DIAGNOSTICS OF ROLLING BEARINGS BY A QUASI-DYNAMIC METHOD

Arkadiusz RYCHLIK

Chair of Vehicle and Machine Structure and Operation, Faculty of Technical Sciences,
University of Warmia and Mazury in Olsztyn
ul. Oczapowskiego 11, 10-719 Olsztyn, e-mail: rychter@uwm.edu.pl

Streszczenie

W pracy przedstawiono sposób identyfikacji stanu technicznego łożysk tocznych, metodą quasi-dynamiczną w której jako narzędzie badawcze zastosowano wahadła fizyczne. Dla prezentowanej metody wyróżniono cechy sygnału diagnostycznego umożliwiającego ocenę stanu technicznego łożyska tocznego na etapie naprawy. W artykule wskazano na współczynnik oporu ruchu łożyska jako uogólniony parametr diagnostyczny oraz na moc i moment tarcia jako miarę intensywności zużycia łożyska tocznego.

Słowa kluczowe: łożysko toczne, moc tarcia, moment tarcia, sygnał diagnostyczny.

DIAGNOSTYKI ŁOŻYSK TOCZNYCH METODĄ QUASI - DYNAMICZNĄ

Summary

This paper presents the technical state identification of rolling bearings by the quasi – dynamic method, where a physical pendulum was used as an investigative tool. For the presented method, the attributes of the diagnostic signal were distinguished. The attributes enable evaluation of the technical state of a rolling bearing over repairing. The coefficient of resistance to motion of a bearing was used as a generalized diagnostic parameter and power and moment of friction were used as a wear measure of a rolling bearing.

Keywords: rolling bearing, friction power, friction torque, diagnostic signal.

1. INTRODUCTION

Rolling bearings are those parts of machines which are among the most frequently replaced in the course of machine operation. Nearly 34% of rolling bearings are dismantled and scrapped prematurely due to a lack of proper assessment of their technical condition [4]. Such actions result mainly from the absence of available methods and diagnostic measures, intended for quick and reliable identification of the technical condition of rolling bearings in verification of systems and parts of technical facilities.

An economical approach to machine operation necessitates a reduction in the costs of maintenance and time of repair of technical facilities. At the same time, "environmental considerations" concerning recycling of faulty or worn products forces repair workshops and manufacturers to seek tools and diagnostic measures to identify the actual technical conditions of rolling bearings before taking a decision to replace or regenerate them.

Regeneration of rolling bearings is not a new idea; however, for various reasons it has not been widely applied yet due to the absence of a cost approach to overhaul or repair policy as regards technical facilities, but also the absence of awareness among company technical staff of the possibility of restoration of the rolling bearing potential in this manner.

The initial operational properties of a rolling bearing can be restored, at the expense of less time and money than for purchasing a new one. Depending on the scope of work, repairing a faulty bearing can save from 50 to 90% of the new one purchase cost [7]. The simplest manner of regeneration may consist in washing a bearing, filling it with new grease and installing new sealing. In the broadest approach: polishing (or grinding) of the balls and raceway, replacement of the bearing cage as well as grease and sealing.

Currently, the most commonly regenerated are rolling bearings with a pinhole diameter of ø76-203 mm. However, bearings of smaller diameters are also regenerated, especially if they are in greater numbers [7].

Though it has numerous advantages, regeneration of a faulty bearing is not always the best solution. For the proper application of the repair technology it is of key importance to determine if and when a bearing needs a repair. A visual inspection of a dismantled bearing is a common, and the only, criterion of qualification of a bearing for further operation or for scrapping.

In the author's opinion, the test procedure proposed in this paper, along with the test stand and distinguished features of a diagnostic signal which identify the technical condition of rolling bearing at the stage of repair, will allow for a quick and unambiguous decision as regards the future fate of an ordinary ball bearing.

