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DEVELOPMENT AND MODERNIZATION OF A COMPLEX OF INSTALLATIONS FOR WEAR TESTING OF METAL-POLYMER COMPOSITE MATERIALS FOR SPHERICAL SLIDING BEARINGS

The fretting corrosion machine has been modernized for testing spherical bearings under vibration conditions. The method of research of anti-friction composite materials and coatings for low-frequency reversible movements has been developed. A method for laboratory resource tests of aviation spherical sliding bearings with metal-polymer composite materials in conditions close to real has been developed.

Key words: *spherical bearing, metal-polymer materials, technique, installation, reversible movement, wear, testing, operating conditions, modernization.*

Introduction. This type of bearing does not have a rolling element. When working, there is no circular rotation. This group of bearings is widely used in aviation industry. Spherical bearings are designed to transmit radial, axial and combined loads in moving or stationary connections of machines and mechanisms. They are used to compensate distortions, temperature and elastic deformations that occur during aircraft operations**.**

Bearings with anti-friction coatings are used in the structural components of the landing gears and the control system of almost all modern aircraft, such as B-767, B-777, B-787, A320, A330, A340, An-124, An-225, etc. where more than a thousand such bearings are used. Props of rocket engines and gas turbine engines in civil aviation aircraft work on self-lubricating coatings [1]. These materials are widely used in turning units and ball bearings of cars and trucks, as well as in special mining equipment, steering rod joints. Similar coatings have found application in the textile industry, for example, loom races. They are used in transport and lifting and transport engineering, in food machines where lubrication is not permissible, in variators, etc.

Many works [2-4] are dedicated to wear resistance tests. According to the international standard ASTM G99 and ISO 7148-2, the study of the wear resistance of polymer and metal-polymer materials is carried out according to the end friction scheme, in which constant speed and load conditions are ensured during the experiment.

However, there are works [5-7] where the load is set gradually and increases during the tests. This simulates the operation of a sliding bearing close to real conditions, where during operation, the contact area of the triboelements increases with an increase in the operating time of the bearing.

However, these techniques do not correspond to the real conditions of spherical bearings operations in aircraft under conditions of reversible friction and vibrations. Therefore, for more research of increasing the durability of spherical bearings and the selection of metal-polymer material for use in them, we developed and modernized existing methods to bring them closer to the real operating conditions of bearings in the aviation industry.

The purpose of the study was to develop a complex of methods for the study of spherical sliding bearings and the metal-polymer materials used in them, and the modernization of existing installations in order to bring the tests closer to the real operating conditions of spherical bearings, in accordance with the requirements of DIN ISO 12240.

Modernization of the fretting corrosion machine, for testing spherical bearings under vibration conditions. For tests of spherical sliding bearings with metal-polymer materials, the existing method of testing materials for fretting corrosion according to [4] was chosen. The choice is due to the fact that more than six spherical bearings work in the conditions of reversible movements, which are the basis for the realization of fretting corrosion conditions.

The analysis of the operating conditions of aircraft spherical bearings [8, 9] shows that most of the time the tribopairs work in slightly different conditions than the usual fretting corrosion. These are an increased relative amplitude of movement of the samples and a reduced sliding speed and a frequency of oscillations.

Therefore, the modernization of the МФК-1 installation includes:

1. Changing of the eccentric of the installation to increase the sufficient amplitude (from -15 to +15 degrees), which corresponds to the real operating conditions of the spherical bearings with diameters of 6, 8, and 10 mm.
2. Changing the device that loads the spherical bearings up to 550 kg in the radial direction.
3. Production of special clamps for holding spherical bearings during resource tests.
4. Reduction of the frequency and, accordingly, the sliding speed of the bearings to 1-3 revolutions per second. It is achieved by installing an additional gearbox and increasing the cooling flow of the electric motor of the fretting corrosion machine.

The oscillation frequency of 1-3 Hz was determined in the course of research [8-10] and was derived from the operating conditions of the hinged bearings in the levers for changing the angle of attack of the rotor blades of the helicopter's swashplate. For example, the nominal revolutions of the Mi-8 helicopter main rotor are 192±2 rpm, which corresponds to the instrument indicators of 95.3%.

