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FRICTION MOMENT EVOLUTION IN THE RUNNING-IN PERIOD OF HIGH-SPEED ANGULAR CONTACT BALL BEARINGS

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ABSTRACT

During the running-in, the contacting surfaces of various mechanisms undergo continuous change of the micro-topography. When the lubricant is able to reach the steady operating state, this transient period stops. The all-steel and hybrid silicon nitride angular contact ball bearings from 7206C series, running at speeds between 9000 and 45000 rpm, axially preloaded and lubricated by mineral oil-mist, were tested on a high-speed test-rig. The friction moment and the developed temperature were monitored. The running-in period last longer for all-steel bearings, the severe wear being more extended than in the hybrid rolling bearings. The friction moment is also greater in all-steel bearings.

Keywords: Ball bearings, friction, running-in, silicon nitride, oil mist

1. INTRODUCTION

An adequate procedure of running-in maximizes the lives of rolling bearings and brings important savings. The omission of the running-in can draw to the catastrophic failure of devices or to the shortening of the lubricant's life.

For a given application, the running-in period is dictated by the ability of a lubricant to reach a steady operating state. Because the micro-topography and the properties of the contacting surfaces change continuously, in the running-in process, it is indicated to maintain the running parameters (speed, load, and temperature) bellow the normal operating values. Consequently, the running-in is desired to be as short as possible.

The running-in can be accomplished by different methods. The first one is the continuously running-in when the speed is gradually increased until the functioning speed is attained. This method allows the detection of the potential problems before a failure happens, but it is time consuming (about 10 hours or more). It is recommended for the running-in of new machines and equipments.

The second method is called intermittent running-in and is used for equipments passing through an uncompleted running-in. The time for this operation can be less than the half of the necessary time for a continuously running-in.

A third method is employed just when there is no possibility to gradually increase the speed, and it is called high-speed running-in. This is the shortest of all, the repeated cycles of running-in of increasing tens of seconds being alternated with breaks of few minutes.

Each manufacturer gives indications for the required running-in, depending on the designed machine and the imposed functioning conditions.

The most recent scientific researches on this subject are shortly presented herein. Blau [1] realized a comprehensive study on the phenomena taking place during the running-in of different surfaces. In normal steady functioning of the rolling bearings, the theoretical prediction of the friction torque can be realized considering a mean roughness of races and rolling elements. During the running-in period, more complex models must be used, considering the distribution of the asperities over the contact area and the contact mechanics [2].

Crăcăoanu [3] proposed a deterministic mixed lubrication friction model, focusing on the forecast of the coefficient of friction and wear depth during the running-in of tribological contacts.

Bosman et al. [4] calculated the surface topography change in the running-in of concentrated contacts, using an elasto-plastic contact model based on a semi-analytical method and combining this method with a local coefficient of friction, which is determined using a mechanical threshold on the protective nature of the lubricant, and a strain related failure to model the smoothening of the surfaces protected by a lubricant.

This paper completes the results previously presented by the author in [5], emphasizing the importance of the running-in for the good functioning of mechanical devices.

2. EXPERIMENTAL PROCEDURE

The continuously change in friction, temperature and wear rate is observed after the start of sliding contacts between unworn solid surfaces. Such fluctuations seem normally, but engineers found that an optimal running-in can improve the performances of bearings, gears and seals.

Any change in the surface topography modifies the lubrication regime, the friction forces and the developed temperature.

Therefore, the tribological phenomena taking places in the running-in of rolling bearings can be monitored by the friction torque and outer ring temperature measurements.

2.1. Materials

All-steel and hybrid angular contact rolling bearings from 7206CTAP4 series were tested on a high-speed test rig, the only difference between the two types of bearings being the balls' material: AISI 52100 rolling bearing steel and silicon nitride (Si_3N_4), respectively. The dimensional precision of rolling bearing elements and their physical properties are indicated in Table 1.

The chemical composition of AISI 52100 steel is: C: 0.95 - 1.1 %, Si: 0.17 - 0.37 %, Si: 0.17 - 0.37 %, Mn: 0.25 - 0.45 %, Cr: 1.30 - 1.65 % (wt. %).

For the HIP Si_3N_4 balls, the chemical composition is: Si_3N_4 ~93% and Y_2O_3 + Al_2O_3 ~7%. In addition, it must be noticed that the cage was made from textile-reinforced phenolic resin and is outer race guided.

The cage to outer and inner ring radial clearances are 0.2...0.252 mm and 1.65...1.725 mm, respectively. The ball to cage clearance is 0.14...0.16 mm.

The lubrication of the bearings is realized by H9 hydraulic mineral oil mist.

