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FOIL BEARING RESEARCH AT PENN STATE

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SUMMARY

Foil journal bearings consist of a compliant metal shell or foil which supports a rigid journal by means of a fluid film. Foil bearings are considered to be a potential alternative to rolling element or traditional rigid surface bearings in cryogenic turbomachinery applications. The prediction of foil bearing performance requires the coupled solution of the foil deflection and the fluid flow in the bearing clearance between the rotor and the foil. The investigations being conducted in the Department of Mechanical Engineering at Penn State are focused in three areas: theoretical prediction of steady state bearing performance, modeling of the dynamic bearing characteristics to determine performance in rotor systems, and experimental verification of analysis codes. The current status and results from these efforts will be discussed.

BACKGROUND

Foil journal bearings are considered to be an alternative to rolling element bearings, and to rigid surface hydrostatic, hydrodynamic, or hybrid journal bearings for rotor support in cryogenic turbomachinery applications such as rocket propulsion engines. Foil bearings offer several advantages[1]: compliance which can compensate for misalignment and deflection of rotors and machinery casings; reduced thermal distortion due to the thin shell structures of the bearing; tolerance of dirt and debris in the lubricant flow; and enhanced dynamic performance.

A foil bearing is generally constructed of a foil or thin shell which supports a rotor by any combination of bending, membrane, or elastic foundation effects. Two basic foil bearing configurations are of general interest in turbomachinery applications; first the elastically supported bearing, and second, the leaf type of foil bearing(see figure 1). The foil surface in the elastically supported foil bearing configuration resists deflection by means of the elastic foundation in back of the foil. The elastic foundation can be constructed from other structural shells, polymers, or springs. The foils in the leaf type bearing support load primarily by the resistance of the foils to bending.

The investigations at Penn State have the following broad objectives aimed at the development of general design tools for foil bearings: (1) develop general physical models of foil journal bearings which will predict steady state and dynamic behavior in rotor systems; (2)investigate the performance of foil bearing configurations which are of significance in rotordynamic applications; and (3) validate the results of predictive codes with basic experimental investigations.

STEADY STATE BEARING PERFORMANCE

The development of robust design tools for the predictive design of foil bearings requires that analyses be able to address different bearing configurations, misalignment of the bearing, geometric defects, and the broad range of fluids which can occur. These requirements have lead to the selection of a direct iteration approach to the solution of the coupled lubricant fluid flow/foil deflection problem. In the direct iteration approach, deflections and pressure distributions are calculated iteratively from displacement and fluid flow formulations. At the completion of the deflection calculation, the new clearance is computed from the rotor location, the nominal foil location, and the foil deflection. The clearance is then under-relaxed before the next calculation of the pressure distribution. The finite element method has been used to calculate both pressure distributions and deflections in the results to be discussed here[2,3].

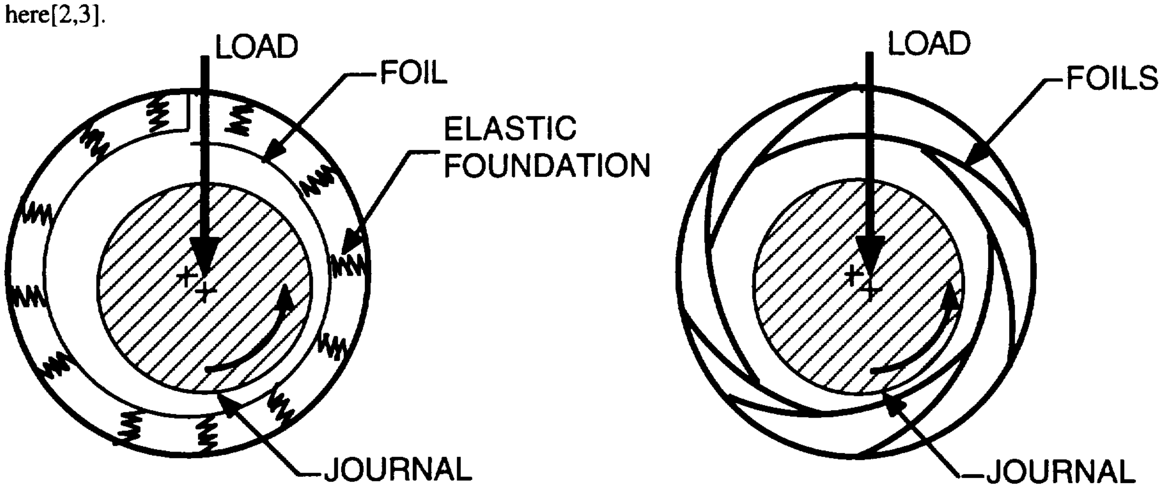

Figure 1- Elastically supported and leaf type foil journal bearings.