2. METHODS OF IDENTIFICATION OF THE TECHNICAL CONDITION OF ROLLING BEARINGS AT THE MACHINE REPAIR STAGE

There are a number of techniques of identification of the technical condition of rolling bearings, with various level of advancement, which can be used to locate a failure in a bearing before it is permanently damaged. However, these are mainly diagnostic measures applied to identify technical facilities and bearing nodes as a whole, and are widely discussed in literature.

In accordance with the aim of the study, in its further part the author will focus on a diagnostic representation used to evaluate the technical condition of a bearing which has already been dismantled and whose technical condition is being verified.

The following diagnostic methods can be distinguished which are used to identify the technical condition of a rolling bearing at the stage of repair:

- a sensory method [8];
- identification of radial and axial clearance and misalignment of a bearing [6, 8, 10];
- physicochemical analysis of the grease which fills the bearing [3, 6, 8];
- measurement of the friction coefficient [2];
- the coasting method[1];

2.1. The limiting value of the diagnostic signal

The literature contains only scarce information on the limiting values of the features of diagnostic signals for rolling bearings intended for bearing verification at the stage of repair. These are mainly data related to geometric features rather than to the utility features, which carry more information about the technical condition of an examined bearing.

This approach to identification of the technical condition of rolling bearings is exemplified in [9]. The paper presents an extensive analysis of diagnostic signals of special rolling bearings and supports the conclusion that using bearing motion anti-torque as an indicator of the rolling bearing technical condition is justified. An increase in the anti-torque to the value typical of a new bearing, which is still wearing in, has been determined as the limiting value of the diagnostic signal [9]. The paper concludes that bearings have a "life curve" which has a shape of a bathtub curve and can be described by the moment of friction function $M_t=f(\tau)$ – Fig. 1.

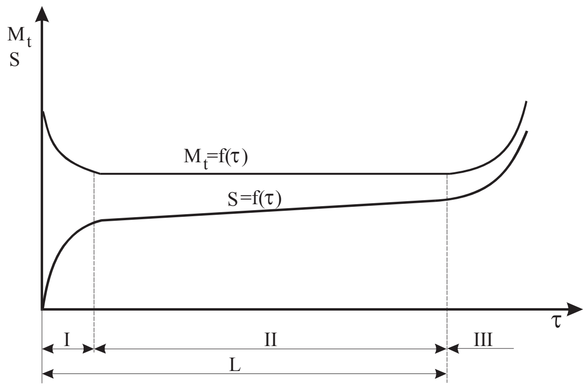

Fig. 1. The "life curve" of rolling bearings as a function of time. $M_t = f(\tau)$ – moment of friction at a constant rate of rotation, $S=f(\tau)$ – intensity of the wearing symptom, I –a stadium of digressive increase in the wearing symptom (wearing-in), II – established level or slight increase, III – progressive increase in the wearing symptom, L – operational durability of a hypothetical rolling bearing, (based on [9])

Another paper [1] shows the power of friction as a diagnostic symptom which is a measure of intensity of the wearing processes in the tribological nodes of a combustion engine. The power of friction is identified during an engine acceleration and coasting, and its measure is the mechanical efficiency and/or the product of the moment of friction and the crankshaft rate of rotation [1].

3. A METHOD OF IDENTIFICATION OF THE TECHNICAL CONDITION OF A ROLLING BEARING BY THE QUASI-DYNAMIC METHOD

The quasi-dynamic method of diagnosing the technical condition of rolling bearings is based on identification of the features of the oscillation of a physical pendulum (fig. 2) in which the pendulum rotates through the bearing which is being examined. The presented diagnostic method consists in identification of changes of the angular velocity of the pendulum, with the known amount of energy supplied to the pendulum in order to unbalance it. The angle of the first deflection α is adopted as the measure of the degree of unbalance.

Measurement of the features of diagnostic signals which are necessary to evaluate the technical condition of the bearing which is being examined is done only on the pendulum clockwise movement back to the state of balance. The measurement of the identified diagnostic parameters in one direction of the pendulum movement does not necessitate its static or dynamic balancing each time a bearing is replaced.