Special clamps are presented in fig. 1 and 2. The clamps allow testing of the real spherical bearings up to 10 mm.

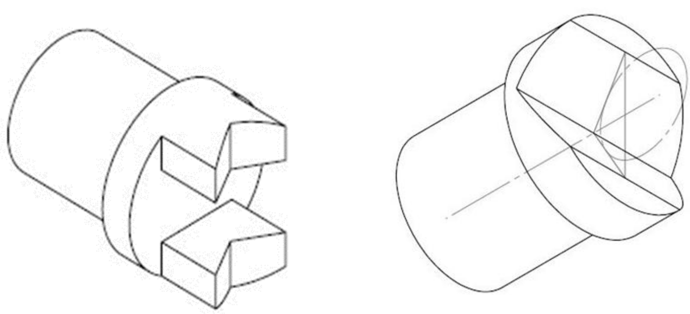

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Fig. 1 – Schemes of clamps of the inner (a) and outer (b) cage of spherical bearings.

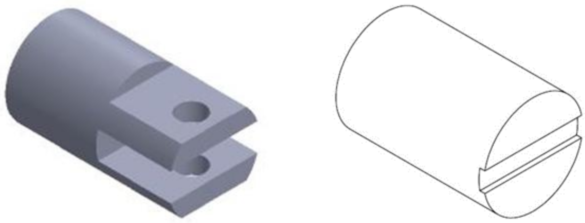

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Fig. 2 – Schemes of clamps of the inner (a) and outer (b) cage of spherical bearings.

The clamps allow securely hold the spherical bearings during resource tests and quickly replace them, a photo of which is presented in fig. 3.

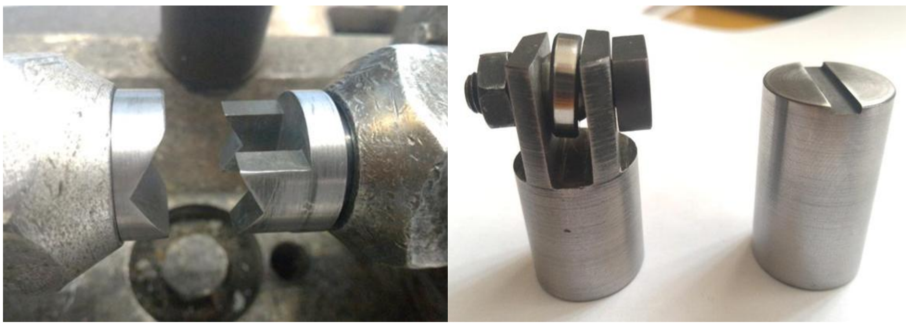

Fig. 3 – A photo of clamps for testing spherical sliding bearings up to 10 mm under vibration conditions on a modernized installation of the fretting-corrosion machine.

The testing according to [4] also allows conducting research in different gas environments and temperatures. Testing of metal-polymer materials used for the production of sliding bearings can also be carried out at appropriate temperatures. The main effective factor affecting the resource is temperature..

According to the operating conditions of bearings on aircraft, their operating temperature is within -50 + 50 °C. If considering the helicopter operating conditions in African continent, the temperature range is from 0 to +120 °C..

Therefore, the influence of temperature on the testinging of metal-polymer materials is a very interesting factor that changes the wear resistance of materials. At the modernized facility, it is possible to conduct tests of hinged bearings with metal-polymer materials up to a temperature of 100 °C with the help of an ordinary hair dryer, which warms up the samples for a few minutes before starting and works throughout the test. It is also possible to carry out tests at negative temperatures (up to -50 °C) using liquid nitrogen.

Development of materials and coatings research methodology for low-frequency reversible movements.

Modernization of the fretting corrosion machine for testing materials in vibration conditions has many advantages, but we faced the task of conducting tests in conditions as close as possible to real ones. Namely, this is the movement of the spherical sliding bearing during operation.

