STLE 74th Annual Meeting & Exhibition, Nashville, Tennessee, May 19-23, 2019
Control ID: 3068957

On the Static Load Performance of a Large Size, Heavily Loaded Spring Supported Thrust Bearing

TRACK OR CATEGORY

Fluid Film Bearings

AUTHORS AND INSTITUTIONS

Rasool Koosha[1], Graduate Research Assistants
Luis San Andrés[1], Mast-Childs Chair Professor and Fellow STLE

[1] J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station, TX, USA, 77843-3123

ABSTRACT

This abstract describes a thermo-elasto-hydrodynamic (TEHD) analysis for prediction of the static load performance of a large size spring-supported thrust bearing (SSTB) operating at a mean surface speed of 20 m/s and 4 MPa specific load. The bearing pads include pockets for hydraulic lift and an internal cooling system with pipes laid out along the radial direction. Pressure induced deformations significantly enlarge the film thickness at the pads' leading and trailing edges. Pad thermal deformations are lesser, except at the pad trailing edge where cooling lines do not reach. Bearing operation transitioning from a nominal rotor speed to a low rotor speed while the bearing pads remain hot simulates a quick shut-down process. With a hot pad the predictions produce a much lesser fluid film thickness than that arising during a slow shut-down process where the bearing pads cool at a steady rate. The gradient of minimum film thickness versus rotor speed is much higher during the fast shutdown process and which could produce a sudden bearing failure (seizure).

INTRODUCTION

For large size high power density applications, spring-supported thrust bearings (SSTBs) are preferred over pivoted ones since they offer advantages such as lesser elastic deformations, self-adjustment against thrust collar misalignment, and a better heat dissipation [1]. Figure 1 shows a schematic view of a pad in a SSTB. As the collar rotates and drag lubricants into the gap between the pad and the collar, a hydrodynamic pressure field rises reacting to the applied load on the bearing. The performance of SSTBs during start-up and shut-down processes is also critical to assure safe and reliable operation.

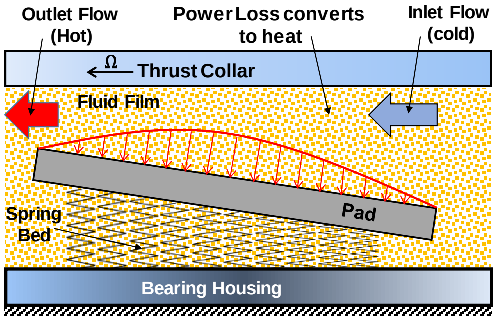


Figure 1. Schematic view of a pad on a spring supported thrust bearing (film thickness and tilt angle exaggerated).

The archival literature [1-3] stresses the importance of pad elastic deformation effects on the load performance of SSTBs and discloses occasions where extensive pad elastic deformations have resulted in pad-collar rubbing followed by an overall bearing collapse. Elastic deformations in a spring-supported pad largely depend on the spring-bed geometry, material, and disposition.

