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Experimental and theoretical study of friction torque from radial ball bearings

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Abstract. In this paper it is presented a numerical simulation and an experimental study of total friction torque from radial ball bearings. For this purpose it is conceived a virtual CAD model of the experimental test bench for bearing friction torque measurement. The virtual model it is used for numerical simulation in Adams software, that allows dynamic study of multi-body systems and in particularly with facility Adams Machinery of dynamic behavior of machine parts. It is manufactured an experimental prototype of the test bench for radial ball bearings friction torque measurement. In order to measure the friction torque of the tested bearings it is used an equal resistance elastic beam element, with strain gauge transducer to measure bending deformations. The actuation electric motor of the bench has the shaft mounted on two bearings and the motor housing is fixed to the free side of the elastic beam, which is bended by a force proportional with the total friction torque. The beam elastic element with strain gauge transducer is calibrated in order to measure the force occurred. Experimental determination of the friction torque is made for several progressive radial loads. It is established the correlation from the friction torque and bearing radial load. The bench allows testing of several types and dimensions of radial bearings, in order to establish the bearing durability and of total friction torque.

1. Introduction

In the literature are presented a large number of studies concerning the friction, lubrication and wear of materials. Test procedures for experimental measuring for the friction torque in rolling bearings are presented in [1]. For this purpose it is used a modified four ball machine, in order to test rolling bearings. It is monitored the friction torque and operating temperature.

Other research [2] examines the frictional power loss of a needle roller bearing lubricated with grease. Obtained results reveal that the test bearing has higher friction compared with bearings lubricated with conventional lubrication.

Low cost systems for the force and torque measurement, for wheel bearings are presented in [3]. Also, a study for the friction of a ball screw is presented in [4]. It is presented a theoretical model for the friction between balls of the screw. The study is useful because provides a theory support for reasonably reducing the screw ball friction.

Studies based on the lubrication theory are presented in [5]. It is studied the wear behavior, using a four ball wear tester. Tests are made with a low viscosity additivated mineral oil. Two types of balls are used, steel and ceramic and obtained results shows greater resistance of the ceramic balls.

The effects of roughness upon friction of the plastics, intended for bearing applications are studied in [6]. Obtained results shows that not exists an optimal roughness for minimum friction for polymers and the friction depends on the bulk properties of the polymer.

Aspects concerning automotive tribology are presented in [7]. In this research is presented an overview of various lubrication aspects, for typical power train, including engine, transmission and driveline. Also an aspect presented consist in the currents status and future trends in automotive lubricants. Other comparative studies on the tribological behavior of lubricants are presented in [8]. Test methods for engine lubricants are presented in ASTM (American Society for Testing and Materials) standards and also are available a large number of patents [9], concerning the bearing friction.

2. Theoretical considerations

The resistant torque that appears in roller bearings is produced by a complex of friction appearance ways. The rolling friction phenomena complexity is generated by a large number of factors that occurs simultaneously. The most important sources for bearing friction are: friction generated by the contact deformations, rolling friction on the contact surfaces, friction produced by the lubricants, sliding of bearing elements, friction from seals. For usual calculations the friction torque can be estimated, with sufficient precision, with relations obtained from experimental results. The equation (1) establishes the total friction torque (M_{tc}).

$$M_{tc} = M_f + M_l \tag{1}$$

where: M_l is the resistant torque produced by the fluid friction of bearing elements in contact with the lubricant; M_f is the resistant torque produced by the bearing load.

Equation (1) is used for bearings that operate to moderate speed and loads. In case of the ball bearings, used for high speed, when the frictions produced by the spin and gyroscopic motion are important, should be considered the friction torque produced by these motions.
The resistant torque (M_f) produced by the bearing load, is computed with the equation (2).

$$M_f = f_1 \cdot F \cdot d_m \tag{2}$$

where: F [N] is the bearing radial load; d_m is the bearing medium diameter, in [m].