In the previous section, it was mentioned that spherical bearings with metal-polymer coatings are used in moving and fixed joints. For non-moving joints and comparative stages in the first stage of our research, the modernized fretting corrosion machine is very suitable for testing. However, in order to bring the tests and load conditions closer to the real ones, it is necessary to develop a device for the implementation of reversible movements under the action of the load as close as possible to the real ones according to the analysis [4, 8, 9] and the requirements of STP 651.02.061-92 and DIN ISO 12240.

In order to develop a methodology for testing spherical bearings under the conditions of reverse movements, the contact unit of the machine was modernized on the basis of МФК-1 and a special device was developed for loading and holding samples for testing.

The samples on which the material for reversible friction tests was applied or glued, is a hexagon with flat working surfaces, which is presented in fig. 4. This sample was fixed in a clamping device and was stationary.

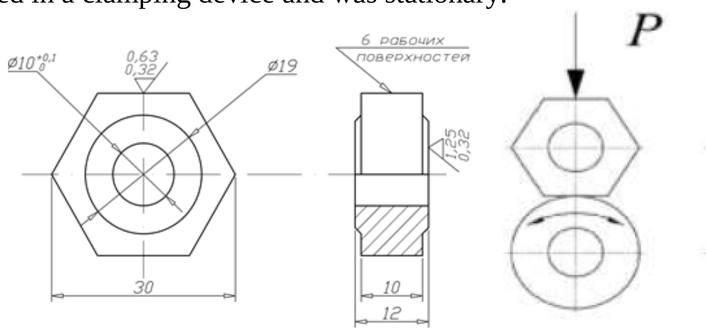

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Fig. 4 – Samples for testing materials and coatings (a) and the load diagram for testing materials and coatings during reverse movements (b).

A suitable movable counter sample can be a 5-10 mm wide ring cut from a real spherical bearing 20-30 mm in diameter. The material of the counter sample is the real material from which the bearings are made and is usually ШХ15, 95Х18 or 12Х18Н9Т.

The counter sample material can be processed by various methods to determine the optimal tribopair. Under normal conditions, in standard sliding bearings of the ШН type, this is polished material 95Х18 або 12Х18Н9Т if the bearing is used in aviation. But there are options with polished chrome and ceramic coatings.

The criterion for evaluating the wear resistance of metallopolymers can be the maximum depth of material damage. Wear can be measured using the HANDYSURF 550 profilometer-profilograph according to ISO 17025:2017 by determining the maximum average damage to the material from 5 sections of the working surface of the sample.

There are works [11, 12] where in similar contacts during tests the wear factor is the volume of the material that was worn during the tests. For example, in works [12], this factor is used to analyze the wear of gas-thermal coatings and cobalt-based materials. In our case, the material is somewhat plastic, so we used linear wear.

Tests should be performed at least three times for each point on the diagram for reliability. To hold the hexagonal samples in the working area, a special device has been developed that allows to load and periodically observe the friction surface of the samples during research. It is very important to observe the contact of the friction surfaces during the tests. But not every installation or device allows to do this. The problem is that the tribocontact must be in the same place, without displacement. This device allows periodically unload the system and observe the action of the mechanisms that occur during friction, without changing the mounting of the sample and the counter sample. For example, there is no such possibility in the fretting corrosion machine. Photos of the unit that loads samples are presented in Figure 5.

