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On the influence of coupled and uncoupled fluid dynamic models in a large scale journal bearing

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ABSTRACT

This study considers the extent to which the coupling of the governing equations influences the fluid dynamics of a large-scale turbo generator journal bearing. The study was conducted by formulating and implementing four fluid models in the OpenFOAM open-source CFD package. The fluid models are constructed so that uncoupled, weakly-coupled and strongly-coupled model formulations can be studied. To reduce the computational costs, a three-dimensional region of the oil film was extracted and considered. This small region was selected because the computational costs would have been extremely high for a full-scale simulation. To this end, the section selected for extraction was the region where the fluid dependencies are known to exert the greatest influence on the fluid behaviour. It was found that for both the weak-coupled and strong-coupled models, the coupling influenced the flow significantly. The extent to which the coupling influenced the fluid behaviour was seen to be dependent on the strength of the coupling, the dependency that introduced the coupling as well as the formulation of the fluid model. The weak-coupling introduced a greater qualitative change where the influence of the coupling was up to half the influence of the pressure dependence. The strong-coupling showed a greater change in the fluid behaviour and the flow departed non-uniformly from the uncoupled models.

1. Introduction

In most research pertaining to the dynamics of rotor-bearing systems, as found in steam turbines for power generation, has used only simplified fluid models. Owing to the various complexities that arise when modelling the rotor-bearing system. The dynamics of the journal bearing influence the dynamics of the entire system, since the bearing supports the rotor. At the same time, studies have been done on the influence of lubricant dependencies on the dynamics of the journal and have highlighted its importance [1, 2]. Since the bearing acts as a support for the rotor, it follows that factors influencing the dynamics of the bearing will influence the dynamics of the rotor [3].

In the classical formulation of the rotor-dynamics problem, the Reynolds equation is used to compute the pressure distribution inside the bearing. The restrictions of this classical model are well known: viscosity dependencies are neglected, the film thickness is assumed to be negligible and nonlinear fluid behaviour is neglected. Consequently the model has been extended to account for various kinds of dependencies [2].

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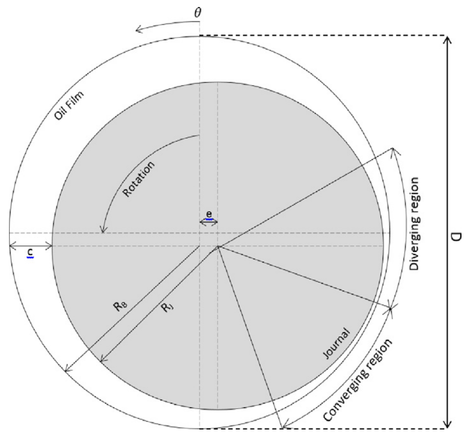

Fig. 1. Schematic of a journal bearing, front view.

The prominence of dependencies has been augmented in recent years due to the addition of various additives to the base oil. The rapid development of oil and bearing technologies and the increased importance of the dependencies have rendered the classical formulation of the problem inapplicable [4].

Mang and Drensel [5] note that the three most prominent dependencies of the lubricant film, which influence the operating conditions of the bearing, are pressure, temperature and shear rate. The influence of the viscoelastic behaviour of the fluid film, due to the addition of polymer additives have been highlighted by Gwynllyw and Phillips [2]. Moreover Li et al. [6] observe that the prominence of viscoelastic behaviour is dependent on the film thickness.

Davies and Li [7] have shown that pressure thickening of the oil film is dominant at high eccentricities of the journal. This is the opposite of the temperature thinning that is dominant at low eccentricities. The thinning of the viscosity decreases and the thickening increases the eccentricity of the journal.

Inertia has also been shown to influence the dynamics of the bearing significantly. In the modelling of the large-scale journal bearings of heavy duty turbines, it has been shown that it is of significance to account for temperature mixing due to turbulence on the bearing [8].

The various dependencies and their influence on bearing dynamics have been highlighted extensively in literature. Accounting for dependencies has been shown to be crucial in accurately modelling the bearings. The influence of various dependencies acting in a system simultaneously and being allowed to interact with one another, has so far been neglected, however.

This paper considers the multi-physics problem, namely the influence of temperature and pressure when the velocity, temperature and stress fields are fully coupled. Coupled fields, in the context of this study, are fields which mutually influence the behaviour of one another. In this study, the allowed interaction was increased in order to determine the influence of these interactions on the flow characteristics. A full-scale simulation of the latter would have been computationally expensive. For this reason, we proceed with the following premise: consider a section of the bearing fluid film that exhibits the greatest dependencies. If coupling the governing equations has no significant influence, we can conclude that overall coupling would not influence the dynamics of the bearing. If, however, we find a significant change in the fluid behaviour, we can conclude that coupling would indeed influence the overall performance. The degree to which the bearing would be influenced, however, would have to be quantified by a full-scale simulation of the bearing.

The article is organised as follows: Section 2 presents the governing equations for four fluid models used to describe the oil film. Section 3 discusses the numerical implementation of the various models and Section 3.4 explains the numerical case to which these models are applied. The results obtained from the numerical study are presented in Section 4. Finally the results are compared and the influence of a coupled formulation is summarised in Section 5.

2. Governing equations

Consider Fig. 1 which represents a bearing, where eccentricity is indicated as *e*, *c* refers to the film thickness, R_B and R_J refer to the bearing and journal radius respectively, and *D* is the diameter of the bearing. The section of the fluid film that is considered specifically in this article is extracted from the converging section of the bearing as illustrated in Fig. 2.

This work used four distinct fluid models to describe the fluid dynamics of the oil film. All the fluid models considered were, however, assumed to be incompressible. The continuity equation therefore reduces to a condition of zero divergence in the velocity field:

$$\rho \, \nabla \cdot \bar{v} = 0 \tag{1}$$