SERBIATRIB`07
10th International Conference on Tribology
and
WORKSHOP`07
Sustainable Development in Industry by Apply Tribology Knowledge

ON THE RELIABILITY OF HIGH SPEED ROLLING BEARINGS TRIBOCONTACTS

Gheorghe D. Hagiu and Cezar Oprisan

"Gh. Asachi" Technical University of Iasi, Department of Machine Design & Mechatronics, Iasi, Romania

Abstract. *To design a high speed rolling bearings assembly with enhanced qualitative performances - high service life and a stable dynamic and thermal regime - two main conditions must be fulfilled: an optimum internal load distribution of the bearings, i.e. load uniform distribution on ball/race contacts, and an efficient and safe lubrication regime, i.e. EHL conditions for all the bearings ball/race contacts during functioning; 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. A theoretical research assisted by an experimental validation was developed to determine an optimum design of the high speed rolling bearings tribocontacts - considering the preload and lubrication regime as main optimising parameters - able to fulfil imposed reliability conditions of the operating bearings assembly, i.e. service life, static rigidity, dynamic and thermal stability.*

Keywords: *reliability, high-speed, rolling bearings, tribocontact, optimum design.*

1. Introduction

The machine tools must fulfil a wide interchange ability of component parts with all the related benefits: multiple increase in labour productivity in machine building as a result of the fundamental simplification of assembly operations, transition to serial and mass production, extensive use of standards components, specialization and cooperation of plants, and so on [1-4].

The spindle, by the direct support between the tool and processed piece, represents one of the most important component part of a machine tool, that decides, in fact, the accuracy level. Consequently, new and severe requirements are imposed, in the last time, for the machine tools spindles: speed, power and working accuracy increase together with both high dynamic and thermal stability in imposed conditions of service life and lubrication system. A rolling bearing, as an important component part of this system, includes some rolling/sliding tribosystems, i.e. ball/race, ball/cage, guided cage/race. The bearing reliability is mainly influenced by the reliability of thesetribosystems.

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 and, as result, the assembly reliability [5-8]. The reliability increase of the ball/race contacts appears as a difficult design problem of great importance to increase the bearings and, as result, assembly reliability and operating performances.

This aim can be, however, realised if two main conditions are fulfilled:

1. An optimum internal load distribution on the bearings assembly, i.e. load uniform

distribution on ball/race contacts; in this sense the determination of an optimum preload represents one of the most important design condition.

2. An efficient and safe lubrication regime, i.e. EHL conditions for all the bearings ball/race contacts during functioning; 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.

2. Preload - service life correlation

In high speed functioning conditions, the preload changes the bearing loads internal distribution on the ball/race contacts and, as result, produces important modifications on the bearing functioning parameters, i.e. kinematics, static rigidity, dynamic and thermal stability [1-7]. 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) [8]. 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 [9-11]. Due to the complex phenomena that occur in the high speed ball bearings functioning and, also, having in view the statistic nature of the fatigue phenomenon in rolling contacts, the bearing service life must be approach on new basis considering the fatigue life of each ball/race contact.

By these considerations the bearing fatigue life

$$L = \left(L_{ir}^{-e} + L_{or}^{-e}\right)^{-1/e}. \qquad (1)$$

In [12], for angular contact ball bearings of type 7207 CTA P4 and 7207 B, in given operating conditions, the theoretical preload-service life correlation was determined, the experimental validation of the results obtained being carried out by endurance tests on groups of bearings. Considering a Weibull distribution of the experimental service lives, the comparisons between theoretical and experimental results obtained (Fig. 1 and 2) (100 % conventional service life correspond to a preload value of 2500 N) emphasised the fact that there are certain preload values that ensure higher service life for the tested bearings.

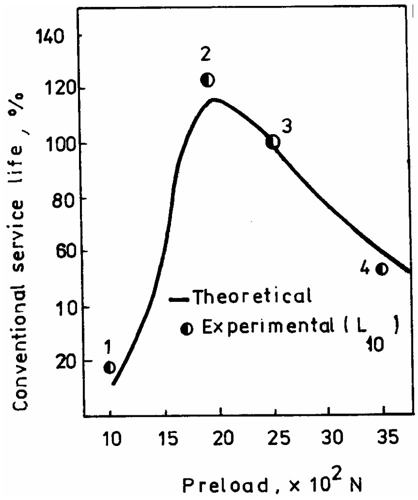

Fig. 1. Preload - service life correlation (bearings of type 7207 CTA P4).