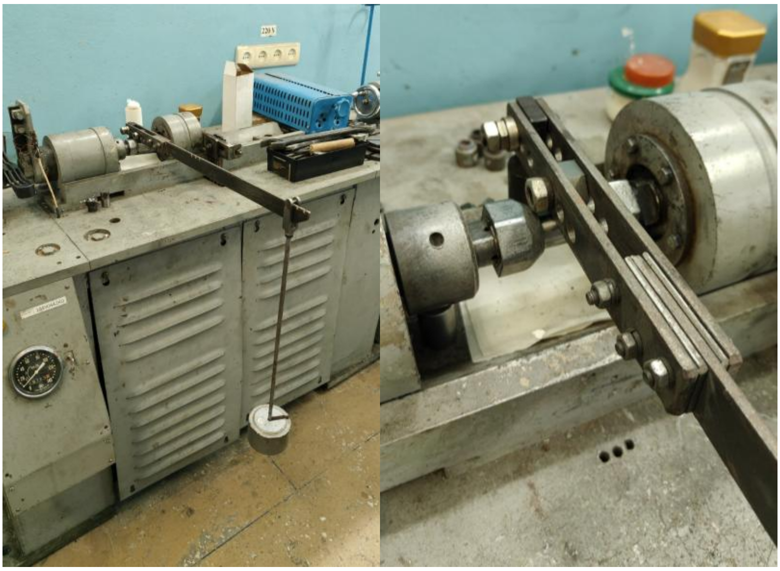

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Fig. 5 – The appearance of the installation (a) and a photo of the device (b) that holds and loads the samples during reverse friction tests.

It should be noted that the developed device also allows conducting research at temperatures up to 100 °C. That is, the advantage of testing the modernized device, which was described above, remains. Heating of materials for testing is possible using a similar method.

Development of a methodology for laboratory resource tests of aviation spherical sliding bearings in conditions close to real ones.

For testing of spherical bearings with metal-polymer composite materials with a diameter of 12 to 30 mm, an installation was developed that simulates special operating conditions of bearings in a wide range of loads. A feature of this installation is that the testing of ready-made spherical bearings with geometric dimensions in accordance with DIN ISO 12240 and GOST 3635-78 (load and number of working cycles, clearance control procedure) and the requirements of СТП 651.02.061-92 (load for articulated bearings, test base for resource studies , test conditions) that were defined during the development of this installation as basic. There are works [13, 14] on the development of similar installations, but they have certain shortcomings and do not meet the operating conditions of articulated bearings.

The installation was developed in accordance with tripartite agreement No. 1049-X16 "Development of methodology and improvement of equipment for testing of spherical bearings" between the National Aviation University, State Enterprise Antonov Plant and LLC "Ukrtekhavia".

The scheme of the installation is presented in Figure 6. The installation allows testing of spherical bearings in conditions of reversible friction with a combined (radial and axial) load of up to 200 kN..

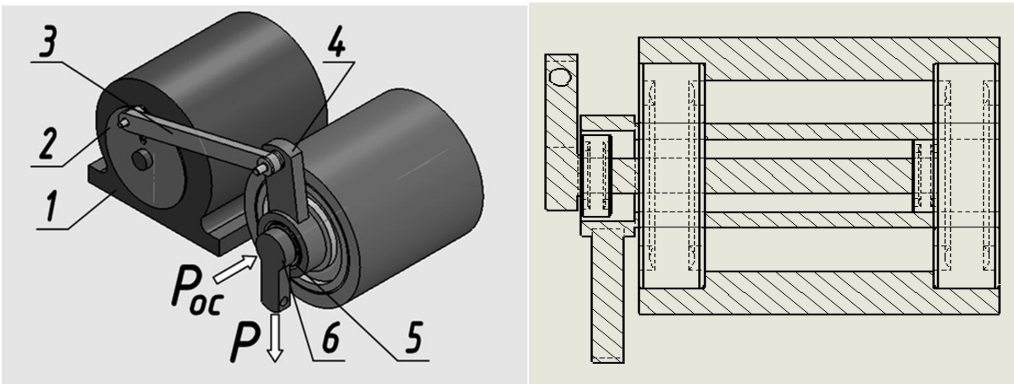

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Fig. 6 – Scheme of the developed installation (a) for resource tests of spherical bearings with a load of up to 200 kN and the design of the housing that allows holding and loading the bearing (b): 1 – electric motor-gearbox, 2 – disk for changing the angle and oscillations, 3 – force transmission lever, 4 – retainer of the outer bracket of the bearing, 5 – housing (main unit) where the hinged bearing is located, 6 – lever of the inner bracket of the hinged bearing.