This analysis approach has been applied to an elastically supported split shell foil bearing(often referred to as a Hydresil bearing configuration). In this configuration, the foil is not continuous in the circumferential direction. As with the complete shell foil bearing, the foil is treated as perfectly flexible and inextensible. The foil is allowed to lift off of the elastic foundation if the pressure on the foundation becomes negative. Typical clearance and pressure results are shown in figure 2. The clearance distribution in figure 2 demonstrates the importance of membrane effects in the analysis by the virtually constant clearance across the width of the bearing. These results are in contrast to earlier analyses[1] wherein the clearance varied in the axial direction. The clearance in the exit region of the bearing remains virtually constant in the circumferential direction as the foil lifts off of the elastic foundation.

TRANSIENT BEARING PERFORMANCE

The design and development of high speed rotor systems requires detailed dynamic analyses of the rotor-bearing system. Although the dynamic system performance is one of the most important factors in rotor operation, the transient performance of foil bearings has recieved very little attention. A common approach to the dynamic performance of a bearing in a rotor system is to characterize the bearing in terms of stiffness and damping coefficients by perturbing the operation of the bearing about the nominal operating state. These coefficients are then used in a larger simulation of the dynamics of the rotor system. In a traditional rigid surface bearing, the bearing stiffness and damping are attributed solely to the behavior of the fluid film. In a foil bearing, the stiffness and damping are dependent on the stiffness and coulomb friction of the foil structure in addition to the fluid film between the foil and the rotor.

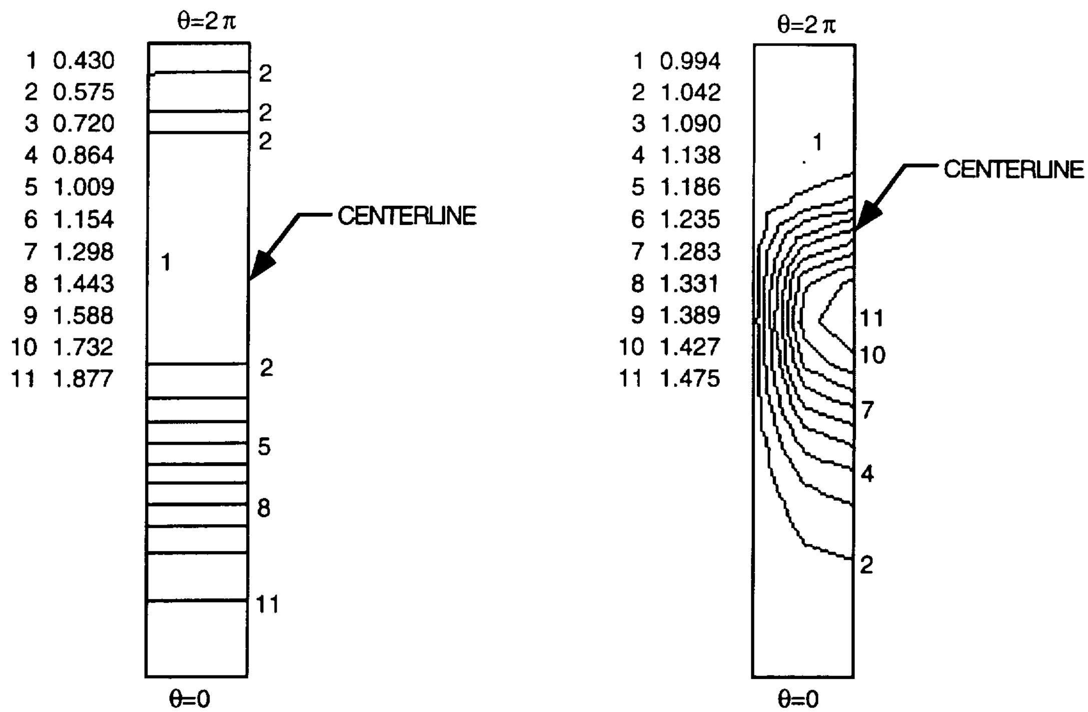

Figure 2 - Clearance and pressure distributions for split foil configuration, Eccentricity ratio, $\varepsilon = 0.9$, Bearing number, $\Lambda = 1.0$, Bearing compliance, $\alpha = 1.0$, Eccentricity angle = π radians, L/d = 1.