For radial ball bearings the factor f_1 is established with the relation:

$$f_1 = 0,0009 \cdot \left(\frac{P_0}{C_0}\right)^{0,55} \tag{3}$$

where: $P_0 = F_r$ [N]; C_0= 8000 N, for radial ball bearing type 6204.
In order to compute the resistant torque (M_l) produced by the fluid friction of bearing elements in contact with the lubricant are used equations (4) or (5):

$$M_l = f_0 \cdot (\nu \cdot n)^{\frac{2}{3}} \cdot d_m \cdot 10^3 \quad \text{[Nm], for } \nu \cdot n \geq 20 \cdot 10^{-3} \tag{4}$$

$$M_l = 16 \cdot f_0 \cdot d_m^3 \quad \text{[Nm], for } \nu \cdot n \leq 20 \cdot 10^{-2} \tag{5}$$

Where: ν is the kinematic viscosity of the lubricant, in [m^2/s]; n is the bearing operating speed, in [rpm]. For the considered case, f_0= 1,5~2 and ν = (25~33)$\cdot 10^{-6}$ [m^2/s].

3. Experimental test bench description

For experimental measurement of the bearing torque it is used the test bench shown in figure 1, where the tested bearing is mounted on the shaft (2) and it has oscillating exterior housing, as see in figure 1.
The actuation is made with an electric motor, with the nominal speed of 1450 rpm.

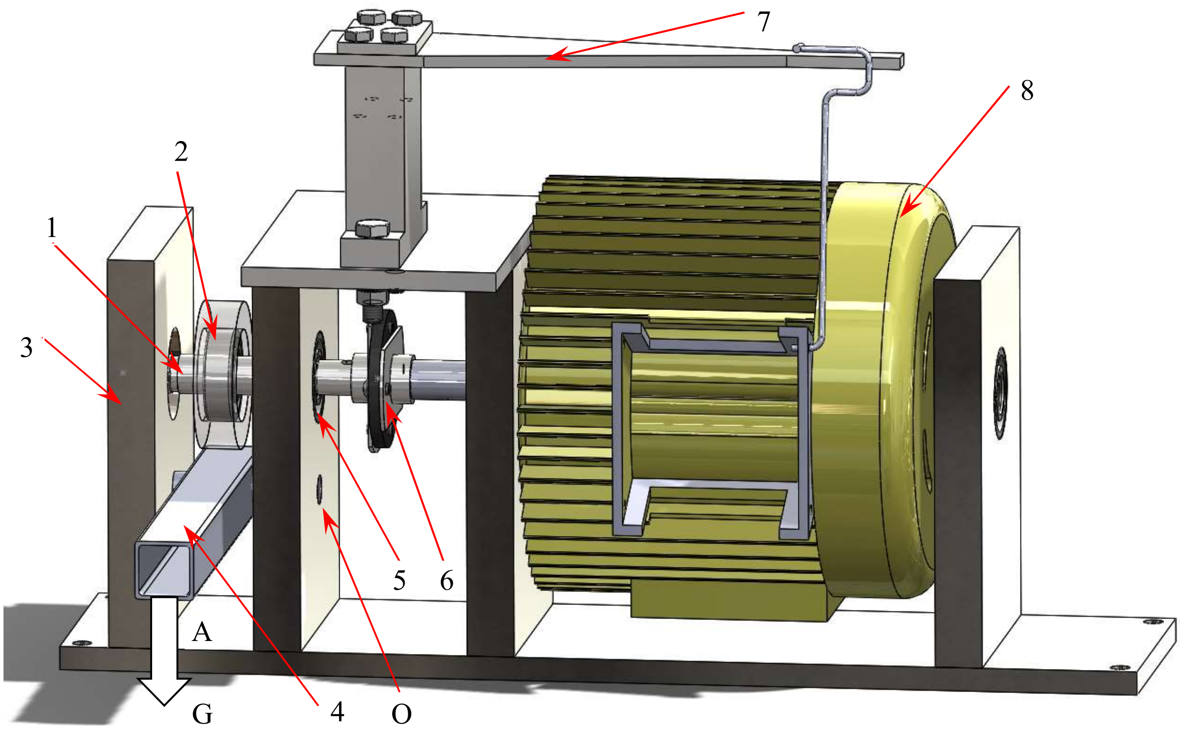

Figure 1. Design of test bench for bearing friction torque measurement.

Components of the test bench are: (1) shaft, (2) –tested bearing, mounted on oscillating housing; (3) – shaft bearings supports; (4) –lever to produce the radial load; (5) –shaft bearings; (6) – elastic coupling; (7) –beam with strain gauge transducers; (8) – electric motor.

