Journal of Physics: Conference Series **671** (2016) 012020 doi:10.1088/1742-6596/671/1/012020

The Statement of Design and Application Questions for the Gyroscope with a Gas-dynamic Suspension of Ball Rotor in the Navigation Support Drilling System

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Abstract. The general issues of creation the inertial navigation system are considered. Analysis of the possible implementation of the gyroscope with a gas-dynamic suspension of ball rotor for using it as a sensor in the information and measuring complex is provided. The permissible layout construction is proposed. The software system variants for the mathematical modelling of the main gas-dynamic bearing characteristics are considered. Mathematical modelling is essential to extend and optimize the design parameters of the developed gyroscopic construction. Some results of modelling, theoretical evaluation and preliminary experimental studies are summarized.

1. Introduction

In the process of well construction measurement accuracy and efficiency of data submission largely determine the construction cost as a whole. Consequently, the creation of reliable measuring systems with an acceptable accuracy, which based on inertial sensors, is a very urgent task. Such systems must suffice the requirements for the drill body orientation in the process of the well development [1].

Currently, the borehole orientation systems which use the magnetical elements are known very well. Accuracy of such systems is highly depends on the presence of the magnetic anomalies near from the flux gate sensors. In contrast, the main advantages of the gyroscopic sensor elements that determine their application in the borehole orientation systems are immunity to ferromagnetic masses and magnetic anomalies, as well as positioning the borehole axis in relation to the geographic coordinate system. But, inertial sensors application in the borehole orientation systems shows their low reliability under the high level of external exposure factors because of their support and other mechanisms. The most stable, in such conditions, can be gas-dynamic bearings as a support of the sensor rotor.

Appliance of the gas-dynamic bearings is mainly designated by the features that characterize the natural gas lubrication [1]. Gases, essentially, have the less viscous than liquid. Environmental temperature has a little impact on them. Even less they affected by the environmental pressure. Such viscosity stability and its small value open up the great possibility for using such type of bearings in the devices which operate at the high speeds over a wide temperature range.

Gas bearings may also be used in the field of high radioactivity as organic lubricant in such conditions loses its operating properties. Moreover, gas-dynamic bearings, compared to other, have no limitation on the service life because of wear absence during operation. Also, these bearings exclude the number of negative phenomena caused of the dense vibrations spectrum as in the case of the ball bearings [1].

2. The statement of the main problem

The main document that sets out requirements for the geophysical equipment is the standard 26116-84. According to this document, during the design process of borehole navigation system their size is strictly limited as the diameter of the well is a standard value. The second decisive factor is the operating conditions, which are regulated by this normative document too [1].

The list of defined parameters which is determined by the system is ordinary: determination of the azimuth, zenith angle and the angle of tool rotation. Accuracy requirements for inertial navigation system elements, in particular for gyroscopes, have a value in the range of 0.25–1 angular degree. It is necessary for the storage accuracy or recreation in another way the reference inertial orientation [2].

The main goal of this research is to develop the sensor, which based on the gyroscope with a gas-dynamic suspension of ball rotor. And inside of this basic goal there are different tasks. At this moment, the most important is a modelling of the main bearing characteristics. It is essential to determine the optimal parameters for the estimation of the technical realization the position sensor or an angular velocity sensor, which can be used in the borehole orientation system.

Accuracy and reliability of the gyroscopic device are requested to ensure due to sufficient reserves of bearing capacity, stiffness of gas-dynamic bearings and, therefore, ensure the gyroscopic device durability [3].

It is expected that the application of this type of sensor in the navigation support drilling system will improve measurement accuracy, reduce human and financial costs without quality loss in the implementation of promising drilling types.

The basic operation principle of borehole orientation system, where developed gyroscopic device can be used, is the following: location of the drilling tool is defined in relation to the geographically oriented coordinate system. For its creation two reference vectors are used: the gravity acceleration at the measuring point and the angular velocity of the Earth's rotation. In order to determine the projection of the gravity acceleration, navigation system must contain, at least, two accelerometers. Information about the angular velocity of the Earth's rotation comes from the gyroscopic device. In this case, the gyroscope is a two-part angular velocity sensor.

