

2017 STLE Annual Meeting & Exhibition
May 21-25, 2017
Hyatt Regency Hotel
Atlanta, Georgia, USA

Thermal, Elastic and Inertia Effects in Water-Lubricated Tilting Pad Thrust Bearings in the High-Turbulence Operating Region

TRACK OR CATEGORY

Fluid Film Bearing VI

AUTHORS AND INSTITUTIONS

Deng, Xin¹, Branagan, Michael¹, Weaver, Brian¹, Wood, Houston¹
Rotating Machinery and Controls Laboratory (ROMAC)
Department of Mechanical and Aerospace Engineering¹
University of Virginia, Charlottesville, VA, USA 22904

INTRODUCTION

Water-lubricated thrust bearings have become increasingly used due to the emergence of sub-sea machinery and environmentally friendly applications [1]. The use of water instead of oil increases Reynolds numbers drastically and therefore makes water-lubricated thrust bearings prone to turbulence and fluid inertia effects [2,3]. This paper presents a study on the influence of elastic and turbulent effects of water-lubricated tilting pad thrust bearings operating in both laminar and turbulent flow regimes, with particular focus on high Reynolds number flows. The study will compare the fluid film thickness for a number of cases, and investigate the effects of deformation and turbulence. Improving the understanding of these effects on thrust bearing performance will help guide the design and modeling of water-lubricated tilting pad thrust bearings.

MODELING

The bearing modeled for this analysis was a sector-pad thrust bearing consisting of six tilting pads as shown in Fig.1. The modeling was performed in a new updated version of THRUST 5.3 developed by the Rotating Machinery and Controls Laboratory at the University of Virginia. An operating speed of 1,800 rpm was calculated with multiple pad loads.

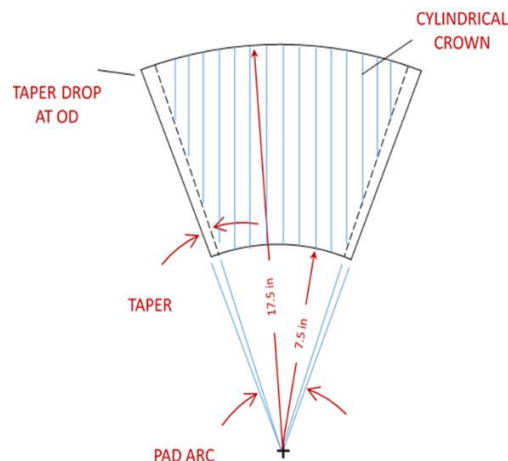


Figure 1. Pad geometry

The eddy-diffusivity model chosen for this work is Reichardt's formula. The sensitivity of delta plus in Reichardt's formula was studied in an attempt to increase accuracy:

$$\frac{\varepsilon_m}{\nu} = \kappa \left[y^+ - \delta_l^+ \tanh\left(\frac{y^+}{\delta_l^+}\right) \right] \quad (1)$$

in which $\kappa = 0.4$ and $\delta_l^+ = 10.7$, as optimized by Ng [4]. In this paper, equation (2) for delta plus recommended by [5] was used to obtain $\delta^+ = 5.2$.

$$\delta^+ = 10.1e^{-1.57E-05Re_p} \quad (2)$$

Where Re_p is the Reynolds number at the pivot of the pad.

THE INFLUENCE OF ELASTIC AND TURBULENT EFFECTS

The turbulence condition of flow is determined by the Reynolds number. The Reynolds number is defined as

$$Re = \frac{Uh}{\nu} = \frac{Uh}{\mu} \rho \quad (3)$$

where U is the rotating surface velocity, h is the film thickness developed in the thrust bearing, ν is the kinematic viscosity, μ is the absolute viscosity, and ρ is the mass density.

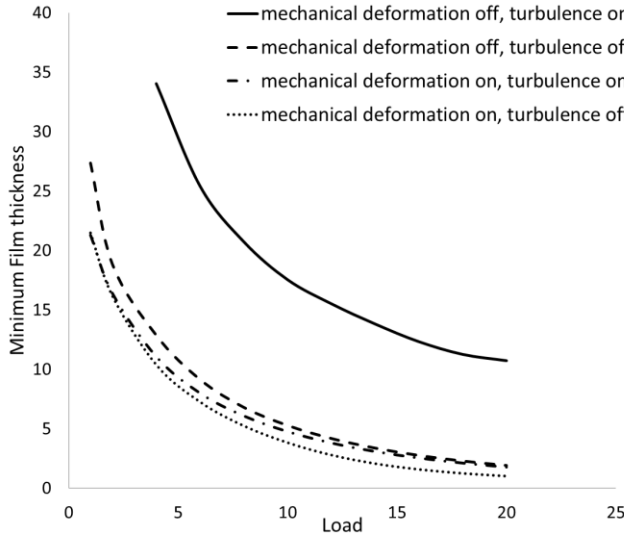


Figure 2. Minimum film thickness for considering mechanical deformation and turbulence effects