Radial ball bearing (2) subjected to experimental tests is mounted on the shaft (1). The outer rig of the tested ball bearing is mounted to an oscillating cylindrical bush. The radial load of the bearing is created with the lever (4) that is articulated to point O (figure 1). To point A are added additional weights G (as see in Fig. 4) in order to create different radial loads for the bearing. Electric motor (8) is used to rotate the shaft (1). The shafts of tested bearing and electric motor are connected with an elastic coupling (6). Electric motor stator is fixed with a tie rod to the elastic beam (7) free side. The elastic beam is subjected to deformations proportional with the motor torque. In order to measure the beam bending force, produced by the motor torque are used the strain gauge transducers (10), as see in figure 2. With experimental calibration is established the dependency between elastic deformation versus bending force and motor torque, which is necessary to be determined.

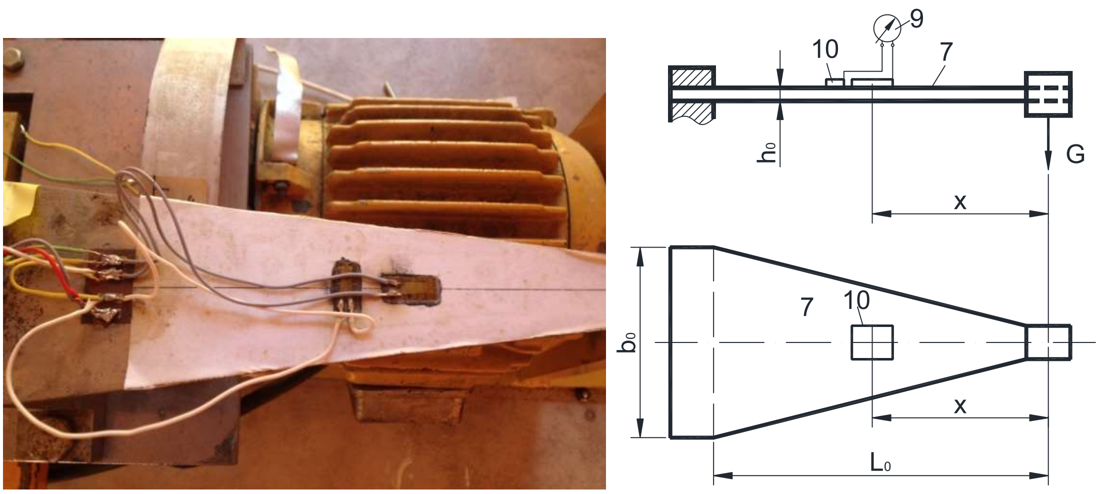

Figure 2. Equal strength beam used to measure bending force.

Bending stress that appears in the beam is computed with equation (6).

$$\sigma_j^{ex}(x) = E \cdot \varepsilon_j^{ex} \cdot 10^{-6} \left[MPa\right] \quad (6)$$

where: E is the Young's module for the beam material, in [MPa], ε_j^{ex} is the experimental measured deformation, in $\left[\mu m/m\right]$. For experimental measurement of the deformation it is used the MGCPlus acquisition system from Hottinger Baldwin Messtechnik. In order to evaluate the bending force, the beam transducer it is calibrated. The calibration diagram of the strain gauge transducer is presented in figure 3.

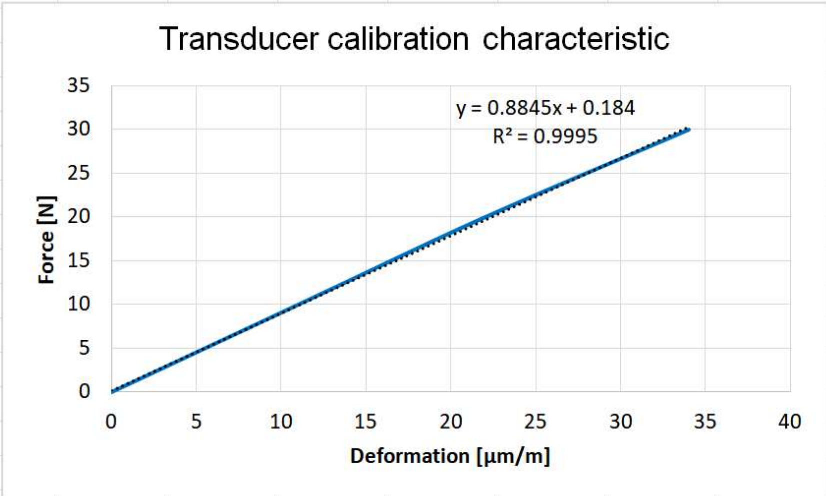

Figure 3. Transducer experimental calibration characteristic.

