INFLUENCE OF PIVOTING FRICTION ON THE FRICTION TORQUE IN A MINIATURE AXIAL BALL BEARING

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Abstract. *This paper investigates the influence of ball pivoting motion on the friction torque in a miniature thrust ball bearing. Experimental investigations were carried out using the spin-down method on a 51100 thrust ball bearing with three balls and without cage, under dry conditions and low axial loads. Friction torque values were determined for various ball diameters, loads, and rotational speeds. The results show that including pivoting motion leads to a reduction of the total friction torque by up to 9%, depending on contact conditions. The obtained results are valid within the investigated load and speed ranges.*

Keywords: *spin-down, ball bearing with 3 balls, friction, torque, loads.*

Introduction

For small-sized bearings used in micromotor and microturbine applications, the specialized literature by Ghalichechian N. [Ghalichechian N., 2007, 2008] considered that the friction torque can be calculated using the spin-down method, which is based on bringing the rotor to a known rotational speed and abruptly stopping the micromotor. Under these conditions, the rotor, which is supported by a micro bearing with 10 micro balls (the micro ball diameter being 0.285 mm), enters a braking process until it comes to a complete stop.

Based on the differential equation of rotational motion of the microrotor, Ghalichechian N. [Ghalichechian N., 2007, 2008] uses the following equation:

$$J\frac{d\omega}{dt} = k\omega \tag{1}$$

where J is the inertia moment of the micro rotor, ω is the angular velocity of the micro rotor and $k\omega$ is the friction torque generated in the micro ball bearing.

It is observed that in the relation (1), the friction torque $k\omega$ varies as a linear function of angular velocity ω. Ghalichechian N. [Ghalichechian N., 2007, 2008] performs the integration of the equation (1) and obtains the following expression for the angular position θ(t) as function of the time in decelerating process:

$$\theta(t) = a \cdot e^{b \cdot t} + c \cdot t + d \tag{2}$$

where the constants *a*, *b*, *c* and *d* are determined based on the boundary conditions: at t = 0, $\omega = \omega_i$, $\theta = 0$, where ω_i is the angular speed of the micro rotor at the beginning of the deceleration process.

McCarthy et al. [McCarthy, 2009] studied the influence of the load and the speed on the friction in a micro ball bearing with 90 micro balls having a diameter of 0.285 mm, with raceways realized by silicon wafer microfabrication. Using the spin-down method, the authors determined the global friction coefficient in the micro ball bearing for rotational speeds between (250 and 5000) rpm and axial loads varying between (10 and 50) mN.

The experimentally values of the friction coefficient obtained range between 0.0005 (at 250 rpm and a load of 50 mN) and 0.025 (at 5000 rpm and a load of 10 mN). The authors also establish the following empirical relationship for determining the friction torque in the micro bearing:

$$M_f = 9 \cdot 10^{-5} \cdot F_N^{0,444} \cdot n \qquad (3)$$

where the friction torque M_f is expressed in µNm, n is the rotational speed expressed in rpm, and F_n is the axial force expressed in mN.

In 2011, Olaru D. et al. [Olaru D.,2012] patented a device and a methodology for determining the rolling friction torque between the balls and raceways in a thrust ball bearing, using only three balls without a cage.

Tests under dry conditions using a 51100 ball bearing with three balls subjected to different loads were presented in the paper [Olaru D.,2011].

At the same time, this paper presents the values of the rolling friction coefficients between the balls and raceways under dry conditions, ranging between 0.0002 and 0.0004.

Subsequently, tests were also performed using the spin-down method regarding the influence of lubricant in thrust ball bearings, also using three balls without a cage [Balan M.R.,2015].

Ianuș G. et al. [Ianus G., 2019] determined the power losses due to friction in a miniature thrust ball bearing lubricated with grease, highlighting the dominant role of grease on bearing friction.

In 2014 Dumitrașcu et al. [Dumitrascu A.C. ,2014] determined the influence of contact pressure on the friction torque in a thrust ball bearings.

More recently, Cojocaru D. et al. [Cojocaru D.,2025 a] studied friction torque in the miniature 7000C angular contact ball bearing grease-lubricated.

Also, Cojocaru D. et al.[Cojocaru D.,2025 b] determined the lubricant film in the 7000C angular contact ball bearing grease lubricated.

Generally, in the tests involving miniature thrust ball bearings with three balls operating at low axially loads the friction generated by pivoting motion was neglected when determining the ball bearing friction torque.

In the present papers are presented the influence of the pivoting friction on the friction torque obtained in a 51100 thrust ball bearing having only three and operating in dry conditions.

