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Study of Wear in Subminiature Thrust Rolling Bearing

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Promising results of wear tests performed on a novel rolling thrust micro-bearing with a diameter below 1 mm are presented. The applied custom measurement setup and the developed method of testing are described. A significantly longer life of the tested bearing was obtained (4.5 times) owing to a modification introduced in the mechanical structure of the bearing, which consisted of machining a groove across the raceway. A similar effect of wear reduction (3 times) was obtained while tilting one of the bearing discs.

topics: rolling bearing, axial bearing, tribology, friction

1. Introduction

Most of the research related to mechanical wear is focused on introducing new materials, as in [1], or applying special coatings, as in [2], in order to improve resistance to wear and usually decrease friction between the mating elements at the same time. However, significant improvement in wear behavior can also be obtained by introducing appropriate modifications in the mechanical structure of the studied elements. A good evidence of the effectiveness of such an approach is the presented study related to a subminiature thrust rolling bearing.

It is well known that requirements regarding the rolling elements for rolling bearings are very demanding: small deviations of the geometrical shape, low surface roughness, high mechanical strength, and durability. Therefore, it is very difficult to fabricate such elements at the low cost of lot production. Whereas in the case of sliding micro-bearings a number of different materials is available, e.g., various polymers [3], in the case of large rolling bearings, the balls are made of either bearing steel or ceramic materials. However, the smallest balls available have a diameter of 0.5 mm. So, while building a micro-bearing that employs smaller balls, it seems that the only economic solution is to use glass balls for micro-lens. A typical material such balls are made of is soda–lime glass [4].

Rolling bearings irrespective of their dimensions, whether miniature (the outer diameter less than 1 mm) or large (the outer diameter up to 1000 mm), have a similar structure, namely they consist of rolling elements moving between two raceways. These bearings have various designs of the raceways and cages, and their members are made of various materials.

At the end of the 1980s, the first designs of non-lubricated micro-scale rolling bearings appeared. When operating under thrust load, these bearings did not meet requirements related to durability. The main reason for this are problems associated with the fabrication of the rolling elements with sufficient accuracy, which determines the slippage that occurs during their operation.

In order to reduce resistance to motion and wear, lubricants are used. However, in bearings with an outer diameter smaller than 1 mm, it is very problematic to apply any lubricant. Besides, the fabrication of raceways having an appropriate shape, over which small balls are to move, is very difficult and expensive for manufacturing reasons. For instance, the complex process of manufacturing the raceways in silicon may take 8 to 12 weeks.

However, the aforementioned slippage can be eliminated by using the patented method described in [5]. A bearing consisting of two rings equipped with raceways, along which the loaded rolling elements travel, has a groove machined in at least one of the raceways. The groove is arranged transversely to the direction of movement of the rolling elements. Such bearings can operate without lubrication.

Miniature rolling bearings were studied by various research teams, usually as members of some more complex devices [6–9]. Results of wear tests performed on members made of silicon were also reported [10, 11].

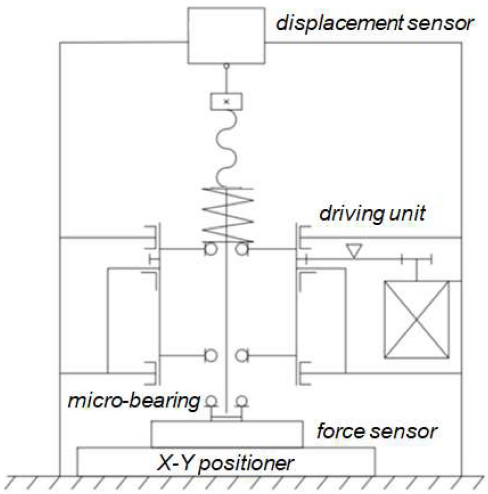

Fig. 1. Kinematic diagram of the measurement setup.