2.2. Testing Machine

The test rig and the testing device are entirely described in [6]. A general view of the test rig is given in Figure 1.

Fig. 1. General view of the test rig

2.3. Testing Conditions

Two types of running-in tests are carried-out:

1) tests on new unworn ball bearings, at 9000 rpm and 200 N axial load, until the friction moment became stable in time;
2) tests on worn bearings, at constant speed and load, until the equilibrium temperatures of the rolling bearings are reached.

3. RESULTS AND DISCUSSIONS

3.1. Tests on Unworn Ball Bearings

Both running-in tests on new unworn all-steel and hybrid ball bearings are carried out in the same conditions: initial temperature, 15°C, axial load 200 N, speed, 35000 rpm, 15 drops of oil per minute in a draught of air at 2 Bars. The evolution of the friction moment of all-steel (upper) and hybrid ball bearings (lower) in the run-in period is given in Fig. 2. Whenever the operating parameters change, a new running-in period starts, until the rolling bearing tribosystem reaches the equilibrium (constant friction moment and temperature).

Table. 1. Rolling bearing materials

Rolling bearing	Steel and hybrid rolling bearings		Steel rolling bearings	Hybrid rolling Bearings
Material	Rolling bearing steel (AISI 52100)			Silicon nitride (HIP Si_3N_4) Ball grade 3
Parameter and unit system	Inner ring	Outer ring	Balls	
Diameter, [mm]	30	62	9.525	
Roughness, R_a [μm]	0.07.. 0.1	0.065.. 0.1	0.018.. 0.035	0.01.. 0.014
Poisson coefficient, ν	0.3			0.25
Density, ρ [Kg/ m^3]	7800			3200
Elasticity modulus, E [GPa]	208			314
Hardness @ 20 ^{0}C, HV10 [Kg/ mm^2]	700			1700
Thermal conductivity @ 20 ^{0}C, λ, [W/m/^{0}C]	43			30.7
Specific heat, c [J/Kg/^{0}C]	460			810

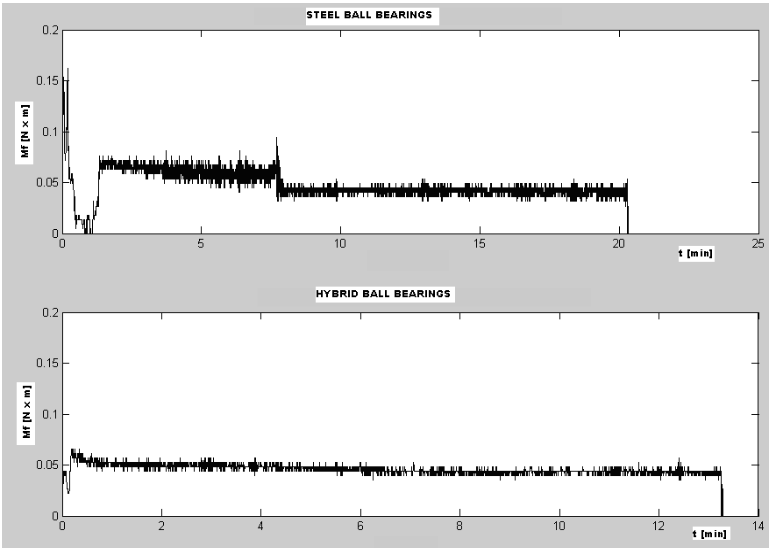

Fig. 2. Results on new unworn bearings

The evolution of friction moment within the all-steel ball bearings is more dynamic than that in the hybrid ball bearings, indicating a longer unsteady operating state.

From Fig. 3, it can be observed from the trend lines that the friction torque is reduced in the hybrid ball bearings, even the speed is not so high (9000 rpm). This is explained by the better finishing of the silicon nitride balls.

The friction torque stabilizes in the hybrid ball bearings in about 2 minutes and keeps constant after, while in all-steel bearings it took longer.

At the end of the tests, the temperature of the hybrid and all-steel ball bearing assemblies was 25°C, and 40°C, respectively.

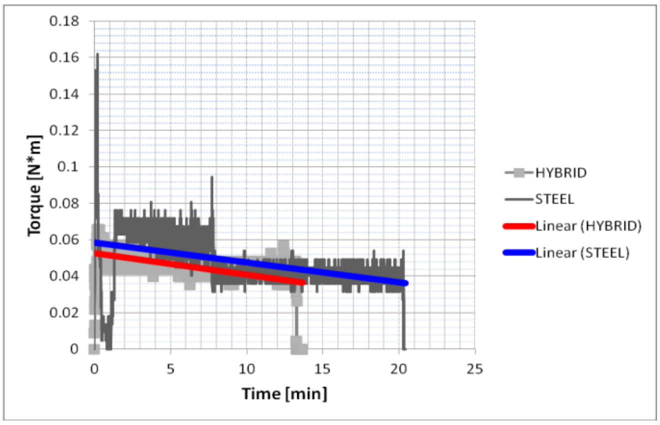

Fig. 3. Comparative results on new unworn bearings

3.2. Tests for the Equilibrium Temperature Reaching

The testing conditions were: speed – 30 000 rpm, axial load – 200 N, oil mist was formed by about 16 drops of oil in a draught of air at 2.4 Bars.