Experimental determinations regarding the influence of pivoting motion on bearing friction torque

Olaru D. et al [Olaru D.,2011] presents the methodology for determining the friction torques generated by pivoting motion produced by the three balls and the two raceways for the 51100 thrust ball bearing operating in dry conditions.

The friction torque has been determined by using the spin-down method.

The identification of the reduced influence of pivoting friction in the 51100 bearing for rotational speeds between(30–210) rpm and loads ranging from Q = (8.68–33.2) mN was performed using the friction torque relationships presented in the paper [Olaru D.,2011].

Figure 1 shows the minimum and maximum influence of the pivoting friction on the friction torque M_f.

The maximum influence was obtained for the axial load Q = 33.2mN and minimum influence was obtained for the axial load Q = 8.68mN.

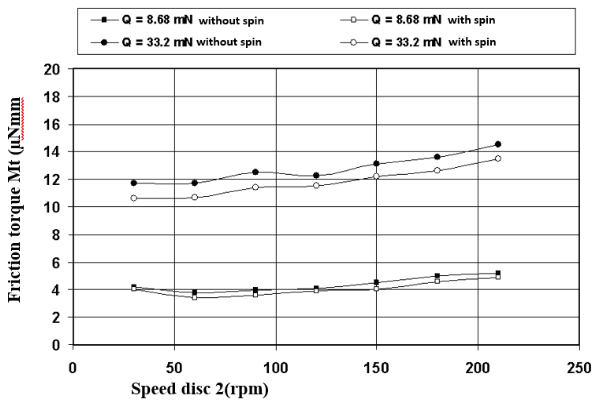

Figure 1. *Friction torque M_f determined using two axial loads, Q = 33.2mN and Q = 8.68mN.*

In the figures 2 – 7 are presented the diagrams for friction torques M_f obtained for various axial loads Q and various ball diameters, in the 51100 thrust ball bearing operating in dry conditions. The friction torques are determined both neglecting the pivoting friction and considering the pivoting friction.

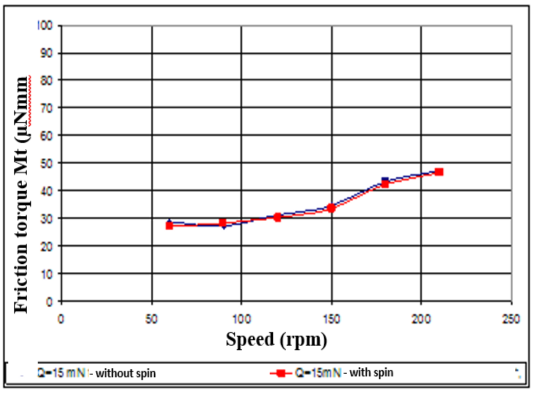

Figure 2. *Values of the friction torque M_f as a function of rotational speed for the micro ball diameter of d = 1.97 mm and an axially load applied to of Q = 15 mN, for the two cases: without considering pivoting motion and with considering pivoting motion.*

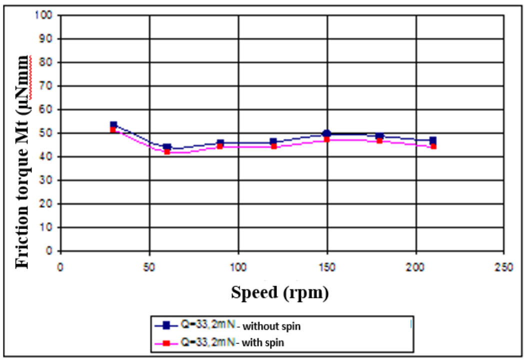

Figure 3. *Values of the friction torque M_f as a function of rotational speed for a micro ball diameter of d = 1.97 mm and an axially load applied of Q = 33.2 mN, for the two cases: without considering pivoting motion and with considering pivoting motion.*

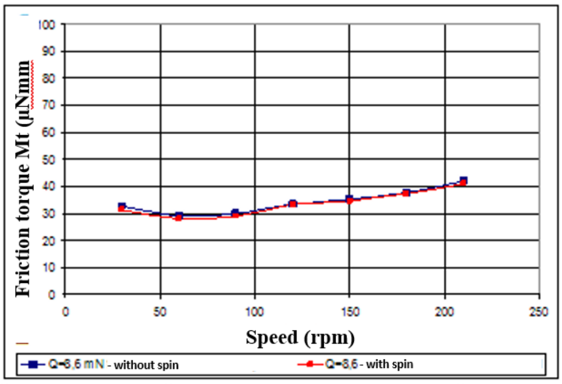

Figure 4. *Values of the friction torque M_f as a function of rotational speed for a micro ball diameter of d = 2.47 mm and an axially load applied to disk 2 of Q = 8.6 mN, for the two cases: without considering pivoting motion and with considering pivoting motion.*