The presented method may be applied to check the technical condition of in-line rolling bearings, without sealing or grease. The examined bearing should have normal clearance (i.e. it should not exceed the limit clearance determined by the manufacturer) and its rings should not be misaligned. In other words, the bearing should have been verified organoleptically with a positive result.

The described method does not take into account the aerodynamic resistance of the pendulum or the mass of the examined bearing.

3.1. The mathematical model of a test stand

The proposed method uses a physical pendulum as a diagnostic tool. The pendulum body with the mounted bearing performs pendular movement (around point O Fig. 2), under its own weight (*mg*) as it is unbalanced and deflected by the angle of α.

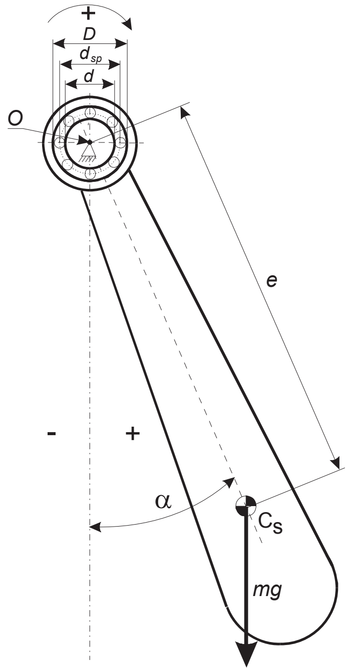

Fig. 2. A graphic model of a physical pendulum, α - first pendulum deflection angle; C_s – position of the pendulum geometric centre; *e* – distance from the pendulum centre of gravity to the centre of rotation O; *mg* – pendulum force of gravity; D, d_{sp} d – external, effective and internal diameter of the bearing, respectively

Oscillations (rotational vibrations) of an unbalanced physical pendulum result from the moments generated by the forces of gravity and inertia. The pendulum position is determined by angle α, and the pendulum equation has the following form:

$$I \cdot \ddot{\alpha} + C_w \cdot \dot{\alpha} = -mg \cdot e \cdot \sin\alpha \qquad (1)$$

where: I_o – mass moment of inertia of the pendulum in relation to the point of rotation O, C_w – coefficient of viscotic resistance of the bearing in its rotation (in relation to the point of rotation O), the other notations – as per Fig. 2.

Equation (*1*) is a non-linear differential equation for which no analytic solution exists. Only an approximate solution of equation (*3*) may be obtained, assuming that the angle of deflection α is small ($\sin \alpha \approx \alpha$).

3.2. Identification of the features of diagnostic signals in the quasi-dynamic method

The following features have been chosen for the evaluation of usability and quality of the diagnostic signal, identified at the lowest point of the pendulum, which transmits information about the technical condition of a bearing in the proposed method:

- duration of the oscillation of the test pendulum – *T*;
- the number of individual swings of a test pendulum – *i,* (the number of times when the test pendulum passes through its lowest point);
- coefficient of friction in the pendulum oscillations – μ_o (own study based on [5]), identified on the basis of individual swings of the pendulum *i*;
- coefficient of the viscotic resistance of the pendulum bearing in its rotation – C_w;
- moment of friction in the bearing – M_t;
- coefficient of rolling friction – f_t [5, 10] as a measure of the condition of surfaces of the elements that work together in a bearing;
- friction power – as a generalised mechanical efficiency of the bearing – W_t.

Table 1 shows the diagnostic signals and their features which have been selected for identification of the technical condition of rolling bearings at the stage of repair.

3.3. The test stand and equipment

The aim of the experiments was to identify the measures of features of the diagnostic signal and their utility in assessment of the technical condition of rolling bearings by a quasi-dynamic method.

