PARTLY POROUS GAS STATIC BEARINGS OF HIGH-SPEED SPINDLE UNITS OF METAL-WORKING MACHINES

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Operating characteristics comparison of gas static supports with porous and, widely used in speedy spindle industrial constructions, gas bearings with feeding holes is given. Construction and technical data of a high-speed unit on gas static supports with porous inserts are described.

One of the important problems of mechanical engineering is in achieving a high accuracy and parametric reliability of metal-working machines.

Already at a stage of design calculations, there is a need to develop such machine assemblies and elements which would be able to provide a specified accuracy of machining throughout their service life. The investigations [1] on estimating the influence of different factors on the accuracy of machining show that it is about 80% determined by a spindle unit. Since the shape-generating motion is carried out by a spindle and spindle bearings, it is precisely they that are of crucial importance in the output characteristics of machines.

The work of spindle units supported by rolling bearings is accompanied, in particular, by an unstable spindle motion and thermal misalignment of bearing assemblies. Using hydrostatic bearings in high-speed spindle units leads to a spindle speed limitation (because of friction loss) and makes the design of bearing assembly more complicated. Spindles supported by electromagnetic-bearings are not widely used so far because of their complication and the high cost of spindles and electronic control systems. Spindle units supported by gas-lubricated bearings are free of the above-listed shortcomings.

A long-standing experience of the Experimental Scientific Research Institute of Metal-Cutting Machines (ESRIMM) [2] in operating high-speed gas-bearing spindle units in conditions of small- and full-scale production has enabled to reveal their main advantages over the rolling-bearing spindle units, namely, longer lifetime determined by the time of spindle operation with a steady quality of grinding, better quality of grinded surface due to lower spindle sensitivity to the unbalance of a mandrel and wheel, no need to warm-up spindle, much lower (4 – 5 times lower) level of vibration, lesser wear of a grinding wheel.

Gas bearings have also some disadvantages which are in a comparatively low stiffness, bearing and damping capacities of the lubricant film. That is why bearings of this kind are used in light-loaded spindle units where the dynamic loads are light and the static loads are regulated.

The output characteristics of high-speed spindle units supported by gas-lubricated bearings can be significantly improved by using gas static bearings with a partly porous shell wall. Some results of the investigation into characteristics of this kind of bearings under radial load on the spindle are presented in Works [3, 4]. Meanwhile, the actual operation of a spindle unit is characterized by that the spindle reacts the radial load which leads to a displacement of the spindle centre in the plane $X O \bar{z}$, simultaneously with the longitudinal moment causing a spindle axis displacement in the plane $X' O \bar{z}$ (Figure 1).

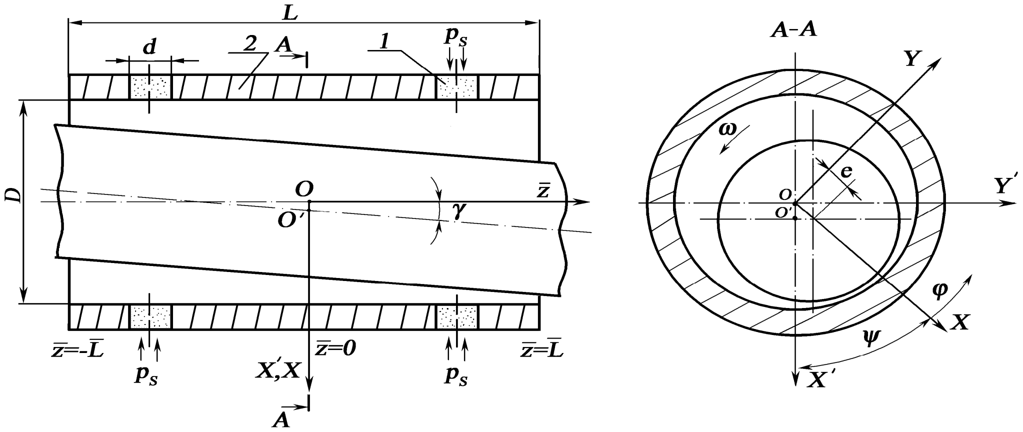

Figure 1. Diagram of spindle position in a double-row gas static bearing with porous inserts: 1 – porous insert, 2 – gas-tight surface of a shell

