



SAFE LUBRICATION FOR HIGH SPEED BALL BEARINGS

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ABSTRACT

In given conditions of geometry, speed, loads and mounting arrangement the lubrication regime can be considered as one of the most important influence parameter of the ball bearings service life and, consequently, of the operating assembly reliability. A complex research program concerning the lubrication of the high speed ball bearings assemblies, considering the dynamic stability and thermal regime as main reliability parameters, was carried out and, for a grinding machine test spindle, in given operating conditions, the optimum lubricant was determined.

KEYWORDS: high speed, ball bearing, lubricant, dynamic stability, thermal regime.

1. INTRODUCTION

The bearing service life is decisively influenced by the reliability of its rolling/sliding tribosystems, i.e. ball/race, ball/cage, guided cage/race. In high speed operating conditions, the centrifugal effects, friction losses and, as result, the heat generated in all of these tribosystems, especially on the ball/race contacts, can drastically reduce the bearing service life. To design a high speed ball bearings assembly with enhanced qualitative performances, the securement of an efficient and safe lubrication regime, i.e. EHL conditions for all the bearings ball/race contacts during functioning, represents one of the most important condition. That means to realise and maintain a lubricant film thickness able to both completely and safety separate the ball/race surfaces in relative movement and, also, to take over an important heat part emitted in the contact zones under high Hertzian stresses [1-4].

According to the fatigue phenomenon the service life of a ball bearing, in a given application, is determined, in most of cases, by the ANSI/AFMBA Standard life rating formula (1990) [5]:

$$L_v = a_1 a_2 a_3 \left(\frac{C}{P} \right)^3, \quad (1)$$

where L_v is the bearing service life in 10^6 revolutions, corresponding to reliability level of $(100-v)$; a_1 – reliability factor; a_2 – material factor; a_3 – lubrication-life factor; C – basic dynamic load rating; P – applied equivalent load.

The lubricant regime has a decisive influence on the bearings service life and, as result, various correction factors have been proposed to be included in the service life formula as: a_3 - Lundberg and Palmgren [6-7]; a_{23} – FAG [8] with a range value of 0.5...3; a_3 and a_4 (considering, in addition, the contamination level) - Sayles and MacPherson [9]; a_{SKF} - SKF [10], considering the lubrication conditions, load and contamination level, with a range value of 0.1...50.

After many authors the ratio λ of the lubricant film minimum thickness to composite ball/race surface roughness can be considered as a tribological safety criterion of the high speed ball bearings functioning [5-7]. Ideal lubrication conditions and, consequently, maximum bearing service life can be obtained if, for all the ball/race contacts are secured values $\lambda > 3$. In agreement with the isothermal EHL theory [5-7] the speed or lubricant viscosity increase determines the lubricant film thickness increase. However, if these operational parameters overtake some limits, i.e. $\lambda > 5$, the operating temperatures increase due to lubricant film shear stresses, the film thickness decreases as result of both thermal and starvation phenomena, that act in interdependence and, consequently, the bearing service life decreases.

On the other side, some recently researches highlighted a significant influence of the lubricant on the dynamic characteristics of the high speed ball bearings: dynamic stability increase with the lubricant viscosity increase as result of the squeeze effects in the lubricant entry region of the ball/race contacts [11].

For the high speed ball bearings assemblies-grinding machine spindles, for exemple-obtaining of a high dynamic stability could become, in many cases,



more important than a long service life and, consequently, the optimum lubricant must be chosen according to this reliability factor [1-4]. So, it is obvious that a safe lubrication for a high speed ball bearings assembly is secured if this compromise, i.e. dynamic stability-thermal regime, can be solved by the choice of an optimum lubricant.