Further, by means of the certain algorithms, orientation parameters of the drilling tool are calculated relative to the reference coordinate system [4]. It is important that the sensor will be efficient and retain their accuracy characteristics at the stopping time of the borehole tool for measurement. If these requirements are achieved it would lead to a fundamentally new level in matters of metrological support drilling.

The factors, which have mentioned above, define the basic requirements for the design and operating conditions of inertial sensors, show that the computational simulation of the bearing characteristics coming to the fore because of several reasons. Firstly, the formulation of the experiment is extremely complicated by the need to provide special materials and technical base. Secondly, manufacture of support elements is difficult. The geometry of the bearing parts has the high demands.

On the other hand, preparation of the settlement programs is also very complex and multifaceted task, because of successful realization is necessary to have certain skills in programming and applied mathematics. There are a number of universal software tools that are used to solve some problems of gas dynamics, such as LS-DYNA, ABAQUS, ANSYS modules - CFX and Fluent, Flow Vision and others. Their usage is conditioned by the fact that they help to solve some problems of gas lubrication. When they are used in this field, there is a set of specific problems, which do not allow using them effectively. This is the basic complexity of the gas-dynamic bearing characteristics mathematical modelling.

The general gyroscope layout view and the construction are shown in figure 1 and figure 2.

The main parts of the gyroscope layout are two hemispherical bowls 7 and rotor 1, which is placed in the cavity of the bowls. Rotor is a standard ball bearing and has an axial bore, where movable elements of angle sensor 4 are pressed. Mating part of the angle sensor 3 is positioned in one of the bowls. The diameter of the bowls for 5 ÷ 10 microns more than the actual diameter of the ball rotor. The rotor diameter is 28.587 mm. This difference provides the initial gap. Ball rotor is rotated by the three-phase asynchronous electric stator 2. Its power is 40 V at frequencies of 500 or 1000 Hz.

As the rotor rotates, the gas is drawn into the initial gap between the bowls and the rotor. With further gas influx into the bearing gap the overpressure is formed. Whereby, the rotor "floats" and when the rotor rotates at nominal speed and it provides the constant gas lubrication.

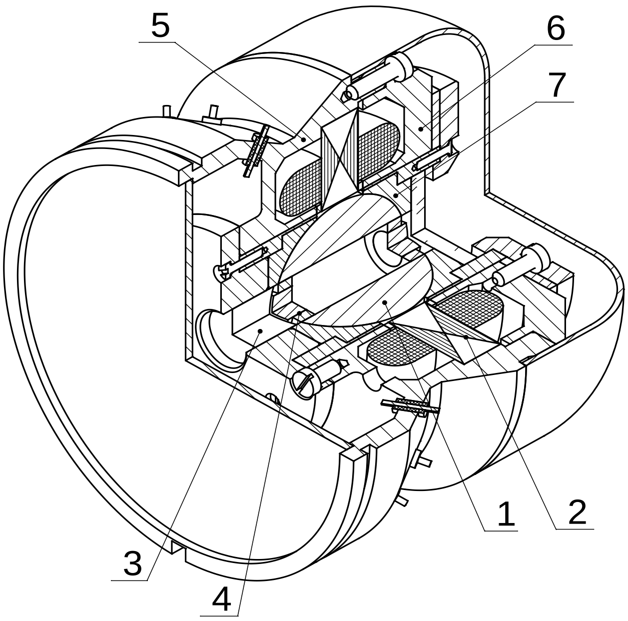

Figure 1. The construction of the gyroscope layout with a gas-dynamic suspension of ball rotor:
1 – ball rotor, 2 – stator of the electric driver, 3 – two-part angle sensor,
4 – mating part of the angle sensor, 5 – device case, 6 – device cover,
7 – hemispherical bowl.