The experimental test bench for bearing friction torque measurement, developed in the Machine Design Laboratory, from Faculty of Mechanics, Craiova, is presented in figure 4. Also is shown the experimental acquisition system MGCPlus used to measure friction torque.

Figure 4. Experimental test bench and acquisition system.

Preliminary obtained results consist in the deformation of the elastic beam measurement. Originally acquired results, with the acquisition software Catman AP are presented in figure 5. The registration presented in figure 5 corresponds to the bearing function with zero radial loads. Tested radial ball bearing is type 6204, manufactured by SKF. To this operating regime the elastic beam deformation is stabilized to 12.5 µm/m. To this deformation corresponds a bending force of 11.06 N. Considering the distance between electric motor shaft and beam longitudinal center, as 71.3 mm, it results a friction measured torque by 788.57 Nmm.

The radial force in order to load the bearing is created by adding metal discs with 1.8 kg weight of the lever (4), as see in figure 4. Registered results of the beam deformations, by adding three supplementary loads are presented in figure 6. Obtained results, corresponding to radial load regime, shows an increase of the total friction torque.

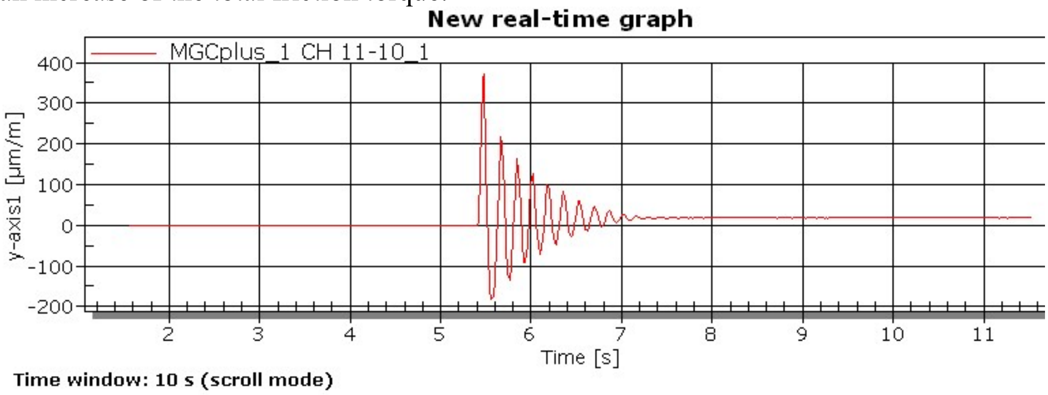

Figure 5. Experimental registered deformations of the elastic beam (bench start and no radial load).

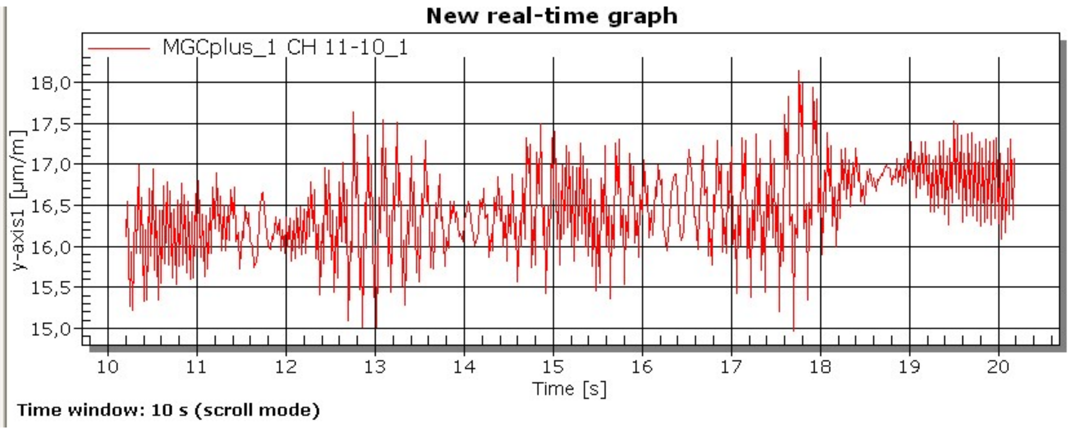

Figure 6. Experimental registered deformations of the elastic beam (with radial load).