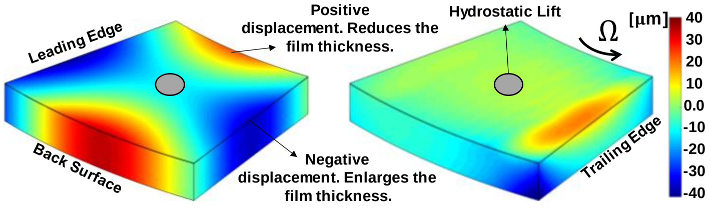
In 1987, Chambers and Mikula [1] experimentally investigate recurring failures of a 2.7 m outer diameter (OD) SSTB in a turbine generator unit operating under a 11.0 MPa specific load and at 257 rpm in rotor speed (maximum surface speed $R_O\Omega = 37$ m/s). The investigation reveals that elastic deformations produce a convex pad top surface, with the rotating collar rubbing on the pad at its edges to wipe out the babbitt layer. In 2003, Ettles et al. [2] perform a transient response analysis of large size SSTBs to study issues during start-up and shutdown processes, and find that the time required for thrust pads to reach a thermal balance condition is proportional to the pad thickness squared. Accordingly, it takes ~ 9 hours for a 250 mm thick babbitted-steel pad to fully reach a thermal balance condition when operating at a 30 m/s shaft mean surface speed. Later in 2016, Ettles et al. [3] perform an analysis to optimize both the design parameters and operating conditions of a large size reversible SSTB used in a pump-turbine generator carrying a 4 MPa specific load. The original design had shown poor performance producing complete failure in several occasions. The authors conduct an optimization process with objective functions to increase the minimum fluid film thickness while minimizing the temperature raise in the film and the pads. The optimum design finds a thickness for the bearing pad equal to 12% of its circumferential arc length, and a spring bed arrangement extending edge-to-edge in the radial direction, but only supporting 55% of the pad circumferential length, i.e., with both the pad leading edge and trailing edge "hanging".

A thermo-elasto-hydrodynamic (TEHD) analysis in Ref. [4] by the authors considers a combined solution for a general Reynolds equation and a 3D thermal energy transport equation in the fluid film, coupled to a heat transfer equation in the pads. In the present work, the finite element model in Ref. [4] extends to account for the spring-bed support and delivers elastic deformation fields induced due to both the pressure field acting on the pad top surface and the temperature gradient across a pad.

RESULTS AND DISCUSSION

The TEHD tool presently produces predictions for a large size SSTB in an industrial unit which had shown a pattern of failure after accumulating a number of startup /shutdown processes ranging from 3k to 5k. The bearing pads have an outer / inner diameter *OD*/*ID*

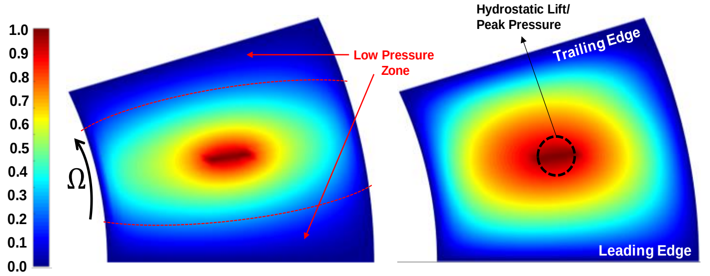
= 1.43, a mean circumferential length / radial length $B/L \approx 1$, and a thickness equal to t_P=0.2B. The pads accommodate a hydrostatic lift pocket and also include an internal multiple-pipe cooling system which circulates cold oil to remove heat. To model the oil cooling system, internal nodes located within the cooling lines are set to a supply temperature. The spring-bed extends over the full edge-to-edge radial length of a pad, but only partially supports the pad in the circumferential direction, as in Ref. [3]. The bearing is lubricated with a heavy viscous mineral oil.



(a) Pressure induced deformation. (b) Temperature induced deformation.

Figure 2. Predicted pad elastic deformations (μm) induced (a) mechanically and (b) thermally. Specific load = 4 MPa and mean surface speed = 20 m/s.

Figure 2 shows predicted pad elastic deformation fields induced (a) due the pressure field acting on the pad top surface (mechanically) and (b) due to the temperature field (thermally) for the SSTB operating under 4.0 MPa and at a 40 m/s mean surface speed. Pad pressure induced deformations are significant and warp a pad (convex curvature) at both its leading edge and trailing edge to open (enlarge) the fluid film thickness. At the same time, the pad OD and ID warp toward the thrust collar (concave curvature) and reduce the film thickness. The pad internal cooling system effectively limits the pad temperature rise and thus thermal elastic deformations are moderate, except at the pad trailing edge where the cooling lines do not reach.