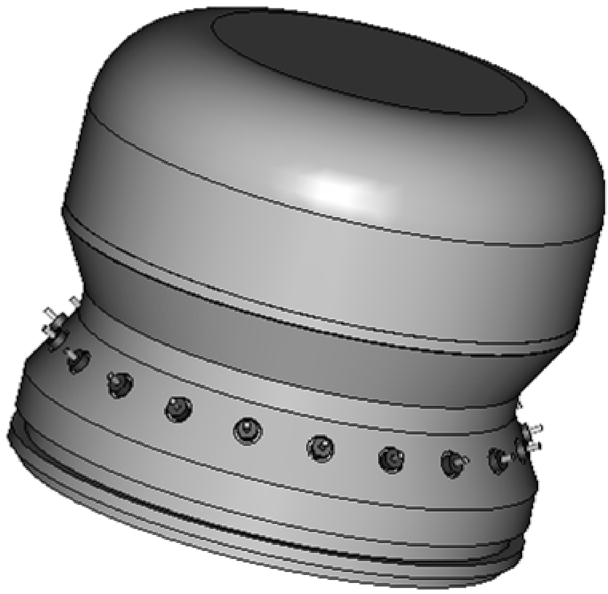

Figure 2. The general view of the gyroscope layout

In the general view do not shown the elements of controlling the ball rotor position.

Layout overall: diameter – 77 mm, length – 68 mm. The dimensions are not final.

3. Results and considerations

The dependence of the pressure distribution in the bearing gap was determined by the mathematical modelling in the software envelope ANSYS 15.0 - Fluent and estimations of the main gas-dynamic bearing characteristics. Also, the influence of the relative eccentricity and radial clearance to the minimum rotor speed at which the bearing starts to work in gas lubrication mode was established. Moreover, the estimation of the viscous friction moment value and stiffness of the suspension at different values of the radial clearance in the bearing were assessed too.

The range of the bearing gap values is from 2 to 20 microns by selecting the diameters of the ball rotors. It was found that the lifting force will be decreased because of clearance reduction and, as well as, pressure reduction in the bearing. The optimal gap values in the bearing up to 2 microns. In this case, the stable operation of the gas lubrication at a given load (at the moment, this load is a own weight which equal to 0.8 N) will be achieved. If the gap value is equal to 2 microns it will mean that we can get a pressure of 3102.8 Pa on a smooth surface of the bearing. This value has an equivalent of the bearing lifting force is 1.24 N at the rotating speed 16 000 rev/min. According to these estimations, the rotor floats at the speed of 300 rev/min. The results are not effective. If the gap is less than 2 microns, we can get the pressure, which is several times greater than the pressure at 2 microns. Such values are guaranteed to provide a margin of the bearing capacity, which is currently unavailable.

The maximum value of the viscous friction moment achieves the value 0.0023 Nm. The magnitude of this parameter makes it possible to evaluate the effect of air resistance to heat and sensitivity of the device. The primary method of the reducing the influence of viscous friction is the introduction of the gaseous medium [5]. It can greatly reduce the heat loss and increase the number of revolutions, thereby providing a stable value of the angular momentum.

As for the stiffness of the suspension, it largely shows the subsidence of the ball rotor [6]. It can lead to an undesirable eccentricity between the ball rotor and the hemispherical bowls. The values, which were achieved, are relatively low. It is also explains by the smooth surface of the bearing. Bearing shaping can be as a primary solution for increasing the rigidity of the bearing. Also, for achieving the maximum suspension stiffness, the clearance must be done as low as possible.

4. Conclusion

Mathematical modelling of the gas-dynamic characteristics for the ball gyroscope shows the convergence of the estimating and full-scale simulation results. It shows that this realization of the gyroscope with a smooth profile of the bearing is inefficiency in terms of bearing capacity.

Further research will be focused on a testing of physical and mathematical model of the gas-dynamic bearing characteristics, increasing of the bearing capacity and rigidity. It will also be connected with an optimization of the ball gyroscope construction in particular bearings profiling, selection of the gaseous medium, and issues related to a control of the ball position. It is necessary for a further application of the gyroscope as a sensor in the underground navigation.

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