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THE USE OF FRICTION PARAMETERS IN EVALUATING THE TECHNICAL CONDITION OF ROLLING BEARINGS BY THE QUASI-DYNAMIC METHOD*

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K e y w o r d s: rolling bearing, technical condition, friction parameters, quasi-dynamic method.

A b s t r a c t

This paper evaluates the technical condition of rolling bearings by the quasi-dynamic method where a physical pendulum was used as an investigative tool. Friction characteristics as attributes of the diagnostic signal were distinguished to support an evaluation of the technical condition of rolling bearings. The coefficient of friction under oscillating motion was identified as a generalized diagnostic parameter in evaluations of the technical condition of ball bearings.

ANALIZA WYKORZYSTANIA PARAMETRÓW TARCIA W OCENIE STANU TECHNICZNEGO ŁOŻYSK TOCZNYCH METODĄ QUASI-DYNAMICZNĄ

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S ł o w a k l u c z o w e: łożyska toczne, stan techniczny, parametry procesów tarcia, metoda quasi-dynamiczna.

A b s t r a k t

Przedstawiono metodę identyfikacji stanu technicznego łożysk tocznych metodą quasi-dynamiczną, w której jako narzędzie badawcze zastosowano wahadło fizyczne. Wyróżniono parametry procesów tarcia jako cechy sygnału diagnostycznego umożliwiającego ocenę stanu technicznego łożysk tocznych. Wskazano na współczynnik tarcia w ruchu oscylacyjnym jako uogólniony parametr diagnostyczny w ocenie stanu technicznego łożysk kulkowych.

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Introduction

Rolling bearings are among the most frequently replaced components during a machine's life. In standard practice, the technical condition of bearings is evaluated subjectively, and as a result, nearly 34% of rolling bearings are prematurely scrapped (DWOJAK, RZEPIELA 2003). In the majority of cases, the above is due to the absence of generally available methods for a quick and reliable identification of the technical condition of bearings in the verification process. The need to optimize machine operating costs and environmental protection requirements call for new methods that support the identification of the actual state of rolling bearings before they are classified as fit for repair or replacement.

The nominal operating parameters of a bearing assembly can be reinstated by replacing or repairing the bearing. Subject to the required servicing effort, the cost of repairing a damaged bearing is equivalent to 50–90% of the price of a brand-new bearing (ROGER 2004).

A number of methods have been proposed for diagnosing the technical condition of rolling bearings of varied complexity and localizing the site of damage in the assembly:

– organoleptic method (*Łożyska toczne* 2005, *Poradnik obsługi...* 1994);

– evaluation of radial clearance, axial clearance and bearing misalignment (*Łożyska toczne* 2005, *Poradnik obsługi...* 1994);

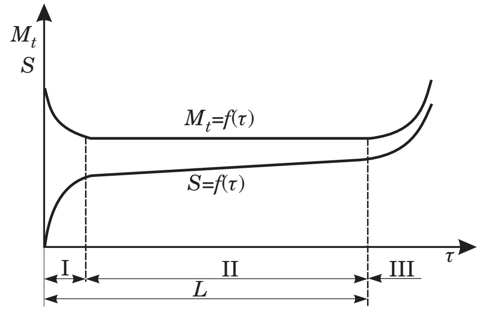
– physical and chemical analyses of bearing lubricant (*Łożyska toczne* 2004, *Poradnik obsługi...* 1994);

– determination of the coefficient of friction (CAPANIDANIS, CZARNY 2003);

– coasting method (BIELAWSKI 2003).

The main problem in evaluating the condition of bearings is the determination of boundary values of the diagnostic signal which support unambiguous identification of the degree of wear. Most of the existing methods for identifying the condition of rolling bearings rely on their geometric characteristics rather than usable properties which generate vast quantities of practical information.

The above approach has been described by STYP-REKOWSKI (2001) who investigated the use of diagnostic signals in analyses of the technical condition of special-purpose rolling bearings. The results of the cited study indicate that the moment of friction is a robust measure of the degree of wear. An increase in the moment of friction to the value referenced for brand-new, broken-in bearings was proposed as the boundary value of the diagnostic signal. The life cycle curve of rolling bearings was shown to have a bathtub shape where the moment of friction is a function of its curvature $M_t = f(\tau)$ – Fig. 1.