(a) Pressure field. (No collar rotation) (b) Pressure field. ($R_m\Omega = 40\ m/s$)

Figure 3. Predicted fluid film pressure field for (a) idle collar and (b) at 40 m/s mean surface speed. Specific load = 4 MPa. Normalized relative to the nominal hydrostatic lift pressure.

Figure 3 portrays predicted normalized pressure fields for the SSTB operating with the hydrostatic lift active and with the thrust collar (a) idle (not turning) and (b) turning at 20 m/s mean surface speed. With the collar rotating, the pressure field extends over the whole pad area, from its leading edge to the trailing edge, and from the ID to the OD. With an idle collar condition, however, predictions show a large area of low pressure, nearly denuded of lubricant at the pad leading edge and trailing edge.

Figure 4 depicts the predicted fluid film thickness field under similar condition as in Figure 3 (a). The film thickness field is critically small at both the pad ID and OD, and which may result in contact between the collar and pad. Figure 5 shows predicted minimum film thickness versus mean surface speed. Predictions obtained using a hot pad while operating at 20 m/s simulate a shut-down process when the pad has not yet reached a thermal balance condition. With a hot pad the predictions produce a much lesser fluid film thickness than that arising during a slow shut-down process where the bearing pads cool at a steady rate. The fast shutdown may lead to sudden seizure of one or more pads in the bearing.

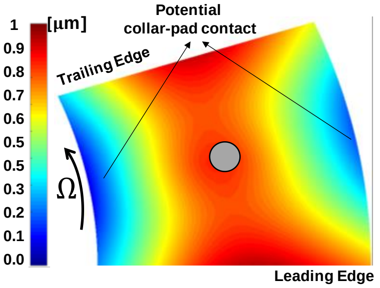


Figure 4. Film thickness field for idle collar. Specific load = 4 MPa and idle collar. Normalized relative to the maximum film thickness.

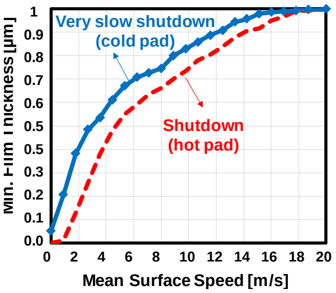


Figure 5. Minimum fluid film thickness for a hot pad and a pad at a thermal balance condition. Specific load = 4 MPa. Normalized relative to the minimum film thickness at the nominal operating condition.

CLOSURE

The abstract presented thermo-elasto-hydrodynamic (TEHD) predictions for the static load performance of a large size spring-supported thrust bearing (SSTB) operating under a heavy specific load of 4 MPa. Predictions demonstrate the importance of pad elastic deformations, in particular during a shutdown process while the pads are still hot. Future work should optimize both the pad and spring bed geometry to assure reliable operation not only during a nominal operating condition but also during quick start-up and shut-down processes.

REFERENCE

[1] Chambers, W.S. and Mikula, A.M., 1987. “Operational Data for a Large Vertical Thrust Bearing in a Pumped Storage Application,” STLE Trans., 31(1), pp.61-65.

[2] Ettles, C.M., Seyler, J. and Bottenschein, M., 2003, “Some Effects of Start-up and Shut-down on Thrust Bearing Assemblies in Hydro-Generators,” J. Tribol, 125(4), pp.824-832.

[3] Ettles, C.M., López, G.D. and Borgna, H., 2016, “Optimized Design of a Large Reversible Thrust Bearing,” J. Tribol, 138(4), p.041701.

[4] San Andrés, L., and Koosha, R., 2018, “A Thermo-elasto-hydrodynamic (TEHD) Computational Analysis for the Dynamic and Static Force Performance of Self-Equalizing Tilting Pad Thrust Bearings,” Annual Progress Report to the Turbomachinery Research Consortium, TRC-B&C-01-018, Texas A&M University, College Station, USA.

KEYWORDS: Fluid film bearings, spring-bed supported, thermos-elasto-hydrodynamic analysis.