The test stand used to identify changes of the angular velocity and to count individual swings of the bearing under test is shown in Fig. 3. The test stand consists of a base (1) and a test pendulum (2). The bearing which is being tested (3) is placed in the pendulum mounting and mounted in the self-centring holder of the test stand so as the inner raceway of the test stand is immobilised against its outer raceway. Changes of the angular velocity of the tested bearing loaded with the test pendulum (*m*=1.67 kg), are recorded with a CF-110 photo-optical sensor and a KSD-400 measuring analyser.

Following initial tests of the identified signal the observed value, a static processing of the observed value (the angular velocity of the tested system) was performed (the pendulum with the outer ring of the bearing). The analyses indicate that in the test conditions, the observed value is a stationary and repeatable signal.

Table 1. Diagnostic signals and their features which have been selected for identification of the technical condition of rolling bearings by the quasi-dynamic method

No.	Feature of the diagnostic signal	Notation	Equation
1	duration of the movement of the test pendulum	T [s]	-
2	number of swings of the pendulum	i [ ]	-
3	coefficient of friction in oscillations	μ_o [ ]	$\mu_o = \frac{720 \cdot mg \cdot e \cdot (1-\cos\alpha)}{\pi \cdot i \cdot \alpha \cdot m \cdot (D+d)}$
4	coefficient of the viscotic resistance of the pendulum	C_w [Nm/s]	$C_w = \frac{mg \cdot e \cdot \sin\alpha - I_o \cdot \varepsilon}{\omega}$
5	moment of friction	M_t [Nm]	$M_t = I_O \cdot \ddot{\alpha} = I_O \cdot \frac{\omega_1 - \omega_2}{\Delta t}$
6	coefficient of the rolling friction	f_t [m]	$f_t = \frac{M_t}{mg}$
7	friction power	W_t [Wat]	$W_t = M_t \cdot \dot{\alpha}$

Fig. 3. A view of the test stand for identification of the technical condition of a rolling bearing. 1 – base with a holder, 2 – test pendulum, 3 – tested bearing, 4 – photo-optical sensor, 5 – recording device KSD-400

4. THE TEST AND ITS RESULTS

Five brand-new 6305 single-row unsealed ball bearings, randomly chosen from a group of 30, were used in the experiment. The number of repetitions for each bearing was established as 5.

After the base was levelled and the pendulum with the bearing was mounted in the self-centring holder, changes in the angular velocity of the pendulum mount were recorded with a photo-optical velocity sensor and a signal recorder.

The test consisted in unbalancing the system by the angle α, and recording the time of passage between two markers situated on the pendulum mount. The markers situated on the pendulum mount facilitated the identification of the pendulum angular velocity at its lowest position, which corresponds to its highest angular velocity. Only times of passage from the right to left (clockwise) were identified for analysis.

The measurements and calculations yielded a range of diagrams of the identified diagnostic signal vs. time. Fig. 4 shows diagrams of the angular velocity vs. time (of the outer raceways) of two bearings with various technical conditions, recorded at the lowest point of the pendulum.

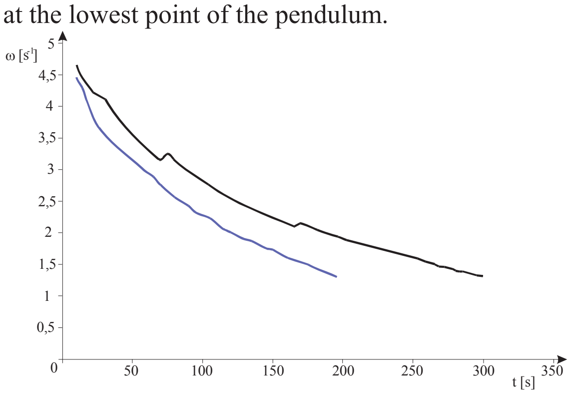

Fig. 4. Comparison of diagrams of the angular velocity vs. time for two 6305 bearings, differing in technical condition, recorded at the test stand

An example diagram of the angular velocity (ω) and acceleration (ε) of the pendulum mount vs. duration of the pendulum movement (t), number of individual swings (i) and the angle of pendulum deflection (α) at the lowest point is shown in Fig. 5.