$Mt = f(\tau)$ – moment of friction at constant rotational speed, $S = f(\tau)$ – intensity of wear symptom, I – degressive increase in wearing symptom (breaking-in), II – constant level or minor increase, III – progressive increase in wear symptom, L – service life of a hypothetical rolling bearing

Fig. 1. Life cycle curve of a rolling bearing as a function of time
Source: STYP-REKOWSKI (2001).

Friction power which is a measure of wear intensity in bearing assemblies of a combustion engine was proposed as the diagnostic signal by BIELAWSKI (2003). Friction power is identified during engine run-up and run-down in terms of mechanical efficiency and/or the product of the moment of friction and the rotational speed of the engine's crankshaft.

The objective of this study was to investigate the option of using friction parameters as diagnostic signals for evaluating the technical condition of ball bearings by the quasi-dynamic method.

Materials and Methods

The quasi-dynamic evaluation of the technical condition of rolling bearings relied on the identification of the characteristics of a physical pendulum's oscillating motion. Changes in the pendulum's angular velocity were analyzed at known energy required to displace the pendulum from its equilibrium position. Initial angular displacement α was adopted as a measure of displacement from equilibrium in accordance with the mathematical model proposed by RYCHLIK (2008). Signals were analyzed in a test stand (Fig. 2) comprising a base (*1*) and a physical pendulum (*2*). The examined bearing (*3*) was placed in the housing of the pendulum machine, and it was mounted in a self-centering clamp to immobilize the bearing's inner raceway relative to its outer raceway. The angular velocity of the bearing which carried the load of the pendulum (m = 1.67 kg) was measured using the CF-110 (*4*) photo-optical sensor and the KSD-400 measurement analyzer (*5*).

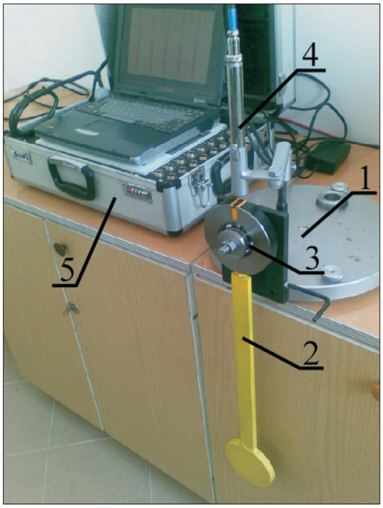


Fig. 2. Test stand for identifying the technical condition of rolling bearings by the quasi-dynamic method (described in the text)

Diagnostic signal parameters required for the assessment of the bearing's technical parameters were measured only during the pendulum's clockwise return to equilibrium. The pendulum's movement was measured in only one direction to avoid static and dynamic calibration during bearing replacement.

The results of previous studies (RYCHLIK 2008) indicate that the above method can be applied to inspect the condition of single-row ball bearings which are characterized by an absence of sealants or lubricants, normal clearance and an absence of ring misalignment. The pendulum's aerodynamic drag and the bearing's mass were not taken into account. Diagnostic signal parameters were identified at the lowest position of the pendulum.

Selected parameters of diagnostic signals for evaluating the usability and the quality of the signal conveying information about the technical condition of bearings are presented in Table 1.

The initial identification of the signal relied on a statistical analysis of the observed angular velocity values of the pendulum and the examined bearing's outer ring. The results of the analysis suggested that in the tested environment, angular velocity was a stationary and a repeatable signal.

Results and Discussion

The experimental material comprised single-row, unsealed rolling bearings. Five brand-new CX 6305 rolling bearings and five bearings with various

Table 1

Parameters of diagnostic signals describing the technical condition of rolling bearings