The installation works as follows. The electric motor-reducer 1 of the МЦ2С-80 type drives the disk 2 on which the lever 3 is fixed. The speed of rotation is from 1 to 5 revolutions per second and it can be changed by changing the speed of rotation of the electric motor. Disc 2 has slots. The movement of the hinge of the lever 3 in the slots of the disk 2 will determine the angle at which the hinge bearing will move during the resource tests. The angle at which the bearing shifts is adjusted by means of hinges and disk 2, which is installed on the motor-reducer 1 and is equal to 15 to 90 degrees. The retainer 4, on which the outer ring of the hinged bearing is fixed, receives the load from the lever 3 and turns it into a reciprocating movement. The holder 4 is located in the housing 5 and has a free rotational movement. The housing 5 holds the holder 4 with the help of two rolling bearings located at the two ends of the shaft. The lever of the inner bracket of the hinged bearing 6 is a shaft, which is held on one side in the housing of the hinged bearing under study, and on the other hand in a conventional rolling bearing. The design load is applied to the lever of the inner bracket of the hinged bearing 6, which is set by a hydraulic jack of the ДГС-10 bottle type in 50 kN (Fig. 1.8b) and is increased to 200 kN with the help of the lever. The pressure is controlled during resource tests using a manometer.

A specific feature of these tests is that for each type-size of hinged bearings with a diameter of 12 to 30 mm, it is necessary to manufacture transitional bushings. With heavy loads, it is necessary reliably hold the hinged bearings in the installation nodes.

It is possible to test a bearing size of 35 mm. To do this, it is necessary to make a transition shaft for this specific size. Resource tests for this type of bearing (35 mm) were not carried out, but such a possibility was included in the development of the main body. It should be noted that the loads in this case will be from 50 kN, and the test duration will be more than 10 hours based on the test base of 100,000 cycles. The load should be carefully monitored because during long-term tests and high pressures, the action of the hydraulic jack decreases due to hydraulic losses.

According to [8-10, 15], the load conditions for spherical bearings during tests are combined. That is, simultaneous action of radial and axial force. This possibility is provided in the developed installation. There is an additional device that loads the holder 4 of the inner bracket of the hinged bearing (Fig. 6) and applies a certain force with the help of a lever. According to regulatory documents, the axial force under combined load is 10% of the radial force.

Therefore, the developed installation for resource tests of spherical bearings of standard sizes from 12 to 35 mm allows conducting research in the following ranges:

1. Oscillation frequency of spherical bearings from 1 to 5 oscillations per second.
2. The radial load of the spherical bearing is up to 200 kN.
3. Axial load of the spherical bearing up to 5 kN.
4. The angle at which the spherical bearing turns during the tests is from 15 to 90 degrees.

A photo of the developed installation for laboratory resource tests of aviation spherical sliding bearings is presented in fig. 7. In fig. 8 presents the main node for holding spherical bearings and a hydraulic jack for realizing real load conditions up to 200kN.

The results of wear of articulated bearings during tests and after disassembly according to the conditions of DIN ISO 12240 and ГОСТ 3635-78 must be carried out according to the scheme presented in fig. 1.9 The wear of spherical bearings means the axial gap between the inner and outer rings under the influence of a certain load. For example, for the ШН30ЮТ spherical bearing, it is 200N according to the technical documentation for the Mi-8/17 helicopter. The developed installation allows determining the axial clearance of the bearing without dismantling it from the place of attachment.

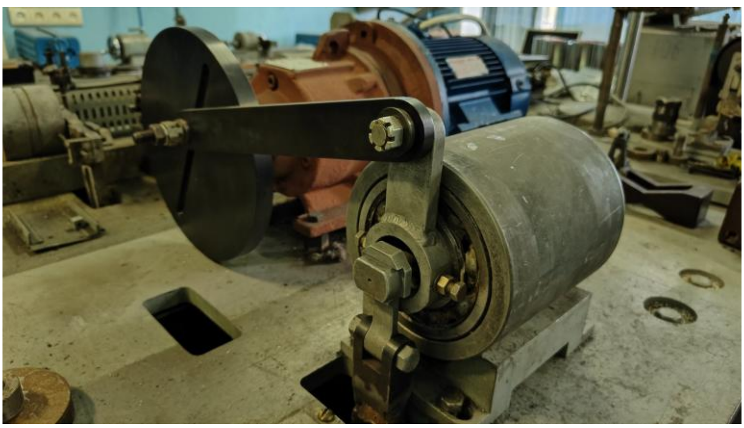

Fig. 7 – A photo of the developed installation for laboratory resource tests of aviation spherical sliding bearings.

