Modeling Tribological Impact on Overall System Dynamics

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INTRODUCTION

While the support bearings are key elements of rotating machinery systems, the overall system performance and design depend on a close integration of several disciplines. For prescribed life and operating environment the applied static loads and speeds on each of the system component may be generally determined by an equilibrium analysis. Conventional rotor dynamics models may be used to model overall system dynamics, rotor response and dynamic loads imposed on the support bearings. As a function of these applied conditions bearing response and dynamic performance is determined by integration of the equations of motion of each bearing element; in the case of rolling bearings, the available bearing dynamics models, such as ADORE (Advanced Dynamics Of Rolling Elements) provide integration of the classical differential equations of motion to model real-time performance of the bearing. With prescribed bearing geometry and applied operating conditions, it is well established that lubricant properties and mechanics play a major role in determining the stability of bearing elements and overall system performance. The rolling-sliding interactions in the concentrated contacts between the bearing elements produce heat, which travels through the bearing and the overall system. This affects temperature of the bearing elements, which in turn changes the bearing geometry and material behavior including the lubricant. Thus overall system design and performance simulation requires a close iteration between the various models at varying levels of sophistication.

In order to facilitate the above iterations and model integration this paper proposes a “virtual design system” which permits the designer to perform the various tasks at the required level of sophistication with minimum expertise in any of the technical areas associated with the models. A graphic users interface basically interacts with the designer to collect the system requirements and output the possible design solutions.

MODELING APPROACH

The proposed model is based a simultaneous integration of mechanical and thermal interactions in each component in the system. Rolling bearings being the key elements of a rotating machinery system, the bearing dynamics code, ADORE, is the main component model. The modeling interfaces and database structures within ADORE permit easy interaction with finite element systems models, both mechanical and thermal,
rotor dynamics models and other component models which may affect the applied conditions on the bearings. At any given operating conditions, prescribed materials, lubricant properties and bearing geometry, ADORE integrates the equations of motion to compute overall bearing dynamics and heat generation. While the dynamic response is viewed in the context of rotor response and overall system dynamics the heat generation is passed on the thermal models to compute temperature fields in the bearings and the system as a whole. The temperature field in the bearing is used to revise the bearing geometry, material properties and lubricant behavior. ADORE is then used again to compute the new dynamic response and heat generation. Such iterations are continued until numerical convergence and compatible response are obtained.

Computation of heat generation in ADORE is based on fairly sophisticated elastohydrodynamic models for the lubricant. Based on experimental traction data obtained with the prescribed lubricants ADORE considers both Newtonian and visco-elastic behavior to model lubricant traction in the given operating environment. Precise rheological response of the lubricant as a function of subtle dynamic changes in applied loads, temperatures, rolling and sliding velocities is ensured by fairly intelligent numerical integration algorithms where the time step is automatically optimized for a given truncation limit. Thus all solutions are numerically sound irrespective on the dynamic variations in the applied conditions.

**PRELIMINARY RESULTS**

To demonstrate the technical feasibility of the above approach, a simplified thermal model is incorporated in ADORE. Here the heat generated at the various contacts is used to calculate the temperature field in the bearing using simplified conduction and convection models. Later these thermal models may be replaced by more sophisticated finite element model. Now since the time scale for mechanical interactions is greatly different the thermal counter part, the computed heat generation is time-averaged over a given duration. This average heat generation is then input to the thermal model to compute the temperature fields. It is postulated that such a step change in temperature may eventually lead to stable steady-state temperatures, when the bearing is stable. Such results, for a typical turbine engine ball bearing, are shown below in figure 1. It is seen that as the bearing reaches steady-state the bulk temperatures of the various bearing elements stabilize to fairly constant level. Thus the proposed approach has a significant design potential.
Figure 1. Bulk temperatures as a result of combined mechanical and thermal interactions as modeled by the bearing dynamics model, ADORE.