Results from a finite difference analysis predicting the stiffness and damping coefficients for the Hydresil bearing configuration[4,5] are presented in figure 3. In the analysis, the foil is supported on an elastic foundation from which it can detach if the force in the foundation becomes tensile. Membrane and bending effects in the foil have been neglected. A compressible fluid was used. The effects of Coulomb friction are included. These results at high speeds demonstrate that as the Coulomb friction is increased, the effective viscous damping will increase. A general finite element based approach has been developed which incorporates a complete three dimensional structural model.

EXPERIMENTAL INVESTIGATION

An foil bearing testbed has been built to verify the steady-state prediction of loads, film thickness distributions, and pressure distributions in an elastically supported foil bearings operating with incompressible lubricants at low speeds. The bearing has a nominal diameter equal to 5 inches and operates at 100 to 1000 RPM using SAE 30 oil as the lubricant. To facilitate accurate measurements, the nominal bearing clearance equals 0.020 inches. Detailed clearance and pressure measurements are made by transducers which have been installed in the jounal.

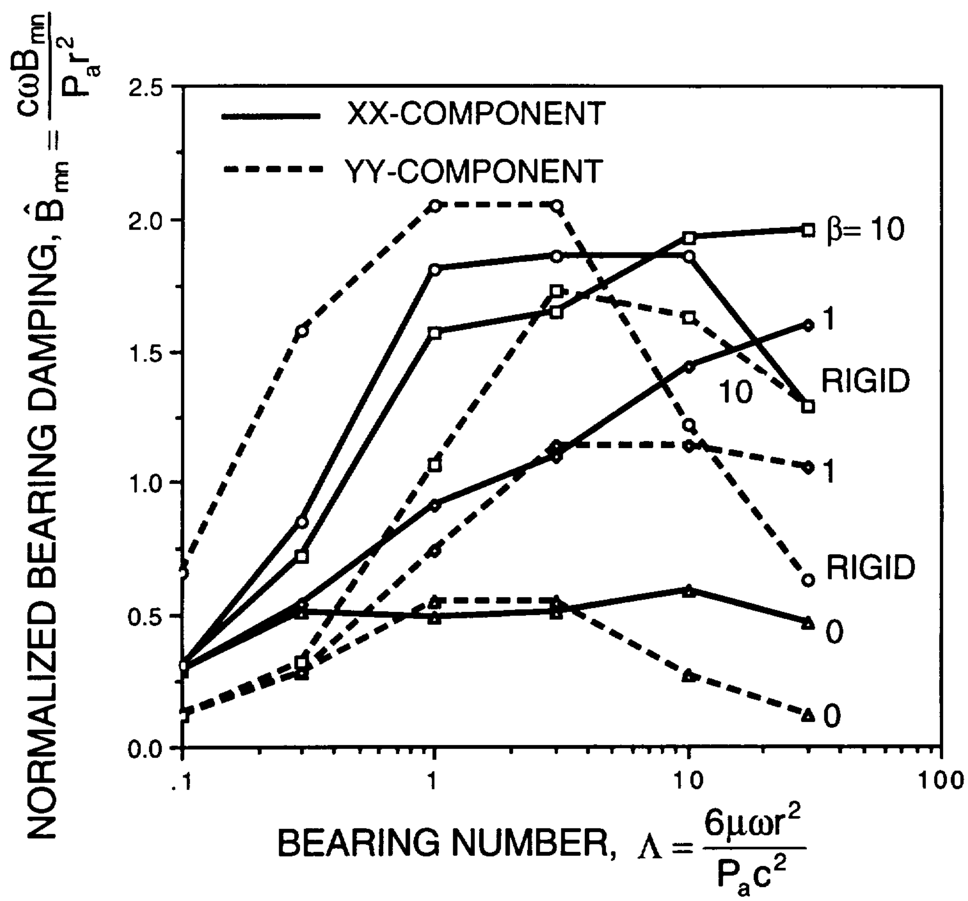

Figure 3 - Effect of bearing compliance, α, on normalized bearing damping $\hat{K}_{xx}$, $L/d = 1.0$, $\varepsilon = 0.5$. Numbers denote bearing compliance.

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