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Fig. 8 – Photo of the main unit for holding the spherical bearings (a) and the hydraulic jack (b) that sets the load during tests.

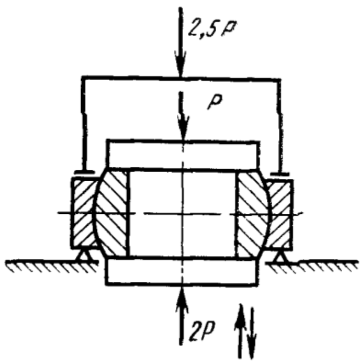

Fig. 9 – Determination of the axial clearance of the hinged bearing according to DIN ISO 12240 та ГОСТ 3635-78.

Conclusions. In this way, the methods of conducting experimental tribotechnical studies aimed at establishing the possibilities of expanding the places of use and effective application of anti-friction composite materials in spherical bearings for the aviation industry have been developed.

A methodology and a special complex of installations for the research of metal-polymeric materials of tribopars, which can be used in spherical sliding bearings for the aviation industry, have been developed. Testing of materials and bearings on a number of installations allows obtaining a special STC (supplemental type certificate) certificate, which is issued in the presence of resource laboratory and industrial tests.

A methodology for the study of metal-polymer materials with low-frequency reversible motions has been developed, which allows testing materials both on laboratory samples and on real spherical sliding bearings with a diameter of up to 12 mm.

A unique methodology and laboratory setup for resource testing of aviation spherical bearings with diameters up to 35 mm has been developed. The installation allows test real spherical bearings and determine the resource depending on the loading conditions, specific operating conditions (vibration, reversible movement, unidirectional movement, oscillation frequency, sliding speed) and specific environment (temperature influence, humidity, dustiness).

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РОЗРОБКА ТА МОДЕРНІЗАЦІЯ КОМПЛЕКСУ УСТАНОВОК ДЛЯ ВИПРОБУВАНЬ НА ЗНОШУВАННЯ МЕТАЛОПОЛІМЕРНИХ КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ ДЛЯ ШАРНІРНИХ ПІДШИПНИКІВ КОВЗАННЯ

Шарнірні підшипники із металополімерними композиційними матеріалами всі ширше застосовують у всіх галузях машинобудування і особливо в авіації. Особливою перевагою цих підшипників є те що вони не потребують обслуговування протягом всього терміну їх служби. Для авіаційній промисловості це переведення обслуговування техніки за фактичним станом, що дозволяє суттєво заощадити на витратах при технічному обслуговуванні. Отже, виникли певні питання у створенні логічної послідовності випробувань матеріалів для підшипників та розробки та модернізації існуючих методик випробувань.

Згідно міжнародному стандарту ASTM G99 та ISO 7148-2 дослідження зносостійкості полімерних та металополімерних матеріалів відбувається за схемою торцевого тертя, при якому забезпечуються незмінні умови швидкості і навантаження протягом експерименту. Однак ці методики не відповідають реальним умовам роботи шарнірних підшипників на повітряних суднах, які працюють в умовах реверсивного тертя та вібрацій. Тому для більш детального дослідження підвищення довговічності шарнірних підшипників та вибору металополімерного матеріалу для застосування в них, нами було розроблено та модернізовано існуючі методики з метою наближення до реальних умов роботи підшипників в авіаційній галузі.

Ключові слова: шарнірний підшипник, металополімерні матеріали, методика, установка, реверсивний рух, зношування, випробовування, умови експлуатації, модернізація.

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