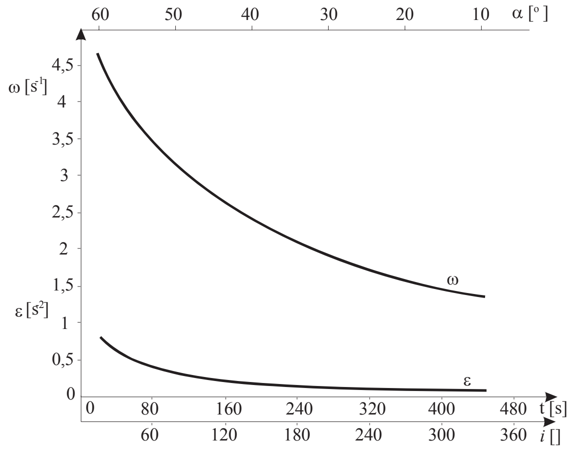

Fig. 5. Angular velocity and acceleration of the outer raceway of a 6305 bearing vs. time, number of swings and the angle of the first deflection angle

Fig. 6 shows an exemplary diagram of the power of friction W_t and the moment of friction M_t for the tested pendulum vs. time of the pendulum movement, identified at the lowest point.

The experiment performed at the test stand resulted in the values of diagnostic signal features for five tested bearings at the lowest point. The obtained values the diagnostic features are shown in Table 2.

The value of the friction coefficient in oscillations μ_o of the bearing under test is much higher than the value of the coefficient of friction, provided by the manufacturer. The coefficient for an unsealed rolling bearing manufactured by CX is equal to μ=0.0010÷0.0015 [6], while for bearings manufactured by SKF it is close to μ=0.0015 [8].

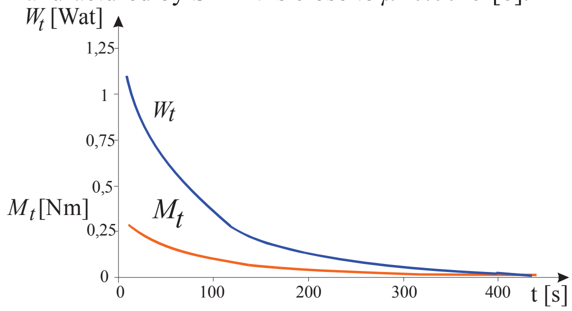

Fig. 6. Characteristic curve of the power of friction (W_t) and the moment of friction (M_t) of a 6305 bearing, identified at the lowest point of the test pendulum

The difference from the values obtained in the tests stems from the fact that the bearings under test were examined at the wearing-in stage, whereas the values given by manufacturers are for worn-in bearings, and the μ is identified at a different bearing load. Another factor which affects such relatively high coefficient values may be the fact that the coefficient of friction decreases with an increase in the angular velocity of the bearing raceway.

The experiment supports the conclusion that each of the selected features of the signal bears diagnostic information related to the technical condition of a rolling bearing in terms of its tribological node.

Table 2. The values of features of diagnostic signals of 6305 bearings, without grease (brand-new), manufactured by CX, obtained during the experiment

No.	Feature of the diagnostic signal	Notation	Mean value	Standard deviation
			for the tested group of bearings	
1	duration of the movement of the test pendulum	T [s]	454.6	2.88
2	number of swings of the pendulum	i [ ]	320.2	1.788
3	coefficient of friction in oscillations	μ_o [ ]	0.01218	0.00011
4	coefficient of the viscotic resistance of the pendulum	C_w [Nm/s]	0.063	0.00408
5	moment of friction	M_t [Nm]	0.278	0.01095
6	coefficient of the rolling friction	f_t [m]	0.0134	0.00612
7	friction power	W_t [Wat]	1.034	0.04560

According to the author, the coefficient of friction in oscillations is the most universal diagnostic feature of a rolling bearing; it may be referred to the value of the conventional coefficient of friction provided by manufacturers for brand-new bearings or compared to historical data obtained in experiments.