Taking this into account, there has been developed a procedure for calculation of operating characteristics of a partly porous gas static bearing with consideration for a spindle axis misalignment in the bearing shell. The procedure is based on a numerical method of calculation of the bearing characteristics at only radial load on the spindle and is detailed in Work [4]. Without going into details of the developed procedure, it should be noted that the relative clearance between the spindle and the shell was given by the following formula:

$$\bar{h} = h/c = 1 - e\cos j - (\bar{g}/\bar{L})\,\bar{z}\cos(j - y),$$

where c is the average radial clearance between the spindle and the shell, $e = e/c$ is the relative eccentricity, $\bar{g} = gL/(2c)$ is the misalignment parameter, `$\bar{L} = L/D$ is the relative length of the bearing, j is the angular coordinate, y is the angle of load orientation, $\bar{z} = 2z/D$ is the relative axial coordinate of the bearing. The integration of Reynolds equation was made in the variation ranges of independent variables $-\bar{L} \le \bar{z} \le \bar{L}$ and $0 \le j \le 2p$.

The devised procedure has enabled to conduct a widespread theoretical investigation into the angular characteristics of gas bearings with porous inserts and to compare them with the characteristics of gas static bearings with supply holes (restrictors) which are usually used in the industry-used designs of high-speed spindle units. This comparison was made at equal values of non-dimensional parameters of bearings – the parameter of regime $\bar{m}$, the relative length of bearings $\bar{L}$, the relative gas boost pressure $\bar{p}_s = p_a / p_s$ and the value of compressibility *B*. So, for example, Figure 2 shows the dependence of the angular stiffness k_g upon the relative eccentricity *e* of the double-row gas static bearings with porous annular inserts and those with supply holes of a simple orifice type and annular type. From the shown dependences it is clear that, excluding the range of very low values of the relative eccentricity (*e* < 0.2), the partly porous gas static bearing has higher values of the angular stiffness.

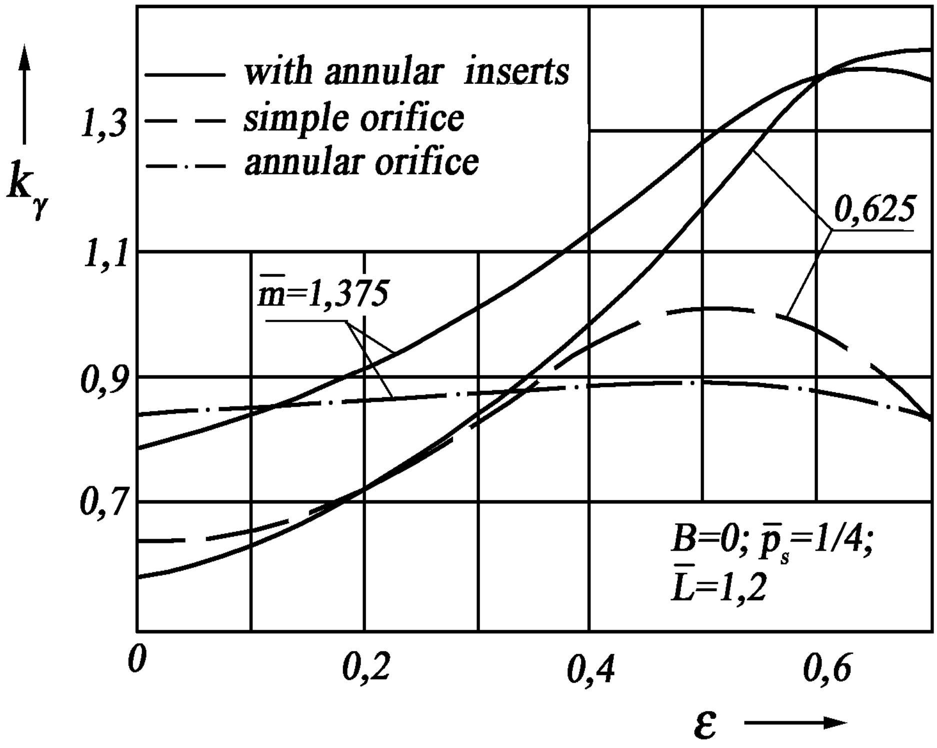

Figure 2. Comparison of characteristics of gas static bearings with annular inserts and those with supply holes in the angular stiffness k_g