2. DYNAMIC STABILITY

The vibration behaviour of a high speed spindle is mainly influenced by the dynamic characteristics of its component parts, i.e. shaft-bearings-housing. If the interfaces shaft/inner ring and housing/outer ring are carefully controlled and considered as "rigid joints", the bearing element interactions, and consequently, its rigidity and damping characteristics, especially of ball/race contacts, can be considered as having a major influence on the spindle dynamic state [1-4]. To design a high speed spindle with enhanced dynamic characteristics, i.e. low vibration levels and critical speeds located away from the running speed by a safe margin in given operating conditions, as essential conditions for a high working accuracy, the designer must estimate and take into account, in a dynamic analysis, all of these characteristics; thus, a theoretical spindle dynamic state more nearly to the real one could be estimated and the failure risk should be more correctly predicted.

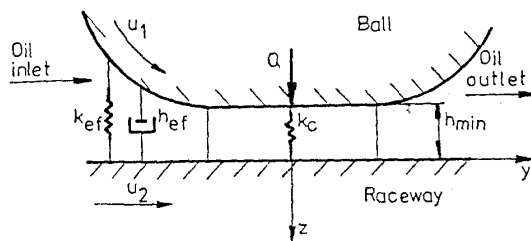


Fig. 1 Dynamic model for a high speed ball/race contact.

In [11] was developed a complex analysis concerning the dynamic characteristics of high speed angular contact ball bearings. Thus, the dynamic mechanism of a high speed ball/race contact operating in EHL conditions (Fig. 1), considering the elastic deformation of the Hertzian contact, both squeeze and damping effects in the lubricant film and, also, the thermal and starvation effects on the lubricant film thickness is governed by:

* elastic rigidity k_c of the Hertzian elastic contact and the film rigidity k_{ef} in the inlet region of the Hertzian contact area acting in parallel and in phase with the displacement δ on z direction;

* film damping h_{ef} in the inlet region of the Hertzian contact area acting in quadrature ($u_{1,2}$ -

speed of ball and race in rolling direction, respectively; Q - normal load on the contact).

Consequently, the normal load on the contact

$$Q = \delta \left[(k_{ef} + k_c) + i h_{ef} \right] \quad (2)$$

By summation of the normal loads on ball/race contacts the load-displacement correlations of the bearing are, respectively:

$$F_{r,a} = \delta_{r,a} (K_{r,a} + i H_{r,a}), \quad M = \varphi (K_m + i H_m), \quad (3)$$

where: $\delta_r, \delta_a, \varphi$ are the displacements between bearing rings on radial, axial and angular directions, respectively; K_r, K_a, K_m - overall rigidities acting in phase with the displacements, respectively; H_r, H_a, H_m - overall dampings acting in quadrature, respectively. By these assumptions, for a high speed angular contact ball bearing under a complex load, the dynamic model presented in figure 2 was proposed.

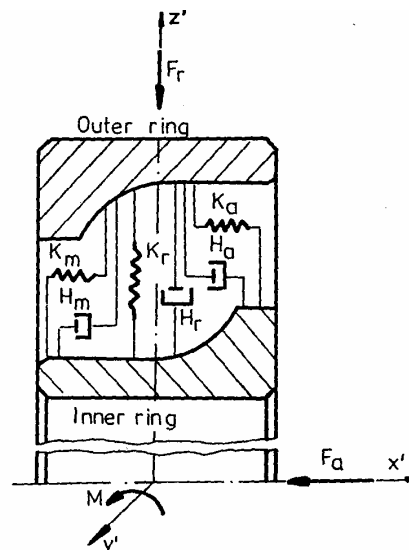


Fig. 2 Dynamic model for a high speed angular contact ball bearing.

To emphasize the lubricant influence on the dynamic behaviour of high speed ball bearings assemblies a complex theoretical and experimental research concerning the dynamic stability of a grinding machine test spindle was achieved. In this sense, the acceleration amplitudes of the transversal vibration of the offset grinding wheel in various conditions of preload F_p , speed n and lubrication were determined, respectively. The results obtained for three oil types, i.e. Te14, H18 and M20 are presented in figure 3 (see next page).