Identification of the moment of friction, coefficient of the rolling friction or the power of friction during a bearing use may be a measure of intensity of use in a bearing node.

5. SUMMARY AND CONCLUSIONS

The main problem faced in verification of dismantled systems, units and parts of machines is the identification of their actual technical condition. This is caused by a variety of restrictions resulting from the construction, test methods and mainly by a lack of knowledge of the nominal or limiting values for specific units or parts. Because of this, when the actual technical condition of a part is unknown, the part is scrapped rather than tested for its technical condition and remounted.

Rolling bearings are parts for which there are no satisfactory diagnostic tools or limiting values for determination of their technical condition at the stage of repair.

The tests and analyses conducted for this study have provided grounds for the following conclusions:

1. The coefficient of resistance for a bearing, which may be referred to the value of the conventional coefficient of friction, provided by manufacturers for a new bearing, or the value of such coefficient determined in an experiment for each of the three states of a bearing "life", is the universal diagnostic feature of a rolling bearing.
2. The use of movement resistance as the moment of friction is justified; it may be practically applied for unsealed ball bearings.
3. Change of the power of friction, as compared to the nominal value, during the life of a bearing, identified in the course of a major overhaul or an emergency repair, is a measure of the intensity of the wearing processes in the tribological nodes of a bearing and may be useful in identification of its current technical condition.
4. The proposed diagnostic method of identification of the technical condition of a rolling bearing may be useful where the coasting method cannot be applied.
5. Further studies of the quasi-dynamic method will aim at interpretation of the presented features of the diagnostic signal as a function of bearing wear (the number of bearing rotations at its nominal load).

6. REFERENCE

[1] Bielawski P.: *Diagnozowanie maszyn z wykorzystaniem mocy tarcia*. Diagnostyka Nr 29/2003. s. 15÷20;
[2] Capanidis D., Czarny A.: *Stanowisko dydaktyczne do wyznaczania oporów ruchu łożysk stożkowych*. Zeszyty naukowe. Zeszyt Nr 8. Wydawnictwo AT-H, Bielsko Biała 2003, s. 135-140;
[3] Conyers J.: *Lekcja z uszkodzenia łożysk*a. Utrzymanie Ruchy, Marzec 2004;
[4] Dwojak J. Rzepiela M.: *Diagnostyka i obsługa techniczna łożysk tocznyc*h. Biuro Gamma. Warszawa 2003;
[5] Kowal A.: *Opory ruchu w mechanizmach maszyn górniczych*. Monografia. Wydawnictwo Politechniki Śląskiej. Gliwice 2003;
[6] Łożyska toczne. *Katalog produktów CX-LO/PL/2.01/07.2005*. Delta Marketing Sp.z o.o., 2005;
[7] Roger L. Oberweiser.: *Naprawa łożyska tocznego jako alternatywa jego wymiany*. Utrzymanie Ruchy, Maj 2004;
[8] SKF: P*oradnik obsługi technicznej łożysk. SKF*, Warszawa, 1994;
[9] Styp-Rekowski M.: *Diagnozowanie specjalnych łożysk tocznych*. Diagnostyka Nr 25/2001. s. 65÷71;
[10] Praca zbiorowa: *Mały Poradnik Mechaniczna*, WNT Warszawa, 1970.

Ph. D. Eng. **Arkadiusz RYCHLIK**, a graduate from the Faculty of Mechanics of the University of Warmia and Mazury in Olsztyn. Currently he is a lecturer at the Chair of Vehicle and Machine Structure and Operation of the Faculty of Technical Sciences of the University of Warmia and Mazury in Olsztyn. He is the head of the Laboratory of Vehicle Diagnostics for Education and Service. In his work he deals with issues related to vehicle and machine operation and diagnostics.