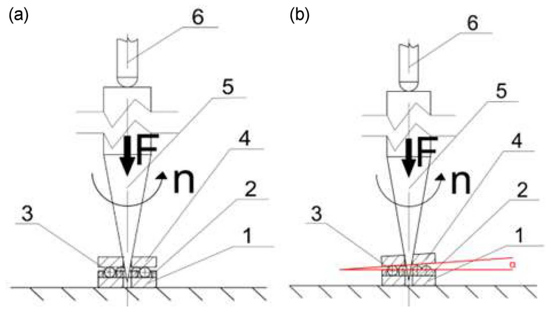

Fig. 2. Connection between the driving shaft and the micro-bearing: 1 — bottom bearing disc, 2 — cage, 3 — rolling elements, 4 — upper bearing disc, 5 — driving shaft with a conical tip, 6 — displacement sensor; (a) standard setup; (b) skewing of the upper disc introduced on purpose.

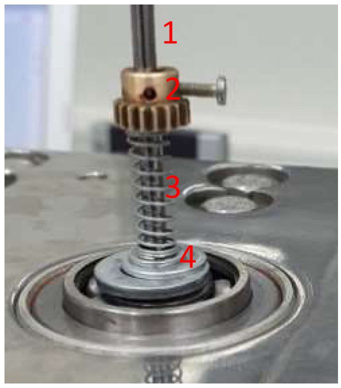

Fig. 3. Unit controlling the axial load employing a cylindrical spring; 1 — driving shaft, 2 — element blocking the spring on the shaft, 3 — spring relieving the tension, 4 — element connecting the spring with the top bearing.

In the presented study, we decided to adapt the method proposed in [5] in order to reduce the wear of a recently designed subminiature rolling thrust bearing, whose raceways are made of stainless steel.

2. Structure of the bearing

In [12], we minutely described the mechanical structure of the tested thrust micro-bearing, and in [13] we discussed the impact of cage thickness and some coatings on friction. In this paper, we focus on the wear of the bearing observed during the experimental study, paying special attention to the influence of the grove created across the raceway of the bearing, exactly as specified in the relevant patent pending [14].

In standard ball bearings loaded radially, some of the balls are usually cyclically unloaded and thus can move freely, which is why the durability of these bearings is significantly greater, even though they may not be lubricated. In the case of a thrust bearing, we propose to create a groove across the raceway in order to reduce the load on the rolling element. Then, the balls are not loaded radially and do not press against the cage. The same effect can be obtained by tilting the upper ring of the bearing.

2.1. The measurement setup

The kinematic diagram of the measurement setup is shown in Fig. 1. The force is measured in real-time by the force sensor (electronic jewellery scale) on which the tested micro-bearing is placed. Precise positioning of the micro-bearing is realized by means of the X–Y positioner (two motorized linear stages), which applies displacements in two perpendicular axes X and Y. The force sensor and the tested bearing are rigidly attached to the positioner.

The driving unit consists of a direct current (DC) motor which drives a driving sleeve through a belt transmission, which contains an overload mechanism transferring the drive to the shaft (no. 5) (Fig. 2). The conical tip of the shaft (no. 5) is connected with the upper disc (no. 4) of the tested micro-bearing; it wedges into a hole created in the center of the disc (no. 4), and thus provides a frictional coupling between these two elements.

Lowering of the driving shaft during the test, which is used as an indicator of wear of the micro-bearing, is measured by means of an inductive linear displacement sensor. The sensor acts also as the loading system, allowing an additional axial force to be applied. The axial force is generated by a spring mounted to the rotating shaft at one end, and resting on the inner ring of the rotating rolling bearing at the other end (Fig. 3). The loading force acting on the micro-bearing is determined by the weight of the shaft, the load imposed by the displacement sensor and adjusted by the tension of the relieving spring.

2.2. Measurement parameters

The measurements were performed using a load of about 330 mN applied with uncertainty of ±30 mN. The bearings were rotated with a speed of 14 rpm in order to keep control of the rotational speed of the cage as related to the speed of the discs. The outer diameter of the bearing was 0.7 mm and the average time of operation was 60 hours. Measurements were divided into three groups: (i) the reference group, which consisted of standard axial bearings; (ii) the group with the correction groove machined; and (iii) the group in which the upper disc was purposefully tilted, for a total of 15 measurements (Fig. 2).

2.3. Materials of the bearing members

The members of the bearings used in the measurements were manufactured by laser cutting out of 304 stainless steel sheet, having smooth surfaces. The rolling elements were soda–lime glass balls with diameter of 0.1 mm, acquired from the Cospheric company. Even though the laser cutting creates rough surfaces, the influence of shape errors and roughness of the holes cut out in the cage does not affect the operation of the bearing, as the balls roll over the smooth surfaces. The influence of various cage thicknesses on the friction within the bearing raceway was studied in [13]. Owing to the obtained results, 50–60 μm thick cages and balls with 100 μm diameter were selected for the wear tests of the bearing.

