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Numerical analysis of contact stress and strain distributions for greased and ungreased high loaded oscillating bearings

D. Tonazzi [a,c,*], E. Houara Komba [a,b], F. Massi [c,d], G. Le Jeune [b], J.B. Coudert [b], Y. Maheo [b], Y. Berthier [a,d]

[a] University of Lyon, CNRS, INSA-Lyon, LaMCoS, UMR5259, 20 rue des Sciences, F-69621 Villeurbanne, France
[b] SKF Aerospace, 29 chemin de Thabor CS90114 26904, Cedex 9, Valence, France
[c] University of Rome 'La Sapienza', Department of Mechanical and Aerospace Engineering, via Eudossiana 18, 00184 Rome, Italy
[d] InTriG, International Tribology Group, Villeurbanne, France

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ABSTRACT

Nowadays rolling bearings are subject to extreme operating conditions due to the increasing of the transmitted power and the optimized design. Consequently, the reduction of the bearing dimensions can lead to a reduction of the contact area and an increasing of the power transmitted per unit of contact area. Some special applications as space engineering, robotics, aeronautics and wind energy require rolling bearings subjected to high contact pressure while the movement is governed by an oscillating motion; such extreme conditions can lead to degradation and failure scenarios which are not linked to classical contact fatigue and are not completely understood yet. The aim of this work is to investigate the contact stress and strain distribution of rolling bearings under high loaded oscillating motion, i.e. high contact pressure and deformation. 3D finite element simulations with elasto-plastic material law have been carried out and a comparison of the results with the classical elastic law is presented. The effect of the friction coefficient, the radial load and the surface conformity have been investigated. The numerical results have been compared with the tribological observations of the degraded bearings under the same load conditions. The presented results contribute to the tribological and physical interpretation of the degradation scenario, for greased and ungreased bearings, by a mechanical point of view.

1. Introduction

The rolling bearing system is a mechanical component used in a wide range of applications such as aeronautic, aerospace, robotic, vehicles, bike, home appliance, civil machines, etc. [1]. Thus, the impact of bearing damage [2] and consequently their lifetime [3–5] is a crucial aspect by a technological, security and maintenance point of view [6]. Understanding the damage mechanisms under different operating conditions can improve the performances and the expected lifetime of bearings.

In many applications, the bearings operate in lubricated continuous motion, where a thin film of lubricant is developed between the rolling elements and the raceways, in order to protect the contact surfaces. However, in several other applications rolling bearings are characterized by oscillating motion instead of continuous motion and, in such operating conditions, the low relative velocity between the contact pairs does not assure a classical elasto-hydrodynamic lubrication; in such cases the grease lubrication [7–10] is often employed to avoid the direct contact and consequently the immediate damage of the bearings.

In this context, several works on bearings with lubricated continuous motion have been carried out to understand the bearing damage scenarios and to predict their behaviour and average lifetime. Some works in the literature [11–14] propose different models to describe the damage evolution and scenario in a more general approach. However, these models cannot account for all the different possible operative conditions and the interaction of the several mechanisms at the origin of the damage. On the other hand, oscillating and discontinuous motion bearings have not deeply investigated in the literature and only few works are available. Some models have been derived for the consideration of oscillating motions to estimate the rolling bearing lifetime [15,16]. Berthier et al. [17] showed the existence of more than one wear mechanism for dry oscillating bearings. The friction and the wear are influenced by the third-body flows [18,19] within the contact. Recently numerical tools have been developed overcoming the problems encountered in the experimental tests (limitation on the investigation of local contact status and stress distribution) [18]. The authors presented a preliminary numerical

* Corresponding author at: University of Rome 'La Sapienza', Department of Mechanical and Aerospace Engineering, via Eudossiana 18, 00184 Rome, Italy.

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analysis [20] on the same ball bearings system comparing the results obtained by 2D and 3D finite element models and highlighting the limits of the 2D model due to the surface conformity of the contact and the plastic material behaviour.

In this context, the present paper shows a 3D numerical analysis of high loaded oscillating bearings submitted to extreme operating conditions. The 3D finite element model has been developed to perform simulations of the bearing system under high radial load and applying an oscillating angle to put in relative motion the contact pairs. The elasto-plastic behaviour of the materials has been accounted for, while the frictional behaviour is accounted for in the model by penalty method and the Coulomb friction law.

In the first part of the paper, a comparison between elastic and elasto-plastic behaviour is presented pointing out the limits of the elastic analysis. Then, the distribution of the stresses and strains in the ball and in the inner ring is discussed by a parametrical analysis performed as a function of the friction coefficient, the radial load and the surface conformity. The difference between greased and ungreased bearings is discussed as a function of the equivalent friction coefficient.