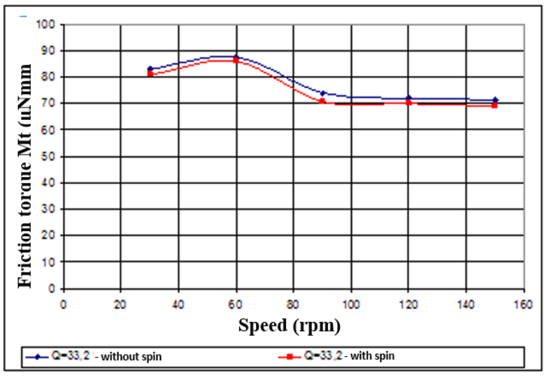

Figure 5. *Values of the friction torque M_f as a function of rotational speed for a micro ball diameter of d = 2.47 mm and an axially load applied to of Q = 33.2 mN, for the two cases: without considering pivoting motion and with considering pivoting motion.*

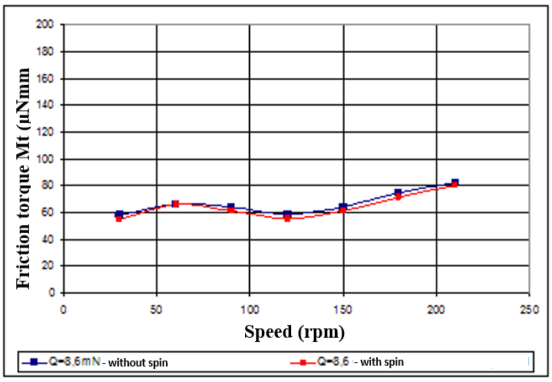

Figure 6. *Values of the friction torque M_f as a function of rotational speed for a microball diameter of d = 4.76 mm and an axially load applied of Q = 8.6 mN, for the two cases: without considering pivoting motion and with considering pivoting motion.*

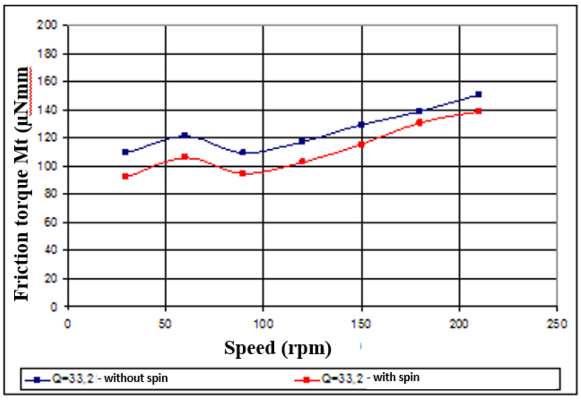

Figure 7. *Values of the friction torque M_f as a function of rotational speed for a microball diameter of d = 4.76 mm and an axially load applied of Q = 33.2 mN, for the two cases: without considering pivoting motion and with considering pivoting motion*.

It is observed, for example, that for a micro ball with a diameter of 1.588 mm, by including the effect of the friction pivoting, the friction torque M_f is reduced by 4% to 9% compared to the value obtained when pivoting motion is neglected.

The smallest differences occur at a load of Q = 8.68 mN, and, as the load increases, due to the increase in the major semi-axis of the contact ellipse, the effect of pivoting motion increases and the difference between the friction torques becomes larger.

In conclusion, it is observed that the friction torque values increase with increasing ball diameters and loads.

For the friction coefficient in calculus of the pivoting friction moment, the authors considered the results experimentally obtained by Dumitrascu A. et al. [Dumitrascu A., 2011].

So, the friction coefficient between a ball with a diameter of 1.588 mm and loaded with normal forces of 8.68 mN and 33.2 mN, on the raceway of the 51100 thrust ball bearing have been determined.

The experiments were conducted under dry conditions at a temperature of 20 °C and a relative humidity between 45–55% RH.

In the figures 8- 12 are presented the diagrams of the experimental friction coefficients for loads of 8.68 mN, 15 mN, 22.3 mN, 27 mN, and 33.2 mN [Dumitrascu A., 2011].

