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[Extended Abstract]

Radial roller bearings with flexible rings: application to rotor dynamics and extension to multibody simulations

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Introduction

Most of bearing models omit structural deformations of rings, considering the shaft and the housing are sufficiently rigid. This assumptions does not hold for modern jet engines, where shafts are commonly hollow and the housing and the outer ring thicknesses may be of comparable magnitudes. Rings deformations in this case can significantly change the bearing stiffness. This factor becomes particularly important if a considerable negative internal clearance occurs at the bearing at its operating regime. In such situations, if the bearing rings are said to be rigid, the computed radial contact forces may be significantly overestimated (for instance, up to 3 times for the clearance[1] of -40μm, as shown in Figure 1). If performed correctly, nonlinear static analysis of the complete three-dimensional FE assembly of the rotor support automatically captures effect of rings flexibility. However, such approach is computationally expensive and nearly unacceptable for rotor dynamics problems of gas turbine engines with several antifriction bearings.

Mathematical model

Besides the rings deformations resulting from radial contact forces, the proposed model accounts for centrifugal forces acting on the rollers and rings expansion due to axial rotation and heating. Interactions between the rollers and the cage are small in comparison to the raceway normal forces. Due to the similar reason, friction is not considered. The hydrodynamics effects are also currently neglected, since their significant contribution appears mainly in ultrahigh-speed applications.

If the relative displacement between the inner and the outer rings is known, it is then possible to construct the following energy functional for each roller:

$$U = \frac{1}{n+1} C_e \delta_e^{n+1} + \frac{1}{n+1} C_i \delta_i^{n+1} - \frac{1}{2} m \omega_r^2 (R_p + v_a)^2 + \frac{2\pi E b (R_h - R_e)}{N(R_h + R_e)} v_e^2 + \frac{2\pi E b (R_i - R_s)}{N(R_i + R_s)} v_i^2, \quad (1)$$

which gathers contributions from contact interaction between the roller and the raceways, centrifugal force and rings deformation. Minimization of (1) results into a set of 3 nonlinear equations with 3 unknowns: v_a — displacement of the roller with respect to its reference position, v_e and v_i — radial deflections of the outer and inner rings, respectively, see Figure 2. This system of equations can

[1]To guarantee optimum bearing life, its internal clearance should remain as low as possible or slightly negative at operating mode. Due to design errors this requirement may be violated that seriously compromises bearing durability.

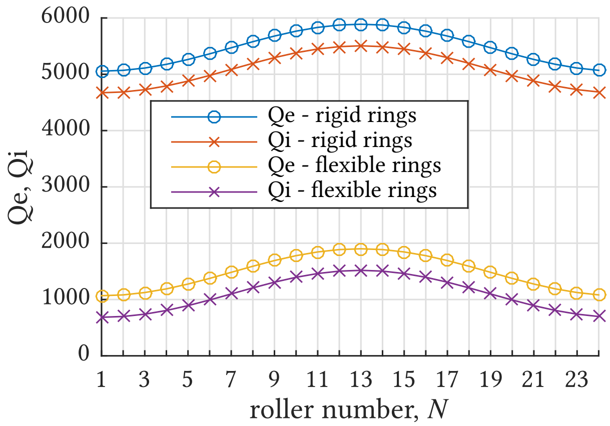

Figure 1. Distribution of radial forces acting on the bearing inner and outer rings.

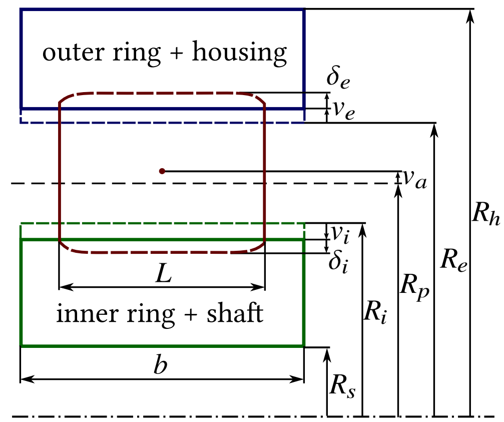

Figure 2. The bearing roller and rings in the deformed configuration.

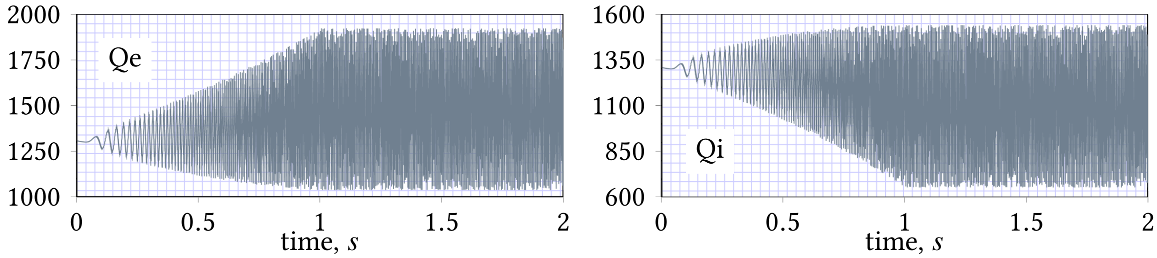

Figure 3. Evolution of radial forces acting on a certain roller in transient analysis.

be resolved by classical Newton–Raphson scheme for each roller separately that positively impacts on the model performance. The corresponding two nodes finite element built on its basis is robust, highly efficient and accurate for practical applications. The obtained distribution of radial forces can be confidently used for subsequent bearing life assessment.

The roller/raceway contact phenomenon is simulated with the aid of classical Hertz theory, whose application renders first two terms in (1) with $n = \frac{10}{9}$ for cylindrical roller bearings and $n = \frac{3}{2}$ for ball bearings, respectively. Non-cylindrical profiled rolling elements can be also handled: in this case the roller curved surface is reproduced by several cylindrical slices [1], which may have unequal lengths.

The last two terms in (1) describe the contraction/expansion of the ring caused by the internal tensile force. According to our numerical experiments, if distribution of N radial forces acting on a ring is relatively smooth and $N \geq 12$, the bending contribution becomes negligible and only tension/compression phenomenon can be considered. If bending factor is essential, Fourier series expansion can be applied to define the ring out-of-roundness produced by a single radial force and then the superposition principle is invoked to determine the deformed shape of the entire ring [2].

Along with quasi-static analysis, the developed radial bearing element can be used in transient and multibody dynamics simulations, see Figure 3 (Dynamics R4 software). To this end, a specific technique that extracts small relative in-plane deflections and an out-of-plane angular misalignment from arbitrary large displacements and rotations is proposed. The developed mathematical wrapper does not depend on the rolling element kinematics and can be used for bearings of any type.

References

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[2] G. Cavallaro, D. Nelias, and F. Bon. Analysis of High–Speed Intershaft Cylindrical Roller Bearing with Flexible Rings. *Tribology Transactions*, 48(2):154–164, 2005.