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An approach for predicting the internal behaviour of ball bearings under high moment load

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ABSTRACT

This paper presents a modelling approach for predicting the internal dynamic behaviour of ball bearings under high moment loads. This type of loading is a specific feature of helicopter main gear boxes because of special design rules and the high structural flexibility of such systems. The ball bearing model proposed here is not limited to planar systems and incorporates several different phenomena such as contact deformation, elastohydrodynamic contact, internal clearance and cage run-out. The cage–race interaction is treated as a hybrid short journal model, which ensures continuity of the contact force at the transition from the hydrodynamic to metal-to-metal regime. In the dynamic analysis of such a severely loaded bearing, the dependence of the shaft-to-inner-ring force on inner race position cannot be neglected. An equivalent viscoelastic hinge joint has been developed, it produces an additional force that represents the overall rigidity of the system. The stiffness parameters of the joint are identified using global finite element simulations. A ball bearing loaded with two different moments is chosen as an example. Relevant results concerning the internal dynamic behaviour are given. The predicted cage trajectory has been compared to experimental observations, and good agreement has been found.

1. Introduction

In the aircraft industry, and in particular the manufacture of helicopters, the quest for maximum performance requires the power weight ratio to be maximized. A power transmission gearbox of 300 kg can transmit several megawatts from the engines to the rotor (see Fig. 1). Weight saving is essentially achieved by reducing the number of parts and their thicknesses. Such a strategy leads to increasingly flexible housings and shafts. Associated with the high power transmitted, this increasing flexibility causes relatively large strains in the power transmission gearbox. Rolling bearings are naturally affected by housing deformation since any misalignment of rolling bearing races may cause damage to rolling element bearings and premature failure [1]. This structural deformation leads to an additional moment load on the rolling bearings. Also, the ball separator or cage becomes a critical component. Previously there simply to ensure a uniform distribution of the rolling elements, it now experiences significant stresses, and cage fracture due to material fatigue frequently occurs. In power transmission gearboxes, rotating shafts are usually supported by three rolling bearings; two roller bearings support radial loads whereas the ball bearing

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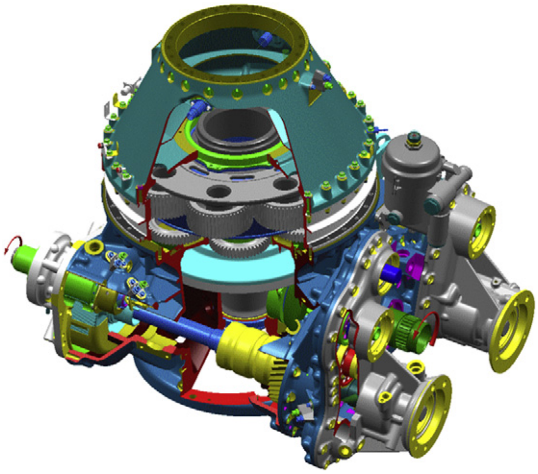

Fig. 1. Helicopter main gearbox.

may experience mainly thrust loads. This load distribution is obtained on account of a large clearance between the outer race of the ball bearing and its housing. As each rolling bearing must experience an appropriate load, improved system reliability is expected. Thus, the load experienced by ball bearings only comprises a thrust load and an additional moment load inherent in structural deformation. Slewing bearings used in wind turbine applications also encounter very high moment load [2,3]. However, it concerns mostly low speed applications making dynamic analyses unnecessary. Finally, the absence of radial load, the combination of thrust load and moment, and the moderate-to-high rotation speed appears to be specific to the helicopter industry. This case seems largely ignored in the literature, indeed, the majority of rolling bearing dynamic analyses published in the literature only consider axial or radial loads.

Because of their critical role, rolling element bearings have been widely investigated. Initial studies focused on static and quasi-static analyses. Stribeck was among the first to investigate the load distribution in rolling elements. Later, Lundberg and Palmgren studied the fatigue behaviour of bearings. Perhaps the first computer code to carry out static analyses of rolling bearings is credited to Jones [4]. This code was able to predict the load distribution, stiffness and fatigue life of rolling bearings. The work of Harris is also of great importance, with an excellent review of the work to be found in [5]. To address the problem of kinematic indeterminacy in quasi-static analyses, Jones [4] proposed the very commonly used *race control hypothesis*. The

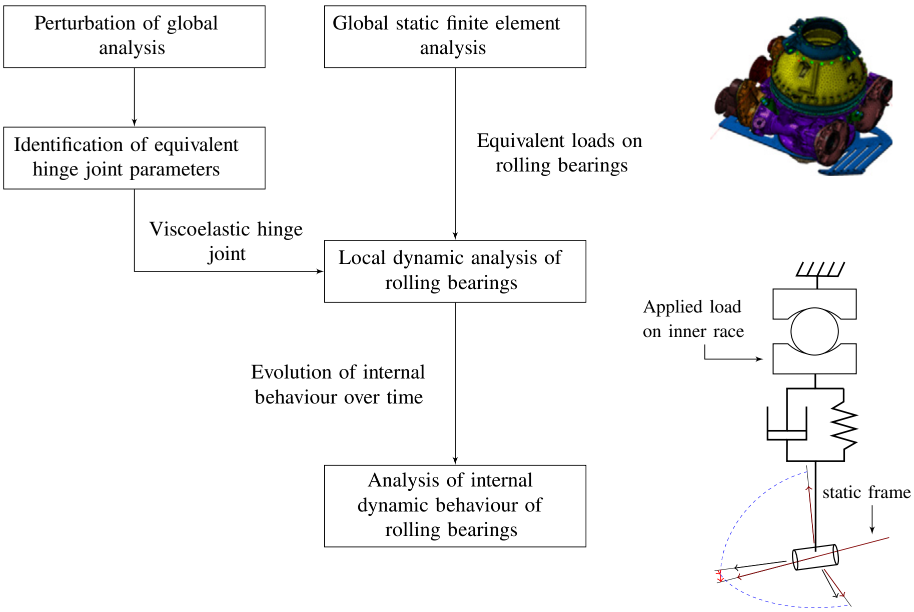

Fig. 2. Modelling approach.