The results obtained highlighted an improved dynamic stability for the oil M20 (higher viscosity) as result of bearing damping increase due to a greater resistance to oil squeeze action in the entry region of the ball/race contacts. In addition, theoretical lubricant ratios $\lambda > 1.5$, determined considering, also, both thermal and starvation effects [6-7, 11], were estimated for all the used oils.

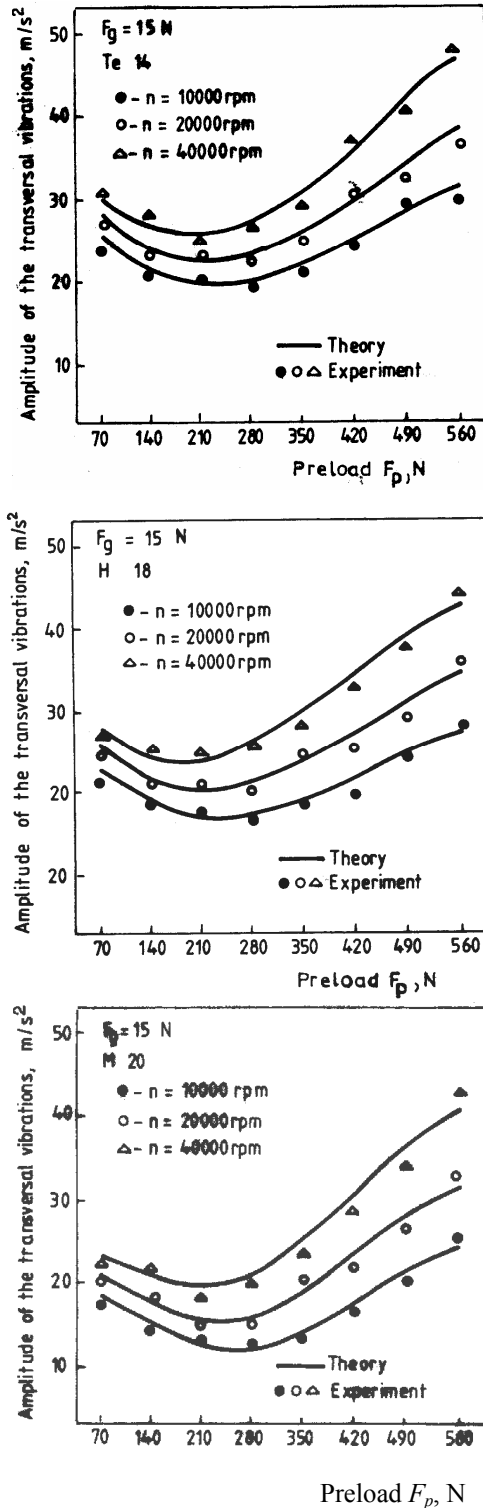


Fig. 3 Vibration levels of the test spindle vs. speed n , bearings preload F_p and lubricant type

3. THERMAL STABILITY

In high speed conditions the operating thermal regime of the bearings, that decide, in fact, the

spindle thermal state, represents the result of some heat sources:

- * viscous friction in lubricant film, i.e. shearing of lubricant as effect of sliding due to contact deformations or spin and gyroscopic motions as result of kinematics changes;

- * intense local heating or cooling phenomena as result of speed variations, internal load distribution changes, lower efficiency of the sealing and cooling systems.

Thus, the spindle operating thermal regime shall be determined, to a great extent, by the amount of the heat transfer balls/races through the lubricant film. Bearing operating temperature increase implies important changes of the lubricant main parameters, especially on the dynamic and kinematics viscosity. Thus, it is very important to realise and maintain a low and stable thermal regime within bearing operating to avoid possible negative successive phenomena: lubricant viscosity decrease, bearing heating, scuffing as result of sudden collapses of the lubricant film, contact failure and bearing assembly out of order [12-15].

In high speed conditions the bearing balls and races operate at different temperatures that, furthermore, vary during functioning. Consequently, the bearing operating temperature is often adopted as a average value because it's very difficult to calculate or measure temperatures as different locations during functioning [16-18].