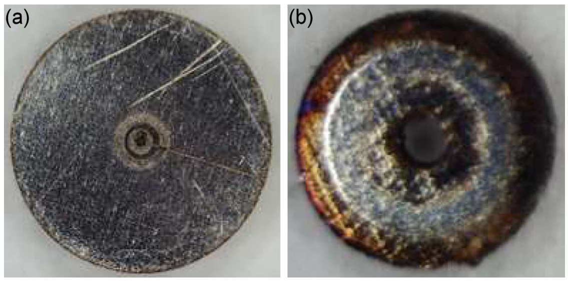

Fig. 4. Wear track of the bearing: (a) the bottom disc (with visible correction groove); (b) the upper disc.

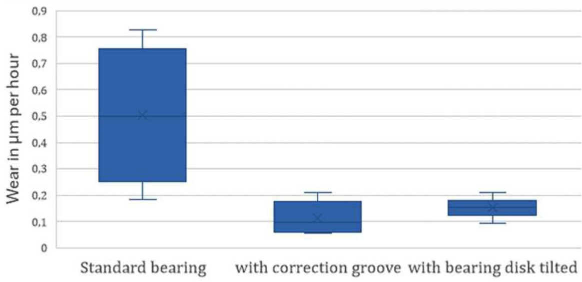

Fig. 5. Wear per hour of operation for each tested group for a total of 15 measurements.

3. Experimental results

After the measurements, the bearings were disassembled and individual members were observed under a microscope. Exemplary members are shown in Fig. 4.

We determined the wear as a decrease in the height of the entire bearing, thus it is the sum of the wear of the raceways and the rolling elements in a linear direction. The results of such wear within the three tested groups are presented in Fig. 5. The wear is illustrated as average per hour of operation of the bearing.

It can be observed in Fig. 5 that the reference group differs significantly from the other two. The t-test between the reference group and the one with a correction groove yielded a value of 0.001, which confirms the discrepancy between the groups. It can be stated that either by using the correction groove or by tilting the upper disc, the wear was significantly reduced.

4. Discussion

Differences in the diameter of the rolling elements make them travel different distances during the same number of revolutions. For instance, when balls have diameters that differ by 2 μm from each other and the bearing rotates at the speed of 500 rpm, the balls can travel in 1 min distances over the raceways that differ even by 10 mm. In thrust rolling bearings, all rolling elements are loaded, so their motion must involve slippage relative to the raceway.

If the slippage occurs, the forces acting between the ball and the cage (or between adjacent balls in the case of a bearing without a cage) must exceed the value of the sliding friction forces. Such an increase in forces and the occurrence of sliding friction lead to faster wear of the rolling elements and the raceways.

However, a transverse groove allows the balls to temporarily operate in a no-load regime and stay in contact with only one of the raceways. As a result, the rolling elements are released from the contact forces with the cage, or the adjacent rolling element, which occurred due to their different diameter. This allows the ball to be moved within the cage opening and thus the forces acting on the cage are reduced. A similar effect can be observed in the case of tilting one of the discs of the thrust bearing. This also suggests a possibility of using at the same time both methods of extending the life of thrust bearings.

5. Conclusions

Thrust micro-bearings were studied to investigate their wear. We tested the impact of the corrective groove, i.e., a transverse cut-out across the raceway, with a rectangular cross-section, created to reduce wear in the bearing by limiting the forces between the rolling elements and the cage that occur due to the difference in the diameters of the rolling elements.

It is worth noting that this problem occurs on all scales, but on a micro-scale it is more evident than on a meso- or macro-scale. This is due to larger differences in diameters among the rolling elements in relation to their size, which results from the applied micro-scale manufacturing methods. The presented results prove that the introduction of a groove or a tilt of the bearing disc can be used to considerably reduce wear in thrust micro-bearings — the reduction observed was from 0.5 μm per hour to 0.11 and 0.15 μm per hour for bearing with a correction groove and tilted top disc, respectively. Due to this, the tested bearing can potentially operate without lubrication.

Acknowledgments

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