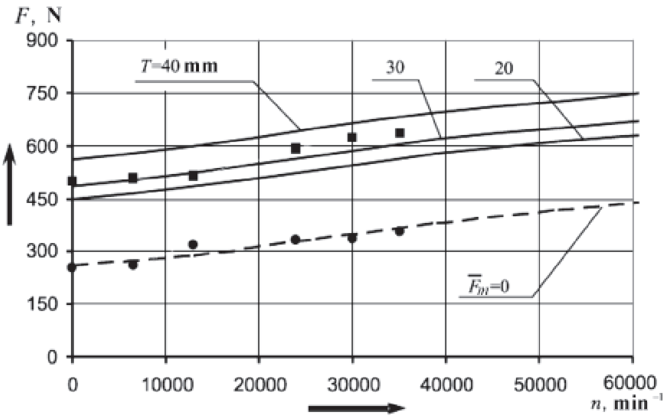

Fig. 3. The relation between load F on the grinding wheel, the spindle rotational speed n and the magnetic conductor length T; — — – SU operating regime with the electromagnet switched off; ——— – SU operating regime with the electromagnet switched on; ■ – the experiment with T = 40 mm; ● – the experiment with the electromagnet switched off

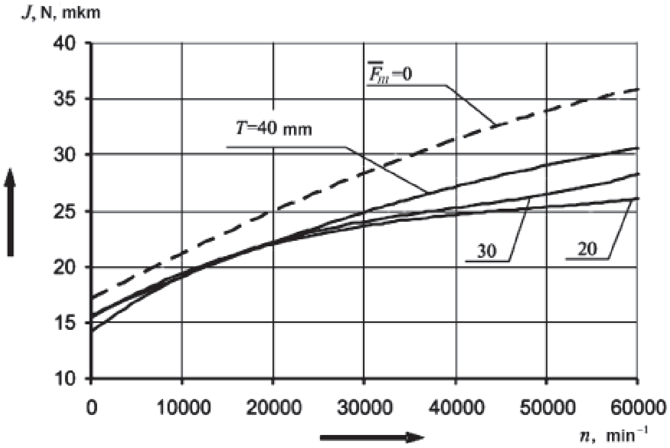

Fig. 4. The relation between hardness J on the grinding wheel, the spindle rotational speed n and the magnetic conductor length T; — — – SU operating regime with the electromagnet switched off; ——— – SU operating regime with the electromagnet switched on

It follows that the application of SU with gas-and-magnetic supports in the machine tools will make it possible to use machinery more effectively due to the matching of the semi-finished and finishing operations in one cutter-settingas well as to get a higher processing quality.

References

1. Bessonov P.A. Theory of Electrical Engineering. – M.: Higher School, 1973. – 752 p.

2. Kosmynin A.V. Performance Characteristics of Gas Bearings of High-Speed Spindle Units / A.V. Kosmynin, Yu.G. Kabaldin, V.S Vinogradov., S.P. Chernobay. – M.: Natural Science Academy, 2006. – 219 p.

3. Kosmynin A.V., Shchetinin V.S., Ivanova N.A., Khvostikov A.V., Blinkov S.S. Test Bench for Spindle Unit Output Characteristics Research on Gas-Magnetic Bearings // STIN. – 2010. – №5. – P. 8–11.

4. Kosmynin A.V. Shchetinin V.S. Bearing Unit and Its Operation Mode // Patent of Russia №2347960.2009. – Bul. № 6.

5. Push A.V. Spindle Units: Quality and Reliability. – M.: Mechanical Engineering, 1992. – 228 p.