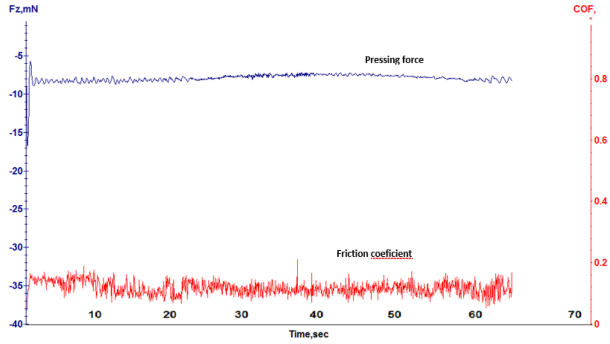

Figure 8. *Friction coefficient for a normal force of 8.68 mN.*

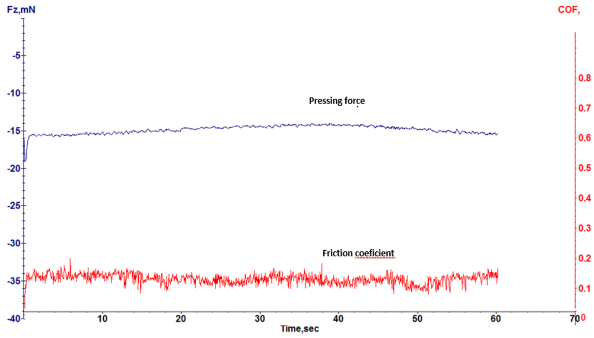

Figure 9. *Friction coefficient for a normal force of 15 mN.*

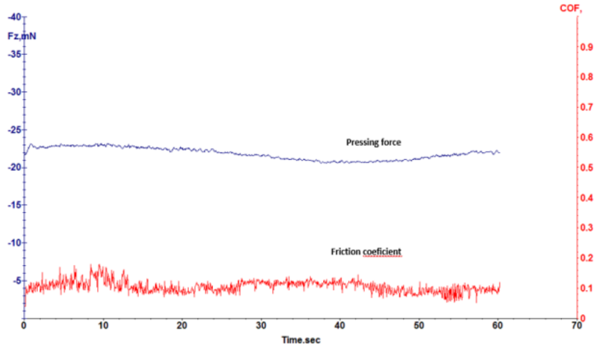

Figure 10. *Friction coefficient for a normal force of 22.3 mN.*

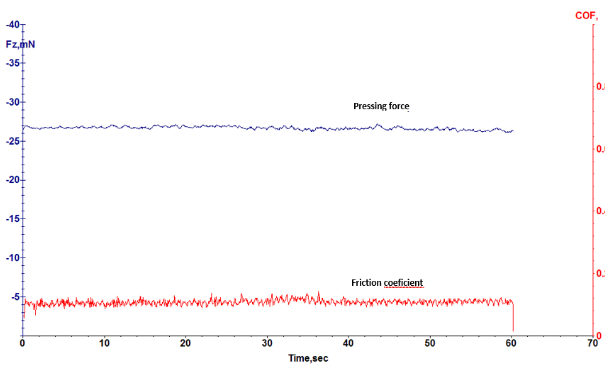

Figure 11. *Friction coefficient for a normal force of 27 mN.*

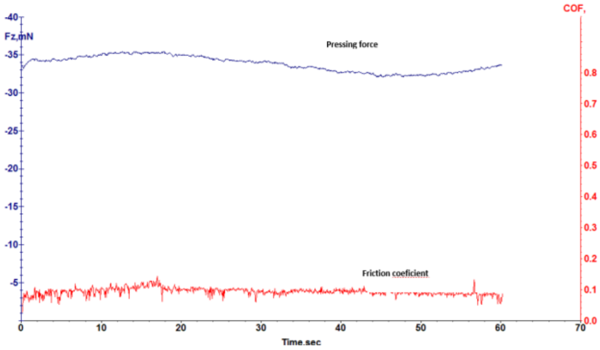

Figure 12. *Friction coefficient for a normal force of 33.2 mN.*

As it can be observed in figures 8 – 12, the resulted friction coefficients varied between 0.1 and 0.15. For calculating pivoting friction moment on the two raceways, an average value of 0.12 was used for the friction coefficient.

Experimental tests were conducted to verify the influence of pivoting on rolling friction torques. It was found that, under loading conditions between (8.6–33.2) mN and rotational speeds between (30–210) rpm, by including the effect of microball pivoting, the total friction torque M_t is reduced by 4% to 9% compared to the friction torques Mt determined when pivoting motion is neglected. Sliding friction coefficient values between 0.1 and 0.2 were obtained.

Conclusions

Using the spin-down method for the 51100 axial bearing with three balls, without a cage, and axially loaded with forces between (8.68 and 33.2) mN, the following conclusions were drawn:

- Since pivoting friction torques depend on the size of the contact ellipse between the balls and raceways, for small-diameter balls and low loads, the influence of pivoting friction is a maximum of 2% of the total bearing friction.

- As the ball diameter and load increase, an increase in pivoting friction torque is observed as a result of the increase in the contact ellipse, reaching up to 9%.

- The obtained values are valid within the limits of the applied loads, the used ball diameters, and the rotational speed range of (30–210) rpm.

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