As a whole, it was found by way of calculation that in the range of working values of the relative eccentricity (e = 0.4 – 0.8) the radial stiffness coefficient of partly porous bearings is 10–30% higher than that of spindle bearings with supply holes, the angular stiffness coefficient is 30–35% higher, and the coefficient of carrying capacity is 10–20% higher.

Additionally, a comparison of stiffness on a grinding wheel for a spindle supported by gas static bearings with porous inserts and those with supply holes was made by an example of their using in the commercial design of the electro spindle Model A24/25, the technical characteristics of which are described in Work [5]. It has been determined that with the spindle supported by the bearings with a partly porous shell wall the stiffness on its grinding wheel can be about 23% higher.

To check the correspondence of the theoretical results of the investigations with the actual data, a physical experiment has been carried out for estimating the influence of the shaft displacement y at the different relative gas boost pressure $\bar{p}$ on the load F measured on the shaft cantilever. The analysis of the obtained results showed in Figure 3 indicates that the error of theoretical determination of the load F on the shaft cantilever does not exceed 17% of the stiffness $k_F = F / y$ – 15%.

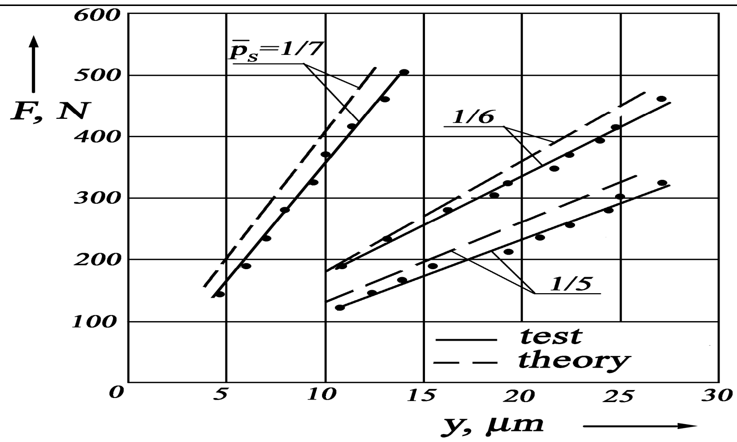

Figure 3. Dependence of the load *F* on the shaft cantilever upon the shaft axis displacement *y* and the relative pressure $\overline{p}_s$

The results of the investigation into operating characteristics of gas static bearings with a partly porous shell wall formed the basis for developing a high-speed spindle unit which was put into operation at the Komsomolsk-on-Amur branch of JSC "Sukhoi Design Bureau". The spindle unit is operated as a part of the grinding machine Model 3A228. Its design is shown in Figure 4.

