Numerical Tribodynamic Analysis of High-Speed Roller Bearings in a Flexible Multi-Body Environment

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A flexible dynamic model with lubricated roller bearings under high-speed operating conditions, representative of electrified powertrains, has been developed. The interaction of tribological behaviour with the dynamics of a shaft-bearing system is investigated. This is achieved using a 6 degree of freedom lubricated component level bearing model within a full system model in a flexible multi-body environment. System dynamics as well as tribological quantities such as elastohydrodynamic pressure, film thickness, lubrication regime and friction are studied. Inclusion of the lubricant film at the roller-race contact leads to a more accurate representation of the dynamic response and tribological performance.

Keywords: High-speed, Roller bearings, Tribodynamics, Elastohydrodynamic Lubrication, Flexible Multi-Body Dynamics

1. Introduction

Significant cost reductions can be achieved using predictive automotive simulation tools. Multi-system vehicle powertrain concepts are requiring the complexity of simulation models to increase, which requires accurate and robust component level understanding. The associated performance characteristics of the bearings such as friction and wear, thermal stability and generated vibration and noise [1] must be modelled accurately at the development stage to ensure full system success.

Roller bearings in electrified powertrains operate with much higher lubricant entrainment velocities, resulting in larger central film thickness values in the same order and sometimes exceeding that of the contact deflection. The assumption of dry Hertzian contact conditions in previous high degree of freedom (DOF) bearing models is no longer valid at these speeds. Neglecting the lubricant film in the contact underestimates the total deflection and hence load. Additionally, tribological phenomena at high speeds cannot be studied.

This study therefore presents a validated model of a 6 DOF flexible dynamic shaft-bearing system, with lubricated roller bearings for more accurate high-speed (up to 15 000 rpm) tribodynamic investigations. These capabilities have not been reported in open literature to the authors' knowledge.

2. Methods

A system level model has been developed in a commercially available flexible multi-body (FMB) dynamic software. A 6 DOF component level bearing model connects the shaft and bearing housing. At each time-step of the simulation, the relative displacement of the shaft and housing are passed to the component level model. Using a contact slicing method, the individual roller load is calculated, with the elastohydrodynamic (EHL) film implicitly included at the inner and outer roller-race conjunctions. The total reaction force and moments on the bearing races are returned to the system level model and used to solve equations of motion in the FMB environment.

For computational efficiency, extrapolated film formulae are used within the component level model. An explicit full numerical EHL solver based on Reynolds equation also provides the film thickness profile and pressure distribution for individual rollers at specific time-steps.

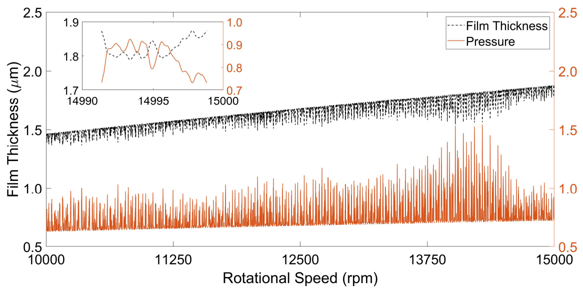

Figure 1: EHL film thickness and maximum EHL contact pressure

Dynamic analyses including frequency spectra, force magnitudes, and acceleration have been obtained for varying speeds and loading conditions up to 15 000 rpm. Combined with surface topography measurements of the modelled bearings, boundary and viscous friction have been calculated. Comparisons between the dry and lubricated contact approaches have also been performed.

3. Discussion

As presented in Figure 1, the EHL film reaches a peak of 1.87 μm at 15 000 rpm. Neglecting this underestimates contact loads within the bearings, affecting the dynamic response of the full flexible system. The inclusion of this is therefore found to be essential for accurate predictive tribodynamic modelling of high-speed electrified powertrains.

4. References

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