In the last part of the paper a comparison of the numerical results with the experimental ones is made. The experimental results carried out on the same rolling bearing system are presented in [21]. The conclusions of this analysis highlighted as the subsurface plasticized material is at the origin of the damage mechanism of the greased bearings under high radial load and oscillating motion, as confirmed from experiments.

2. Numerical model

2.1. 3D finite element model

A 3D finite element model has been developed and solved using a commercial code in order to analyse and investigate the origin of the degradation scenario of rolling bearings submitted to high radial load and oscillating motion. Starting from a rolling bearing system composed by 12 balls, inner ring and outer ring without cage (Fig. 1-a) the system has been reduced as shown in Fig. 1-b to perform the contact simulations on the most loaded ball. In fact, the dimension of the full bearing system doesn't allow to carry out simulations on the whole system, because of the high computational effort due to the contact non-linearities. Then, the analysis is focused on the most loaded ball (radial direction) taking in account the inner and outer ring sectors, as shown in Fig. 1-b. Moreover, the numerical analyses with contact interfaces need to model the surfaces in contact with fine meshing, ensuring a reliable distribution of the contact stress and strain distributions. At this aim, during the CAD phase, the system (ball and rings respectively) has been divided in many subparts in order to refine the element dimensions and ensure accuracy at the contact during the solution process. In particular, the surface of the ball in contact with the inner ring raceway has been highly refined within a thin layer of 100 μm (Fig. 1) to ensure the reliability of the results at the contact zone. The strategy described above, adopted for modelling the rolling bearing system, allowed for an accurate convergence of the frictional simulations. The reduced geometry of the model and the related mesh used to perform the contact static simulations are reported in Fig. 1, highlighting the mesh and the element shape of the model along the XZ and XY section planes. The mesh properties of the rolling bearing model are reported in Table 1.

2.2. Materials, mesh properties and boundary conditions

The material of the bearing system considered to carry out the numerical simulations is the 100cr6 and the related elastic properties are reported in the Table 2. For the plastic behaviour, a specific hardening model of the material has been used. The plastic properties have been previously determined by comparison

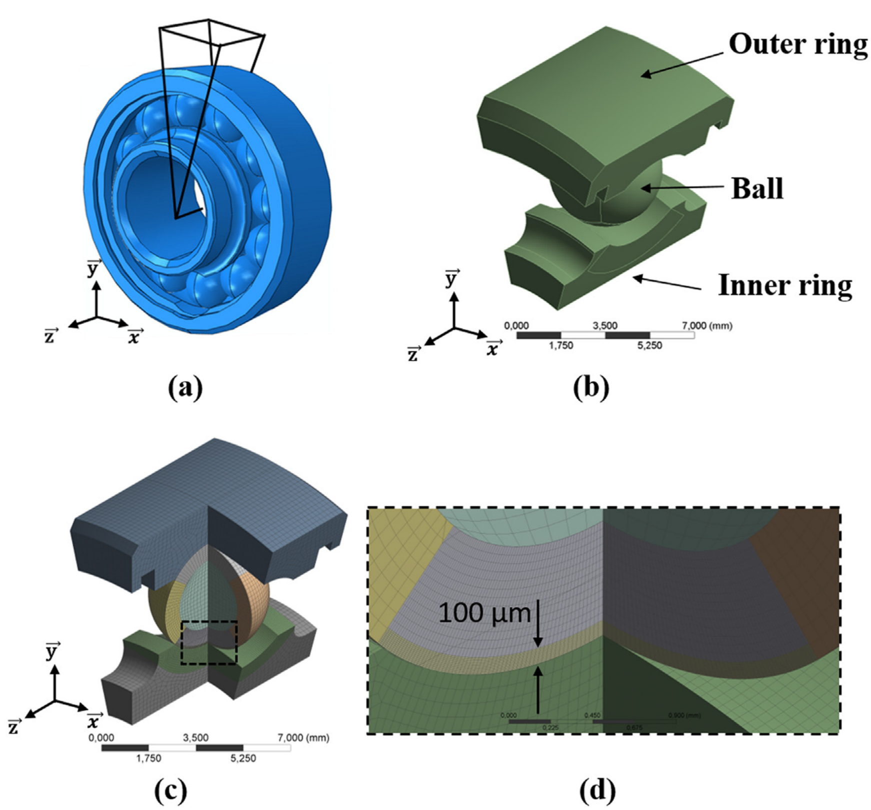

Fig. 1. (a) Full rolling bearing geometry; (b) reduced rolling bearing geometry; (c)-(d) mesh of the reduced model along the YZ and YX section planes.