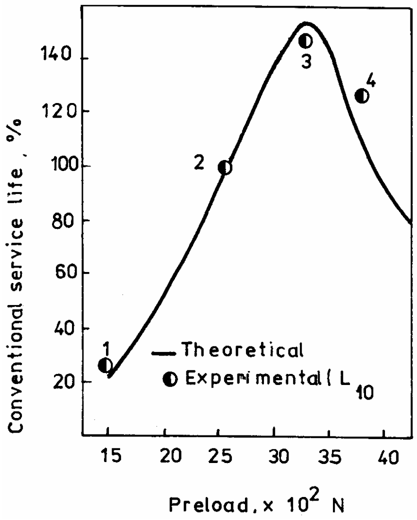

Fig. 2. Preload - service life correlation (bearings of type 7207 B).

3. Lubricant - dynamic and thermal stability correlation

Ideal lubrication conditions and, consequently, maximum bearing service life can be obtained if, for all the ball/race contacts values $\lambda > 3$ - considered as a tribological safety criterion [5-7] - are secured. In agreement with the isothermal EHL theory 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 both ball/race contacts and bearings service life decrease. Some recently researches highlighted a significant influence of the lubricant on the dynamic characteristics of the high speed ball bearings: dynamic stability increase together with the lubricant viscosity increase as result of squeeze and damping effects in the lubricant entry region of the ball/race contacts [13-14].

A complex analysis developed in [15-16] highlighted that the dynamic mechanism of a high speed ball/race contact operating in EHL conditions (Fig. 3), 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:

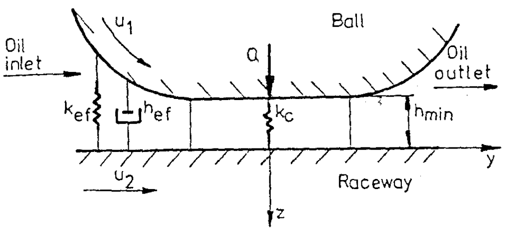

Fig. 3. Dynamic model for a high speed ball/race contact.

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

2. 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

$$Q = \delta\left[\left(k_{ef} + k_c\right) + ih_{ef}\right] \qquad (2)$$

To emphasize the lubricant influence on the dynamic behaviour of a high speed ball/race contact - for a test spindle bearing loaded by a radial force F_r, axial force F_a and bending moment M - a complex research concerning the dynamic stability of a grinding machine test spindle (Fig. 4) was achieved (the acceleration amplitudes of the transversal vibration of the offset grinding wheel in various preload F_p, speed n and lubrication were determined, respectively).

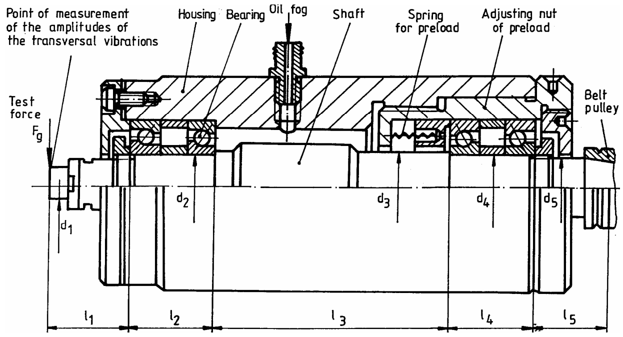

Fig. 4. Test spindle.

The results obtained for three oil types, i.e. *Te14, H18* and *M20*, highlighted an improved dynamic stability of the test spindle for a higher viscosity (oil *M20*) as result of bearing damping increase due to a greater resistance to oil squeeze action in the entry region of the ball/race contacts (Fig. 5).

Although the oil *Te14* secures lower bearings functioning temperature in the given operating conditions, to obtain a high dynamic stability, the oil *M20* should be recommended.

5. Conclusions

From the analysis of the results obtained some conclusions are to highlight:

1. The preload and lubrication regime represents two of the most important factors that must be considered to design a reliable high speed rolling tribocontact, and, as result, a reliable high speed rolling bearings assembly. An adequate preload secures an optimum internal load distribution on the ball/race contacts and, consequently, a high service life of the both bearings and assembly. The necessary bearings preload value must be determined according to the assembly reliability parameters imposed by the working process: service life, static rigidity, dynamic and thermal stability.

2. Dynamic and thermal stability, securing an imposed lubricant ratio λ, can be considered as an important lubrication safety criteria in the functioning of the high speed ball bearings assemblies. An efficient and safe lubrication regime, i.e. EHL conditions for all the bearings ball/race contacts during functioning, could secure a stable dynamic and thermal regime.