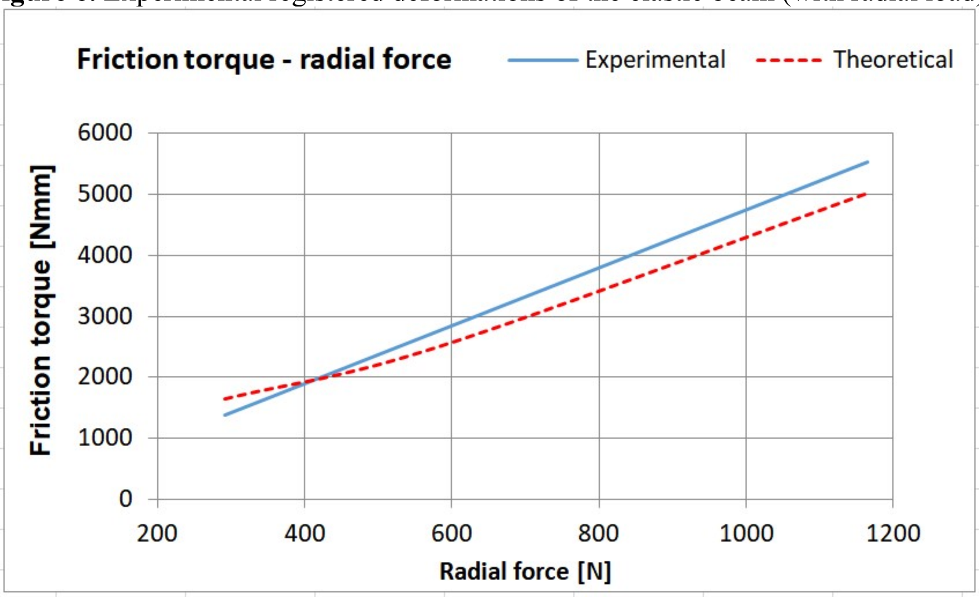

Figure 7. Experimental and theoretical variation of the bearing friction torque versus radial load.

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Obtained theoretical dependence of the bearing friction torque versus radial load is presented in figure 7. Also, experimental obtained dependence of the bearing friction torque versus redial bearing load is presented in the same graphic, figure 7. It is observed a linear dependence, the friction torque increasing with the bearing radial load. Similar linear dependencies for the friction torque versus radial load are obtained by bearing manufacturer, to performed tests [10].

4. Numerical simulation in ADAMS of bearing test bench

ADAMS software offers the possibility with machinery plug-in to define a various number of machine elements. To design the dynamic model of the bearing test bench in ADAMS, for the kinematic elements have been specified the materials and are defined the revolute joints as ball bearings.
The ball bearing construction in Adams Machinery is specified as shown in figure 8.