Diagnostic signal parameter	Symbol	Formula	Remarks
Period of swing	T [s]	–	
Number of swings	i	–	the number of times the pendulum swings through its lowest position
Coefficient of friction under oscillating motion	μ_o	$\mu_o = \dfrac{720 \cdot mg \cdot e \cdot (1-\cos\alpha)}{\pi \cdot i \cdot \alpha \cdot m \cdot (D+d)}$	–
Viscotic damping coefficient	C_w [Nm s^{-1}]	$C_w = \dfrac{mg \cdot e \cdot sin\ \alpha - I_o\ \cdot \varepsilon}{\omega}$	coefficient defined in angular motion
Moment of friction	M_t [Nm]	$M_t = I_o \cdot \alpha = \mathrm{I_o} \cdot \dfrac{\omega_1 - \omega_2}{\Delta t}$	–
Coefficient of rolling friction	f_t [m]	$f_t = \dfrac{M_t}{mg}$	indicates the condition of the surface of bearing elements
Friction power	W_t [Wat]	$W_t = M_t \cdot \alpha$	generalized mechanical efficiency of a bearing

where: α – initial angular displacement; e – distance between the pendulum's center of gravity and the pivoting point; mg – pendulum's gravity force; D, d – bearing's outer and inner diameter, respectively; I_o – pendulum's mass moment of inertia relative to the pivoting point; ω_1, ω_2 – pendulum's angular velocity at the lowest position for two successive swings.

Source: own study based on KOWAL (2003), RYCHLIK (2008)

wear symptoms, up to 89 million revolutions at the nominal load torque, were used. The investigated parameters were measured for each bearing in five replications.

The base of the test stand was leveled, and the pendulum with the bearing were mounted in a self-centering clamp. Changes in the pendulum's angular velocity were registered using a photo-optical speed sensor and a signal recorder.

The pendulum was displaced from its equilibrium position by angle α, and changes in the period of swing between two mark points on the pendulum machine were registered. The mark points supported the identification of the pendulum's angular velocity at its lowest position which corresponds to its highest angular velocity. The time of the pendulum's swing between mark points was measured only in the clockwise direction (right to left).

The obtained results suggest that angular velocity of the bearing's outer raceway increased with a rise in the period of swing, and that a higher degree of bearing wear was accompanied by lower angular velocity. The above did not apply to brand-new bearings. The time course of angular velocity of outer raceways in bearings marked by a higher degree of wear, determined at the lowest position of the pendulum, is presented in Figure 3.

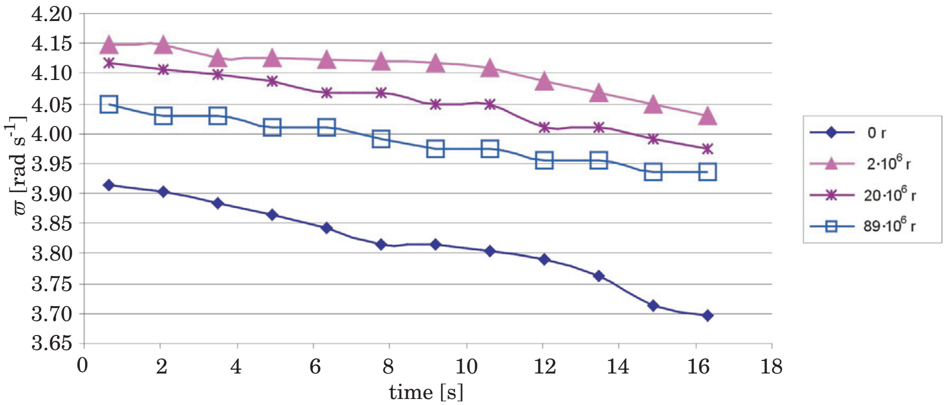


Fig. 3. Time course of angular velocity of bearings 6305 marked by different degree of wear

The angular velocity (ω) and angular acceleration (ε) of the pendulum for brand-new bearings as a function of: period of swing (t), number of swings (i) and the angle of displacement (α) at the lowest position of the pendulum, are presented in Figure 4.

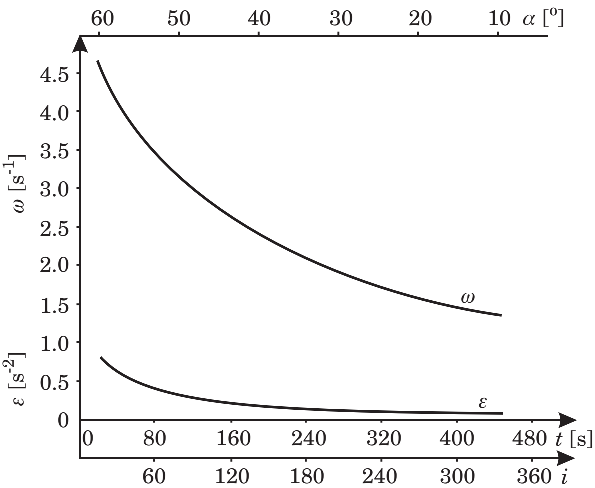


Fig. 4. Time course of angular velocity and angular acceleration of the outer raceway of bearing 6305, subject to the period of swing, the number of swings and initial angular displacement