By these considerations, in the same operating and lubrication conditions, the average steady state functioning temperatures of the test spindle bearings were determined.

The results obtained (Fig. 4) highlighted higher functioning temperatures for the oils with higher viscosity.

According to these results, for the test spindle used in the experiments, the optimum lubricant can be estimated. So, although the oil Te14 secures lower bearing functioning temperature in the given operating conditions, to obtain a high dynamic stability, the oil M20 should be recommended.

4. CONCLUSIONS

A complex research program concerning the lubrication of the high speed ball bearings assemblies, considering the dynamic stability and thermal regime as main reliability parameters, was carried out.

From the results obtained some important conclusions are to highlight:

1. Dynamic and thermal stability can be considered as important lubrication safety criteria in the functioning of high speed ball bearings assemblies. Obviously, this task implies a complicate mathematical apparatus justified, however, by the high reliability and accuracy requirements imposed to the high speed spindles; in this case the results obtained could have a content nearly by the reality and, also, a supplementary thrust degree.

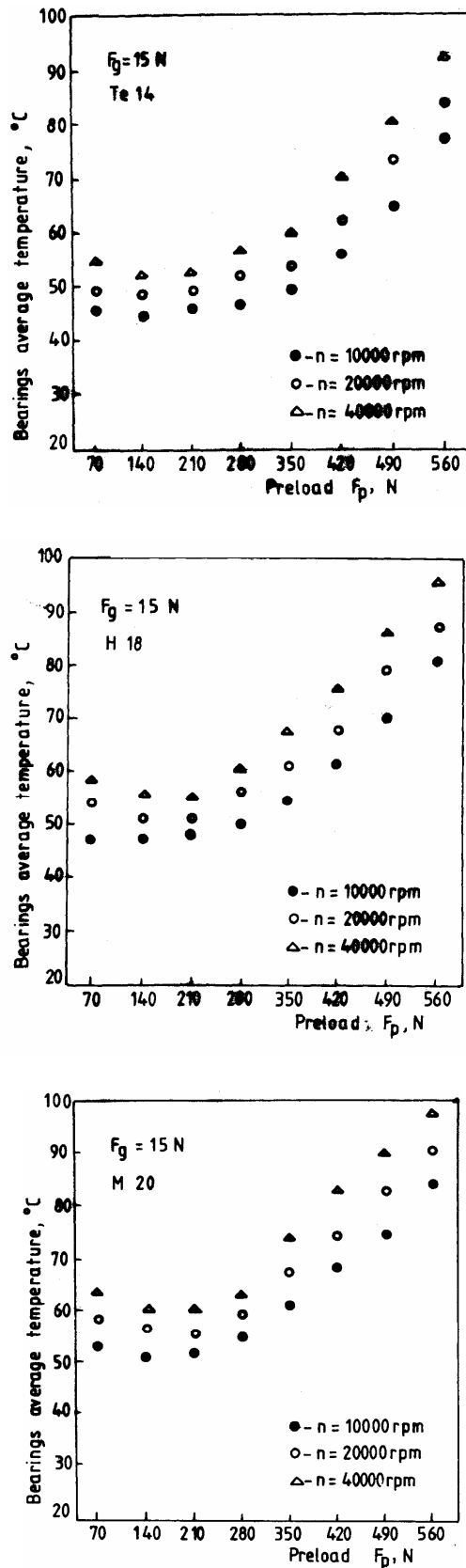


Fig. 4 Average steady state functioning temperatures of the test spindle bearings vs. speed n , bearings preload F_p and lubricant type.

2. To secure a safe lubrication for a high speed spindle assembly, in given operating conditions, represents a difficult task for the designer mainly due to of two opposite effects that occur simultaneously:

* firstly, a higher oil viscosity will increase the bearings damping derived from the ball/race contacts due to an extra resistance to squeeze;

* secondly, conversely, a higher oil viscosity will increase the film thickness together with the contact squeeze ability.

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