Euromech Colloquium 573 "VIBRATION ANALYSIS OF ROTATING SHAFT ON TEXTURED HYDRODYNAMIC JOURNAL BEARINGS"

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Abstract: The aim of this study is to analyse the influence of surface texturing on the dynamic behavior of a shaft on two hydrodynamic bearings. A prediction algorithm is presented with Fluid Structure Interaction (FSI) between the rotating shaft and the lubricant based on finite element method. Cavitation in bearings is taken into account. The hydrodynamic flow in the texturing pattern is modeled by two multi-scale algorithms. Static, modal and transient analyses are performed in order to predict the impact of several texturing patterns on the system vibrations.

Keywords: *Hydrodynamic journal bearings, monolithic FSI coupling, cavitation, surface texturing, multi-scale homogenization*

1 Introduction

Advanced rotating machinery, using small rotors or working at high rotating speeds, require a complete control of the vibration components. Lubrication systems, such as hydrodynamic journal bearings play a crucial role in the dynamic behavior of the whole machinery and have a significant influence on structures vibrations. Fluid Structure Interaction between the lubricant and the rotating shaft has to be taken into account. Predictions of the shaft vibrations are difficult because of the nonlinear behavior of the hydrodynamic bearing. Moreover, cavitation in the lubricant appears and changes drastically the pressure distribution. Several cavitation models could be retained leading, in most cases to different behaviors. Besides, recent improvements in surface texturing have shown several enhancements in hydrodynamic lubrication such as friction reduction or improvement of drag force. However, effects of the texture pattern on the dynamic behavior of the system are not well known and need to be properly analyzed.

2 Hydrodynamic bearing with cavitation

The pressure in hydrodynamic bearings can be low enough for the lubricant to vaporized in the low pressure zone. In this work, the cavitation phenomenon in the lubricant is modeled by a free surface problem between two fluid domains, with Reynolds equations and the Jakobsson-Floberg-Olsson / Elrod-Adams (Elrod (1981)) mass flow conservation model in a finite element formulation. The problem is written as a Linear Complementary Problem (LCP), and the Lemke algorithm is used to compute the pressure profile and the cavitation boundaries in the fluid film.

3 Monolithic algorithm for vibrations analysis

The pressure profile is projected on the structure, modeled by a Timoshenko beam. The finite element method is used to discretize the conservation of momentum of the system (Lalanne and Ferraris (1990)) :

$$\mathbb{M}\ddot{\delta} + [\mathbb{D} + \mathbb{G}]\dot{\delta} + [\mathbb{K} + \mathbb{C}]\delta = \mathbb{H}p(\delta, \dot{\delta}, \dot{\phi}) + \dot{\phi}^2 F(\phi) \tag{1}$$

where δ is the displacement vector of the structure, p the pressure vector of the fluid degrees of freedom, ϕ the angular position of the mass unbalance, $\mathbb{M}$ the mass matrix, $\mathbb{D}$ the dissipation matrix, $\mathbb{G}$ the gyroscopic matrix, $\mathbb{K}$ the stiffness matrix, $\mathbb{C}$ the circulatory matrix, $\mathbb{H}$ the projection matrix of the pressure degrees of freedom of the fluid elements on structure elements, F the unbalance force excitation. The dependance of the pressure p in δ and $\dot{\delta}$ is highly nonlinear.
Newton's method is used to compute the static equilibrium of the system. Modal analysis can give information on linearized vibrations around equilibrium positions taking into account shaft misalignment in bearings. An implicit algorithm realizes time integration in order to find limit cycles for the shaft orbits.

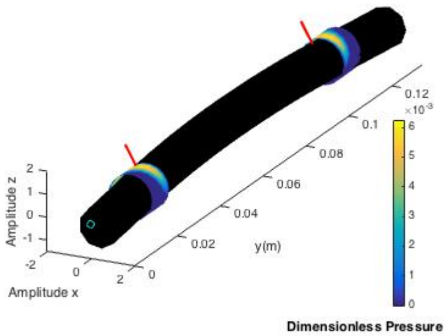

Figure 1: Hydrodynamic pressure projected on the rotating flexible shaft (in black) with rotating unbalance (in red).

4 Surface texturing

Lightly loaded journal bearing rotating at high speed are known to be unstable. Surface texturing could be used to control the system vibrations. By manufacturing a pattern on the rotating shaft or on the bearing sleeve, the whole lubricant flow in the bearing clearance is modified. This lead to modifications of the pressure profile and of the dynamic behavior of the whole system. Laser surface texturing can be used to perform dimples of the size of the bearing clearance (figure 2). One can control the dimples depth, radius, or the surface covering rate in order to modify the system vibrations. First, homogenization techniques of Reynolds equation are used to analyze surface texturing influence on the monolithic system. Flow factor based on the work of Bayada et al. (2005) are used to modify Reynolds equation. The impact of the flow factor is analyzed of the system vibrations. Second, flow factor are computed by averaging Navier-Stokes equation using CFD computation (de Kraker et al. (2010)).

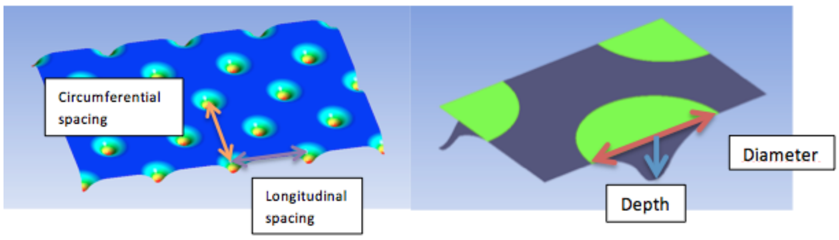

Figure 2: Parameters of the dimple texturing pattern

References

G. Bayada, S. Martin, and C. Vázquez. An Average Flow Model of the Reynolds Roughness Including a Mass-Flow Preserving Cavitation Model. *Journal of Tribology*, 127(4):793–802, May 2005. ISSN 0742-4787. doi: 10.1115/1.2005307. URL `http://dx.doi.org/10.1115/1.2005307`.

A. de Kraker, R. A. J. van Ostayen, and D. J. Rixen. Development of a texture averaged Reynolds equation. *Tribology International*, 43(11):2100–2109, Nov. 2010. ISSN 0301-679X. doi: 10.1016/j.triboint.2010.06.001. URL `http://www.sciencedirect.com/science/article/pii/S0301679X10001544`.

H. G. Elrod. A Cavitation Algorithm. *Journal of Tribology*, 103(3):350–354, July 1981. ISSN 0742-4787. doi: 10.1115/1.3251669. URL `http://dx.doi.org/10.1115/1.3251669`.

M. Lalanne and G. Ferraris. *Rotordynamics prediction in engineering*. Wiley, July 1990. ISBN 9780471926337.