Figure 5 illustrates changes in friction power W_t and the moment of friction M_t of brand-new bearings as a function of the period of swing at the lowest position of the pendulum.

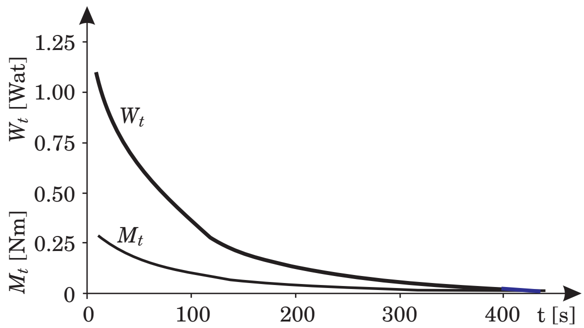


Fig. 5. Time course of friction power (W_t) and the moment of friction (M_t) of bearing 6305

The results of the experiment supported the determination of the values of diagnostic signal parameters for five brand-new bearings at the lowest position of the pendulum. The resulting values are presented in Table 2.

Table 2

Values of diagnostic signal parameters for bearing 6305

Diagnostic signal parameter	Symbol	Average value	Standard deviation
Period of swing	T [s]	454.6	2.88
Number of swings	i	320.2	1.788
Coefficient of friction under oscillating motion	μ_o	0.01218	0.00011
Viscotic damping coefficient	C_w [Nm/s]	0.063	0.00408
Moment of friction	M_t (Nm]	0.278	0.01095
Coefficient of rolling resistance	f_t [m]	0.0134	0.00612
Friction power	W_t [Wat]	1.034	0.04560

The value of the coefficient of friction under oscillating motion μ_o is significantly higher than the referenced value stated by the manufacturer. The coefficient of friction for an unsealed CX rolling ball bearing is $\mu = 0.0010 \div 0.0015$ (*Łożyska toczne* 2005), and for an SKF bearing – $\mu = 0.0015$ (*Poradnik obsługi...* 1994).

The differences in the referenced values of μ and the values noted in this study could be attributed to the industrial practice of stating friction coefficients for broken-in bearings for different bearing load values and standard lubrication (elastohydrodynamic lubrication). For this reason, the values of μ indicated by manufacturer are only reference values. Frictional resistance is determined mainly by contact pressures between the balls and the raceway and micro-spins in contact zones resulting from elastic strain of the raceway and the balls. Therefore, the value of the friction coefficient will be determined by the bearing's rotational speed and load (KRZEMIŃSKI-FREDA 1989).

The obtained results indicate that every selected signal parameter carries diagnostic information for evaluating the technical condition of rolling bearings. The results of previous experiments suggest that the coefficient of friction under oscillating motion is a generalized parameter of a rolling bearing's diagnostic signal. The values of the coefficient of friction may be compared with the referenced values for brand-new bearings or with historical values.

The moment of friction, the coefficient of rolling resistance or friction power during bearing operation are identified as reliable indicators of the degree of wear of a bearing assembly.

Conclusions

The results of this experiment lead to the following conclusions:

– The quasi-dynamic method supports a relatively simple evaluation of the technical condition of rolling bearings at different stages of their life cycle.

– The coefficient of friction under oscillating motion is a generalized parameter of a rolling bearing's diagnostic signal. The values of the coefficient of friction may be compared with the values referenced for brand-new bearings by the supplier.

– The use of the coefficient of rolling friction, the moment of friction and friction power is justified when boundary values that unanimously describe the bearing's technical condition are determined.

– In further studies aiming to improve the techniques for identifying the condition of rolling bearings with the use of the quasi-dynamic method, the presented diagnostic signal parameters should be analyzed as a function of the degree of bearing wear.

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