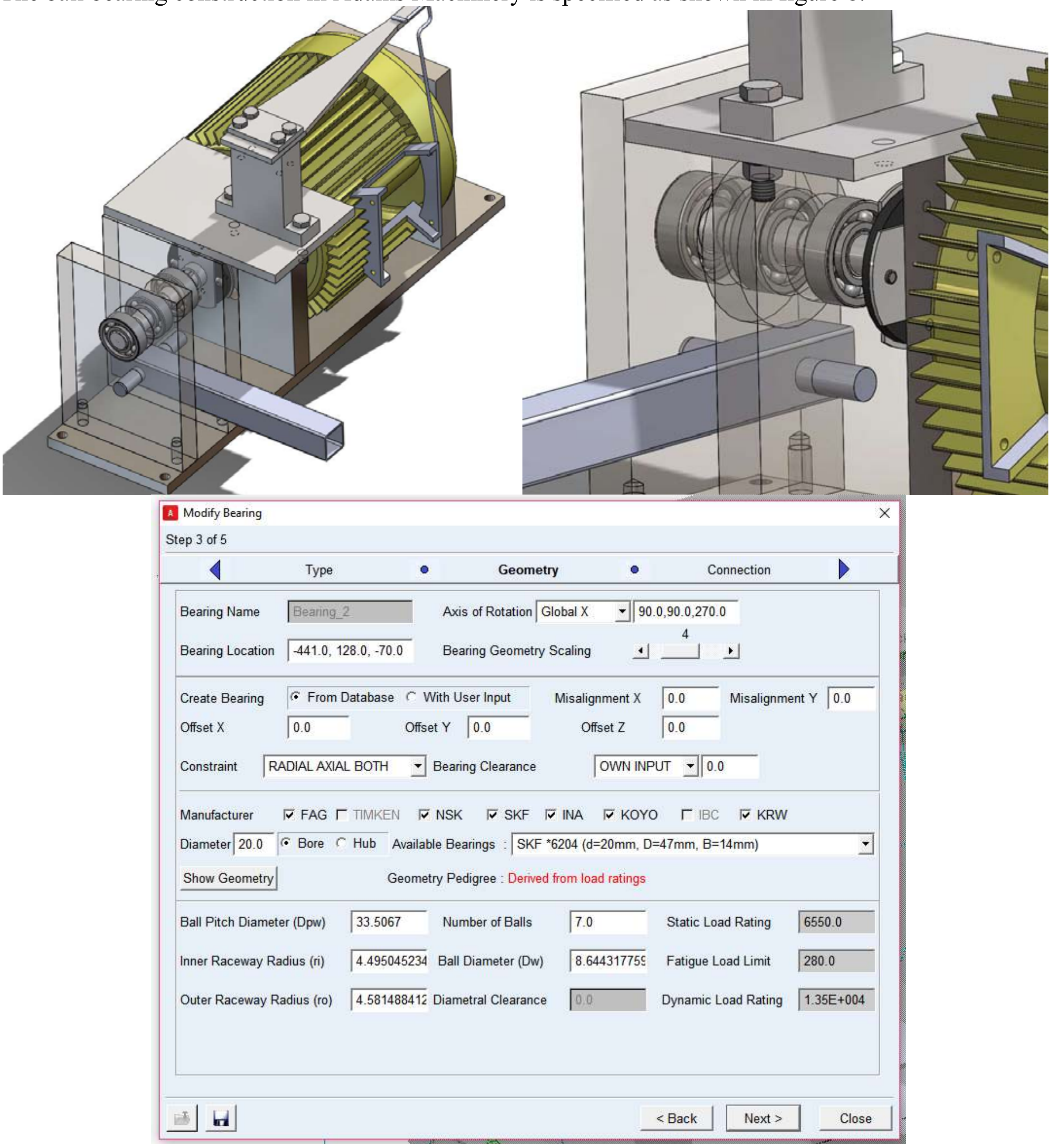

Figure 8. Definition of ball bearing using Adams Machinery feature.

The motion for the electric motor is defined to 157 rad/s. To obtain accurate results the shaft (1) of the test bench is considered as a deformable body. Based on Adams Machinery feature, the tested bearing life is 526 hours, as presented in figure 9.

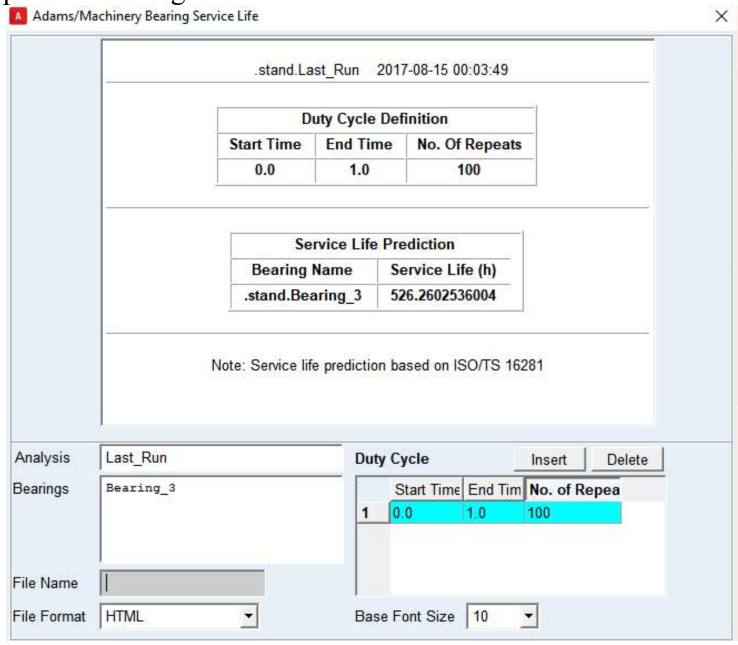

Figure 9. Bearing life report using Adams Machinery feature.

In figure 10, is presented the bearing center marker translational displacement upon X axis (axial). In figure 11, is presented the computed translational displacement of bearing center marker upon Y axis (radial). The axial displacement has small values (reaches 0.0015 mm), and the radial displacement is larger, reaching the value of 0.022 mm. Adams computed translational deformation of the shaft (1) center marker are shown in figure 12.

