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Numerical computation of the main gas-dynamic bearing static characteristics for the ball gyroscope

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Abstract. The numerical computation questions and analysis of the engineering calculation of the main gas-dynamic bearing static characteristics for the ball gyroscope experimental model are considered. The developed gyroscopic device construction is provided. These investigations for evaluation of the possibility to realize a sensitive element, which base on the developed device were provided. It is supposed, that this sensitive element can be used in information measuring systems of various applications. The main calculation data, such as load-bearing capacity and other characteristics of the hemispherical gas-dynamic bearing is carried out. According to the attained results, preliminary implications are stated. The basic problems for the further research are determined.

1 Introduction

One of the most important gas bearing advantages is using the ambient air as a lubricant reservoir directly. A bearing, where gas is injected in the lubricating gap by the motion of the lubricated surfaces and there are no additional sources of pressurized gas, are known as self-supporting or gas-dynamic. This type of bearing was taken as a basis for the designed device [1].

Gas lubrication has special features which are typical for its nature. In comparison with liquids, gas has the less viscosity. Ambient temperature acts on the gas properties with a small effect. Ambient pressure impacts on the gases far less. Such viscous stability and its small quantity open the wide variety of gas bearing application in devices working on a high speed with a wide range of operational temperature and pressure [1]. Therefore, gas bearing application is determined by these unique advantages in cases when the traditional types of bearings lose their properties [2].

At this stage, the main project purpose is to define the mathematical model for calculation of the main static gas-dynamic bearing characteristics. It is necessary for evaluating the possibility to use this kind of bearing as a suspension of the gyroscope ball rotor. It is planned that developed gyroscopic device can be used as a position sensor of information measuring systems working under the severe climatic and mechanical conditions. Due to this fact, such sensor has to meet requirements connected with efficiency, surety, and accuracy [1, 3].

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2 Device construction

Figure 1 shows the developed gyroscopic device construction with gas-dynamic bearings. The main elements of the experimental model are: as the bearings, there are two hemispherical bowls 7, rotor 1 is placed in the cavity of these bowls. It is a standard ball bearing. It has an axial bore, additionally. Moving parts of the dual axis angle transducer 4 are pressed in the pole places of the axial bore. The transducer mating part 3 is placed in one of the bowls. The diameter of the bowl forming sphere for 5÷10 mm more than actual diameter of the ball rotor, which is 28,587 mm. Thereby, such difference provides the initial gap which is necessary for operational regime.

The ball rotor is rotated by a three-phase asynchronous motor 2. Power 40 V, at frequencies 500 or 1000 Hz.

In general view control position elements of the ball rotor are not shown.

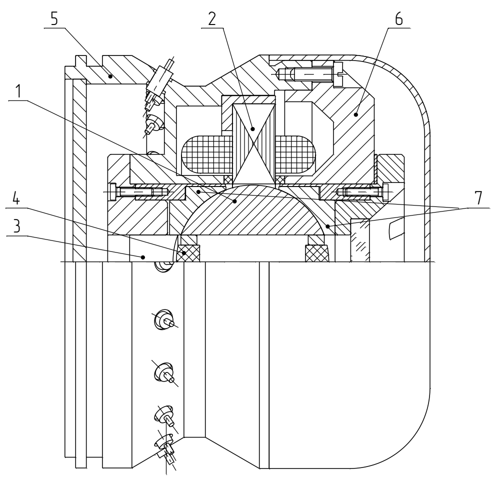

Figure 1. General view of the gyroscope experimental model:
1 –ball rotor, 2 – stator part, 3 – dual axis angle transducer, 4 – moving part of the transducer, 5 – case, 6 – cover, 7 – hemispherical bowls.

3 Modeling procedure

Experimental and, especially, theoretical research plays a crucial role in assessing the gas-dynamic bearing characteristics. Mathematical modeling comes to the fore as an experiment for units operating on gas lubricant at the design stage. It is attributable to difficulties and expensiveness of the high precision manufacturing suspension parts.

The principal characteristics estimating efficiency and reliability of the units with gas lubrication are: load-bearing capacity, bearing stiffness, and quantities of the viscous and dry friction momentums (the last value is important only for the initial start time) [3].

A number of several characteristics such as bearing radius, clearance, presence of the grooves, parameters of the gaseous medium (viscosity, free-path length of gas molecules, pressure and temperature), magnetic traction, geometric errors of the “contact” surfaces, injection capability, bearing microprofile, and other parameters, have a huge impact on the gas-dynamic bearing characteristics in general [4].

At this point, there are a number of universal software tools using to solve some problems of gas dynamics. These software tools are: LS-DYNA, ABAQUS, STAR-CD, ANSYS modules - CFX and Fluent, Flow Vision and others [5].