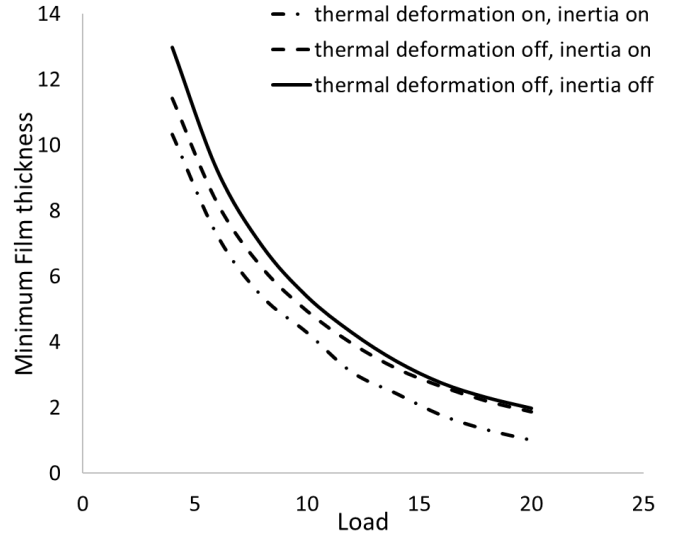


Figure 3. Minimum film thickness for considering thermal and inertia effects

Based on equation (3), with a rotating speed of 1800 rpm the flow in the film is in the high turbulence region. This study compared film thickness values while considering elastic and turbulent effects. The influence of elasticity was studied by comparing cases with pad and runner mechanical deformations included against cases where they were excluded. The influence of turbulence was studied similarly by including or excluding these effects from the solution. From nondimensionalized film thickness data presented in Fig. 2 with an isothermal setting, when turning turbulence on the minimum film thickness of both deformation cases is increased when compared to those with turbulence excluded. With deformation off and turbulence on, the minimum film thickness is significantly increased, while with deformation on and turbulence off, the minimum film thickness is the smallest. In water lubricated

bearings, the influence of turbulence on minimum film thickness is the opposite of that found in oil lubricated bearings, in which adding turbulent effects will decrease the minimum film thickness.

THE INFLUENCE OF THERMAL AND INERTIA EFFECTS

Thermal effects were studied by including or excluding pad and runner thermal deformations in the solution. When thermal deformation was included conduction from the film to the runner and pad bearing surfaces was also considered, allowing temperature to vary three-dimensionally within the pad according to thermal boundary conditions applied to the pad (including conduction from the film and convection applied over the majority of the remainder of the pad). However, whether thermal deformations were included or not, this did not prevent the film thermal conductivity from being modified by the turbulence correction factor. Inertia effects were studied by including or excluding the linearized centrifugal inertia term in the Reynolds equation solution. The calculations were then performed with mechanical deformation and turbulence excluded. From Fig. 3, with mechanical deformation off and turbulence off, when turning thermal and inertia effects off the largest values of minimum film thickness are predicted, while when turning thermal and inertia effects on the minimum film thickness is reduced.

DISCUSSION AND CONCLUSIONS

54 cases were analyzed in total: nine different pad loads were considered at a single operating speed. Six sets of nine were then performed based on including various mechanical deformation effects, turbulence effects, thermal deformation effects, inertia effects, and various combinations of these. The results of these seven series of results are shown in Figures 2 and 3. It was found that adding turbulent effects will increase minimum film thickness in water lubricated bearings, which is the opposite to that in oil lubricated bearings. Adding thermal deformation effects or adding inertia effects will decrease minimum film thickness. Among these effects, turbulence effects demonstrated the largest influence which indicates that the accuracy of the turbulence model is critical to modeling water lubricated bearings.

ACKNOWLEDGMENTS

This work was supported by the Rotating Machinery and Controls Laboratory at the University of Virginia.

REFERENCES

- [1] Pai, Raghuvir, and D. J. Hargreaves. "Water lubricated bearings." In *Green Tribology*, pp. 347-391. Springer Berlin Heidelberg, 2012.
- [2] San Andres LA. Analysis of Turbulent Hydrostatic Bearings With a Barotropic Cryogenic Fluid. *ASME. J. Tribol.* 1992;114(4):755-764. doi:10.1115/1.2920945.
- [3] Songa, Zhixiang, Fei Guoa, Xiangfeng Liua, and Ying Liua. "Inertia Effect And The Turbulence On The Lubrication Performance Of The High Speed Water-Lubricated Thrust Bearing."
- [4] Ng, Chung-Wah. "Fluid dynamic foundation of turbulent lubrication theory." *Asle Transactions* 7.4 (1964): 311-321.
- [5] Armentrout, Richard W., Minhui He, Thomas Haykin, and Arthur E. Reed. "Analysis of Turbulence and Convective Inertia in a Water-Lubricated Tilting-Pad Journal Bearing Using Conventional and CFD Approaches." *Tribology Transactions* just-accepted (2016).

KEYWORDS

Hydrodynamics:Hydrodynamic Bearings (General), Hydrodynamics:Inertia Effects in Hydrodynamics