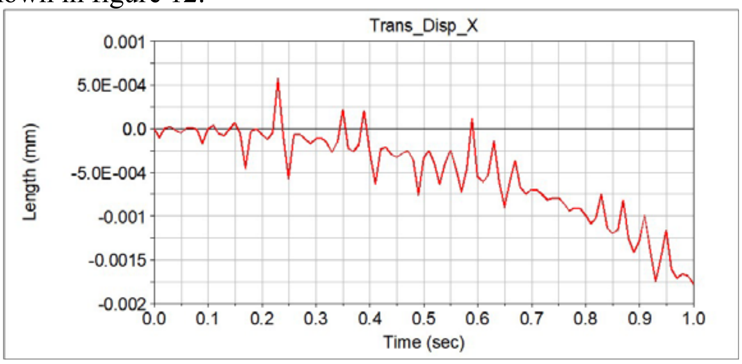

Figure 10. Bearing center marker axial displacement.

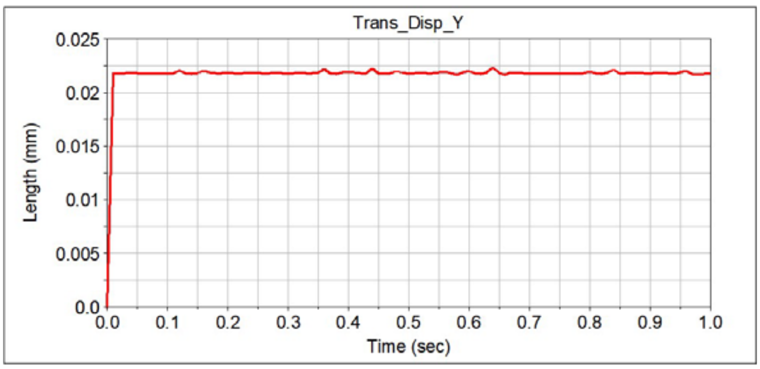

Figure 11. Bearing center marker radial displacement.

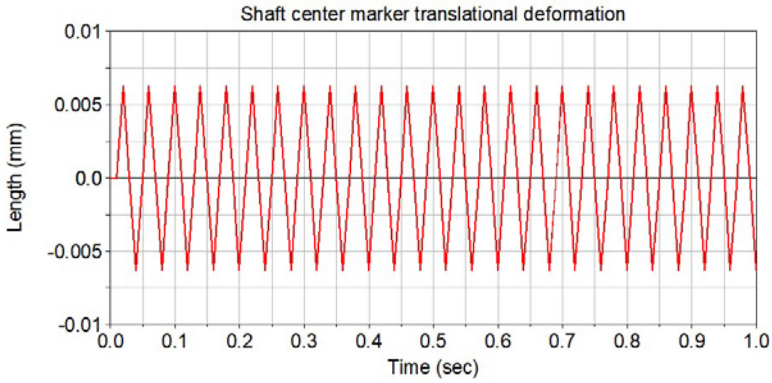

Figure 12. Shaft center marker vertical translational deformation.

5. Conclusion

In this paper it is presented the design of a test bench for bearing friction torque measurement. The ball bearing subjected to tests in this study is type SKF 6204. From theory and experimental tests are obtained similar linear dependencies between the friction torque and bearing radial load. A graphic comparison for the obtained theoretical and experimental obtained results is presented in figure 7. Theoretically, it is computed a total friction torque of 1647.96 Nmm for the radial load of 291 N and the torque increases to 5018.17 Nmm in case of 1164 N bearing radial load. Experimentally, at 291 N bearing radial load it is measured a total torque of 1383.22 Nmm and for the maximum radial load of 1164 N the value of the friction torque reaches 5532.88 Nmm. The numerical simulation of the test bench is performed with Adams software, considering as flexible body the shaft mounted on bearings. Adams machinery reports a bearing life of 526.26 hours, as presented in figure 9. Are computed in Adams and presented in the paper the bearing center marker translational displacements. Because of the radial load it is computed a translational of 0.022 mm for the marker attached to the bearing center. The shaft deformations shown in figure 12, have the maximum amplitude of 0.13 mm. Proposed test bench can be used to tests different types of radial bearings, with different lubricants.

6. References

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