The ball bearings from the previous test are used. The test for establishing the equilibrium temperature in the all-steel and hybrid ball bearings proved that a stable friction torque is achieved faster in the hybrid ball bearings. Also, the friction torque in the hybrid bearings pair is reduced during the whole test of 36 minutes, being about one half of the friction torque measured in all-steel bearings.

For both tests, the start temperature was 40°C. At the end of the tests, the measured temperature on the house of the testing device was 72°C for the hybrid bearings and 83°C for the steel bearings.

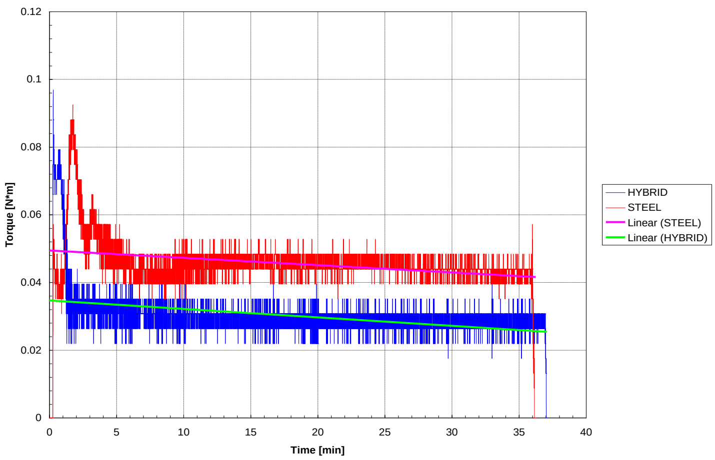

Fig. 4. Tests for the equilibrium temperature

At high speed, the reduced friction and temperature in the hybrid bearings are obtained not only due to the better finishing of silicon nitride balls, but also due to the lower centrifugal forces acting on the ceramic balls, the density of the ceramic balls being about 40% of that of the steel balls.

5. CONCLUSIONS

Any change in the surface topography modifies the lubrication regime, the friction forces and the developed temperature. Therefore, the tribological phenomena taking places in the running-in of rolling bearings can be monitored by the friction torque and the outer ring temperature measurements.

For a given application, the run-in period is dictated by the ability of a lubricant to reach a steady operating state. Because the micro-topography and the properties of the contacting surfaces change continuously, in the running-in process, it is indicated to maintain the running parameters (speed, load, and temperature) bellow the normal operating values. Consequently, the running-in is desired to be as short as possible.

Whenever the operating parameters change, a new running-in period starts, until the rolling bearing tribosystem reaches the equilibrium (constant friction moment and temperature).

All-steel and hybrid angular contact rolling bearings from 7206CTAP4 series were tested on a high-speed test rig, the only difference between the two types of bearings being the balls' material: AISI 52100 rolling bearing steel and silicon nitride (Si_3N_4), respectively. The lubrication of the bearings is realized by H9 hydraulic mineral oil mist.

Two types of running-in tests are carried-out:

1) tests on new unworn ball bearings, at 9000 rpm and 200 N axial load, until the friction moment became stable in time;
2) tests on worn bearings at constant speed and load, until the equilibrium temperatures of the rolling bearings were reached.

The running-in period of the hybrid bearings is shorter than that of geometrically similar all-steel bearings, at both low and high speeds.

The evolution of friction moment within the all-steel ball bearings is more dynamic than in the hybrid ball bearings, indicating a longer unsteady operating state, no matter if the test are carried out on new unworn bearings (case of test no. 1) or on worn bearings (case of test no. 2).

It can be observed from the trend lines (Fig. 3) that the friction torque is reduced in hybrid ball bearings, even the speed is not so high (9000 rpm). At such a speed, the centrifugal forces acting on balls are not very important and the mentioned difference is supposed to be rather due to the better finishing of the silicon nitride balls.

At high speed (30 000 rpm), the reduced friction and temperature in the hybrid bearings are obtained not only due to the better finishing of the silicon nitride balls, but also due to the lower centrifugal forces acting on the ceramic balls, the density of the ceramic balls being about 40% from that for the steel balls.

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