Among them, the most appropriate software package is ANSYS 15.0 (Fluent and CFX modules). The mathematical model is based on solving the equations system. This system consists of the fundamental laws of mass, momentum and energy conservation. The system is closed by initial and boundary conditions, as well as defining relations. If some effects are not accounted by the grouped equations, it will taking into account by the special turbulence equations. The resulting synthesized system is the Navier-Stokes equation. It is general equation of the laminar flow of viscous gas dynamics.

Initial data for the computation is shown in Table 1. It contains information about geometric and gaseous medium parameters, and rotation speed.

Table 1. Initial data for parameters computation of the working gas-dynamic bearing variant (unshaped).

Mathematical model	AKN, SST
Gap range, microns	2÷20
Gap minimum value providing by the existing elements, microns	5
Rotor nominal speed at the supply frequencies, rad/s 500 Hz 1000 Hz	 850 1675
Gaseous medium	air
Gaseous medium model	incompressible ideal gas
Temperature and pressure conditions	normal

Using software package ANSYS 15.0 – Fluent, two-dimensional model of the system "rotor-bearing" was formed. Also, operating pressure in the gap bearing was calculated. The simulation results are presented in Figure 2.

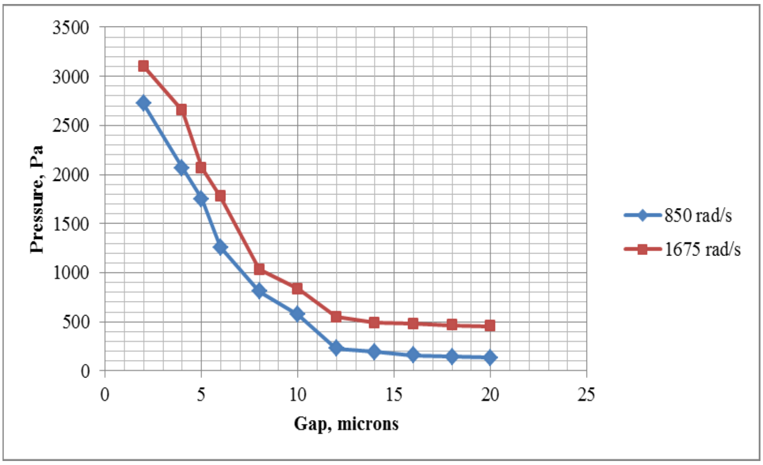

Figure 2. Dependence of the pressure distribution on the gap bearing at the rotor nominal speed 850 rad/s and 1675 rad/s.

If clearance increases, pressure in the gap will decrease. It reduces load-bearing capacity efficiency. The highest pressure can be obtained when the gap magnitude less than 2 microns.

In reality, the minimum gap value, which can be provided by existing elements base of the experimental model, is about 5 microns.

Table 2 presents mathematical modeling results and estimating computation of the gas layer parameters at the 5 microns gap. It was provided at two basic nominal frequencies of rotation as shown in Table 1.

Table 2. The main gas-dynamic bearing characteristics (unshaped).

Parameter	**Value**	
Rotor speed, rad/s	850	1675
Ball rotor weight, N	0,8	
Reference suspension area, cm^2	4	
Operating pressure, Pa	1749,2	2067,3
Load-bearing capacity, N	0,7	0,83
Maximum viscous momentum, N·m	0,0012	0,0023

Calculated values of the load-bearing capacity show the following. When the gap magnitude is equal to 5 microns and rotor speed is 850 rad/s, bearing, at a given load (own weight), will not work in the gas lubrication regime. The load-bearing capacity is less than the ball rotor weight.

In comparison with the full-scale simulation, results are different. It is assumed, that geometric and technological errors of the hemispherical bowls working surfaces increase the injection capability. In theoretical model such results were not observed, since the injection capability was not included, due to the consideration of smooth, perfectly shaped hemispherical bowls [6].

At the rotor speed 1675 rad/s, bearing worked in the gas lubrication regime, which was confirmed experimentally.

The viscous friction momentum effects on the rotor acceleration, determines the required electric power, characterizes heating, and influences on the device sensitivity. The more the gap bearing is, the less viscous friction momentum effects. At the same time, the load-bearing capacity and rigidity become lower, and device sensitivity decreases too [6]. Decreasing of the last values will adversely affect the possibility of using this type of bearing as the suspension for the gyroscopic sensor. Therefore, the main solution for reducing viscous friction momentum influence is to feed into gaseous medium (not air). It will reduce the aerodynamic drag and accelerate the processes of heat removal, as well as allows designing of a reliable sensory system with satisfactory accuracy [7].

4 Conclusion

Investigations of the main gas-dynamic bearing static characteristics for the ball gyroscope show the convergence results for both mathematical and physical experiments [6]. It is found that the effectiveness of this bearing realization is not high in terms of load-bearing capacity and, obviously, the device sensitivity as an inertial sensor. It should be noted that geometric errors of the rotor surfaces and hemispherical bowls were not taken into account in the theoretical model. Further research will be focused on improving physico-mathematical model, parameters optimization [8], as well as to address the other issues related to costing and achieving acceptable results.

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