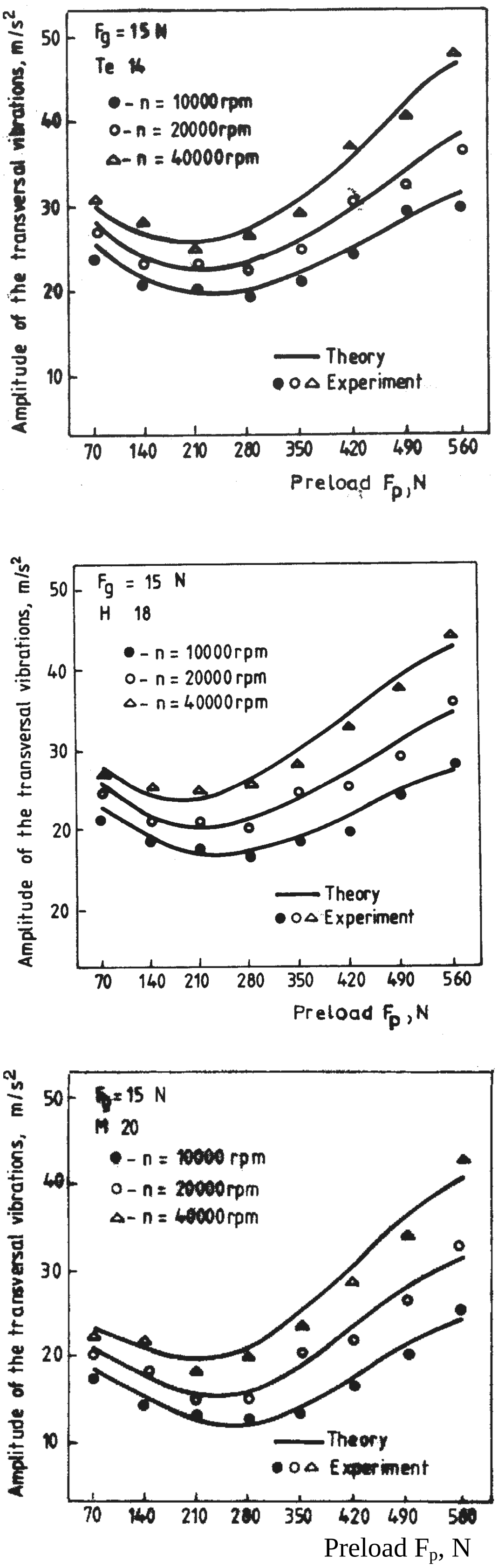

Fig. 5. Vibration levels of the test spindle *vs.* speed n, bearings preload F_p and lubricant type.

References

[1] Reshetov, D.N., Portman, D.N., Accuracy of Machine Tools, ASME Press Translation, New York, 1989.

[2] *** The Design of Rolling Bearing Mountings. Publ. FAG WL 00 200/5 EA, 2000.

[3] Weck, M., Hanrath, G., Tüllmann, U., Erhöhung der Drehzahlgrenze und Lebensdauer von Spindellagern. Antriebstechnik 36(9), 1997, 73-77.

[4] Weck, M., Tüllmann, U., Butz, F., Schrägkugellager-Maschinenelement zur Lagerung Schnelldrehender Spindeln. Seminar „Gestaltung von Spindel-Lagersystemen“, 2000, Aachen.

[5] Gafitanu, M.D, et. al., Rolling Bearing Analysis, Vols. I and II, Ed. Tehnica, Bucuresti, 1985 (in Romanian).

[6] Harris, T.A., Rolling Bearing Analysis, 3rd Ed., Wiley, New York, 1991.

[7] Eschmann, P., Hasbargen, L., Weigang, K., Ball and Roller Bearings, Wiley, New York, 1985.

[8] Harris, T.A., McCool, J.I., On the Accuracy of Rolling Bearing Fatigue Life Prediction. Transactions ASME, Journal Lubrication Technology 118, 1996, 297-310.

[9] *** FAG Wälzlager, Katalog WL 41 520 DB, Weppert GmbH & Co. KG, Schweinfurt, 1995.

[10] Sayles, R., MacPherson, P., Influence of Wear Debris on Rolling Contact Fatigue, ASTM STP 771, J. Hoo. Ed., 1982, 255-274.

[11] *** SKF Hauptkatalog, 4000/IV T, Media Print Inf., Paderborn, 1994.

[12] Hagiu, G.D., Gafitanu, M.D., Preload Service Life Correlation for Ball Bearings on Machine Tools Main Spindles, Wear 172, 1994, 79-83.

[13] Lörosch, H., Reliable Lubrication of Machine Tools Bearings, Pub. FAG WL 02 113 EA, 1987, 28-35.

[14] Hoeprich, M.R., Rolling-Element Bearing Internal Temperatures, Tribology Transactions 39(4), 1996, 855-858.

[15] Hagiu, G.D., Gafitanu, M.D., Dynamic Characteristics of High Speed Angular Contact Ball Bearings, Wear 211, 1997, 22-29.

[16] Hagiu, G.D., Gafitanu, M.D., Optimum Lubricant: Best Compromise Dynamic Stability-Functioning Temperature for High Speed Ball Bearings, 12th International Colloquium Tribology, January 13-15, Esslingen, 2000, 1237-1244.