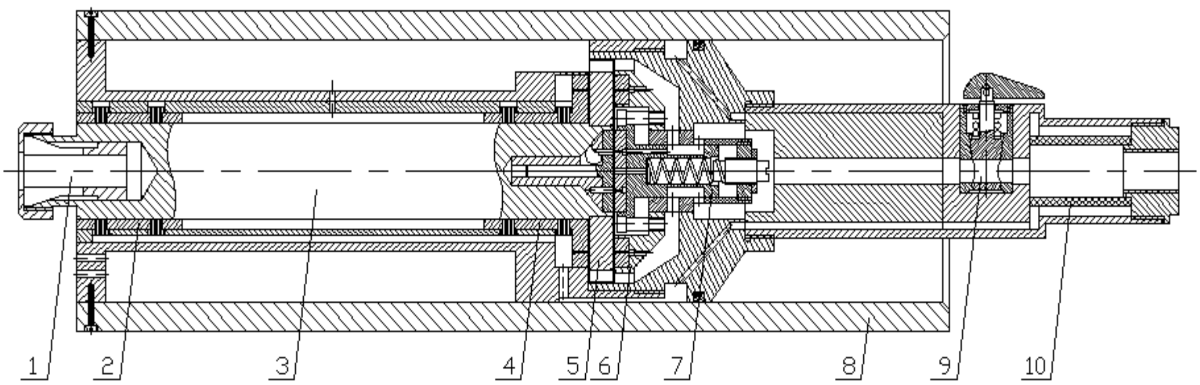

Figure 4. Design of the high-speed internal grinding spindle unit:
1 – collet chuck, 2 – journal bearing, 3 – spindle, 4 – journal-thrust bearing,
5 – turbine wheel, 6 – nozzle diaphragm, 7 – limiting rotational speed governor,
8 – sleeve, 9 –valve, 10 – filter

The gas bearings of the spindle are one double-sided thrust bearing with micro labyrinths and two radial bearings with partly porous shell walls. The radial bearings each have two rows of porous inserts 4 mm in diameter which are evenly situated over the circumference. The material of the inserts is porous bronze made by the method of powder metallurgy.

With a spindle diameter of 30 mm, the relative length of bearings is 1.2. The relative distance between the porous inserts and the bearing end surfaces is 0.26. The average radial clearance *c* is 17 µm. The bearing shells are of bronze Br010 (Бр010) and the spindle is of high-speed steel P18 (grade in accordance with GOST). Once been turned, the spindle was hardened to the *HRC* 60-62 hardness with cooling below 70 °C between intermediate temperings. Such heat treatment stabilizes the structure of the metal and thereby prevents the spindle from warpage in the future. Once the spindle surface has been finished, the form deviations such as taper, out-of-roundness, barrelshapedness, etc., were no more than 10 µm.

At an excess air pressure of 0.5 MPa, the spindle unit has the following technical characteristics:

Power, kW	1.6
Rotational speed, rpm	32000
Specific speed, mm/min	$9.6 \cdot 10^5$
Diameter of hole grinded, mm	max. 200
Diameter of grinding wheel, mm	max.70
Overall dimensions:	
sleeve diameter, mm	100
length, mm	400
Weight, kg	18

The testing of the prototype internal grinding spindle head carried out at the branch of JSC "Sukhoi Design Bureau" has shown a good quality of holes grinded by the 25CT18K electrocorundum wheel (steel X18H10T (grade with accordance to GOST), the roughness R_a does not exceed 0.04 µm), a high accuracy of machining them (the circularity deviation is no more than 0.2 µm, the surface undulation in lapping mode has not been found) and a trouble-free operation of the gas bearings. Also it was determined that, when using the developed spindle unit design, the wear of grinding wheel is 1.4 times less in comparison with the industry-used high-speed spindle head Mod. ВШГ 000.000РЭЭ supported by rolling bearings. The labour productivity in this case is 2.3 times higher.

Literature

1. Push A.V. Spindle units. Quality and Reliability [Text] / Push A.V. – M.: Machine Building, 1992. – p. 228.

2. Kazntsev Ye.L. Performance and technological capabilities of aerodynamic support spindles. Control Materials [Text] / Kazntsev Ye.L. – M.: Publishing House ENIMS, 1971. – p. 48.

3. Kosmynin A.V. Analytical calculations of general properties of radial gas-lubricated bearings with porous fuse elements [Text] / Kosmynin A.V., Vinogradov V.S., Lyamkina Ye.M. // Machine Building Reporter. - 2001. -№5. – pp. 15–18.

4. Kosmynin A.V. Method of analysis of steady-state properties of radial gas bearings with partially porous pillow wall [Text] / Kosmynin A.V. // Machine Building Reporter. - 2002. -№12. - pp. 3–7.

5. Sheinberg S.A. Gas-lubricated slider bearings [Text] / Sheinberg S.A., Zhed V.P., Shisheyev M.D. and others; under the reduction of Sheinberg S.A. – 2nd issue, and added. – M.: Machine Building, 1979. – p. 336.