IMPROVEMENTS TO TILTING PAD JOURNAL BEARINGS
A MODEL FOR THE INLET FLOW IN A FEEDING GROOVE

Dr. Luis San Andrés, Mast-Childs Tribology Professor   Behzad Abdollahi, Graduate Research Assistant
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SIGNIFICANCE

Analysis of fluid film bearings has reached great complexity as 3D computational fluid dynamics models are coupled to finite element structural models for the pads, journal and bearing cartridge. The aim is to reach great levels of confidence (accuracy) in prediction of bearing performance without resorting to (expensive and time consuming) testing. Alas in models, either simple or complex, boundary conditions for the exchange of thermal energy in bearings remain obscure, even more so for the mixing of flow and thermal energy at a feeding arrangement that sets the temperature of the lubricant at a pad leading edge. Accurate knowledge of this temperature (and inlet oil viscosity) and the flow rate entering a pad largely determine the temperature rise along the pad lubricated surface as well as the shear drag power loss and ultimate load capacity. Without an accurate characterization of the static load performance in a bearing, prediction of reliable rotordynamic force coefficients will remain elusive.

To date the thermal mixing models in the groove (or feed mechanism) in between two pads remains overly simplified. This region comprises an orifice supplying *cold* or fresh lubricant into a groove, the upstream pad discharging *warm lubricant* into the groove along with a layer of hot oil attached to the journal surface, and the downstream pad that demands of a certain amount of lubricant to fully fill in the clearance. These models rely on a mixing parameter (λ), empirical in nature, that sets the fraction of upstream thermal energy and flow entering into the next pad. The simple model fails in a highly loaded condition where the overall amount of flow entering a pad is in the opposite direction to that of the shaft surface speed.

The lubricant flow adds the shear flow dragged by the spinning journal to the pressure driven flow in the reverse direction, more acute as the applied load increases. Note that industry applications only monitor total flow rate and this phenomenon cannot be detected.

For a single orifice feed (conventional), Figure 1 shows the heat fluxes across the boundaries and a reverse flow downstream of the groove. The 'cold' supply flow mixes with the sump oil in the inner groove region before mixing with the hot oil carried over from the upstream pad. Thus, the effective temperature for the supply 'cold' lubricant increases before mixing with the hot oil from the upstream pad.

The simple concept of the *hot oil* carryover, adapted by virtually all prediction tools, is not accurate for bearings under a large specific load (>1.7 MPa specific load). The current mixing model is most appropriate for spray bar feed since it does not account for the lubricant churning in the inner groove region and convection with bearing pads, and the effective supply temperature does not increase substantially.
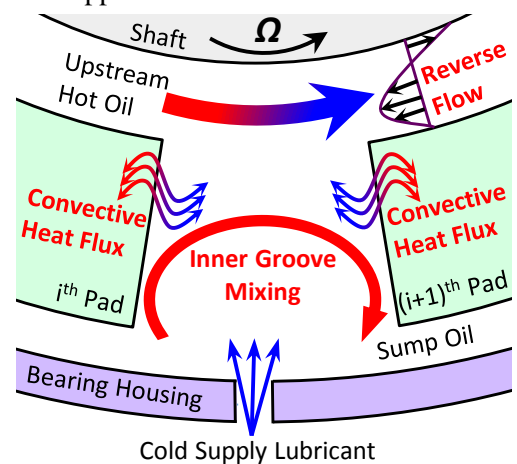

Fig. 1 Heat fluxes across the boundaries and mixing in a lubricant feed groove.

SUMMARY OF WORK 2014-2016

In moderately loaded to heavily loaded tilting pad journal bearings (TPJBs), pad surface deformations due to both mechanical pressure and thermally induced stresses affect the operating film thickness, thus producing a bearing performance with excessive temperature rise and a likely drop in damping force coefficients. These surface deformations effectively change the pad curvature and increase its machined preload. Since 2014 TRC funds to develop a crafted analysis that includes a thermo-elasto-hydrodynamic model (TEHD) coupling the film pressure generation to the pads' structural mechanics and including pivot elastic displacements, both due to pressure and temperature changes.

In 2015-2016, Behzad Abdollahi, M.S. student, performed a thorough thermo-elasticity analysis of typical bearings pads subject to thermal gradients and used a commercial (FE) software to calculate 3D pad deformation fields. The theoretical analysis along with physically sound assumptions led to a simple formula for prediction of the thermally induced deformation as a function of the temperature difference between the inner and back surfaces, both circumferentially averaged. The simple equation delivers results in agreement with the FE structure model for a number of cases.

The simplicity of the model allowed its implementation in the existing predictive tool (XLTPJB®) avoiding a cumbersome iterative procedure and complexity. The student also optimized the GUI and the FORTRAN code to be more stable, faster (run time ~40 seconds) and user friendly. Predictions are benchmarked against test data for two distinctive

bearings, one is a large size TPJB for a steam turbine, and the other one tested at TAMU Turbomachinery Laboratory. Figure 2 shows some of the predictions compared to the test data in Ref. [1].

Fig. 2 Predicted fields and comparison to test data in Ref [1]: 5 tilting pad bearing with shaft diameter=0.5 m and bearing length=0.35 m, operating with shaft speed =3 kRPM and under LBP specific load= 2.5 MPa.
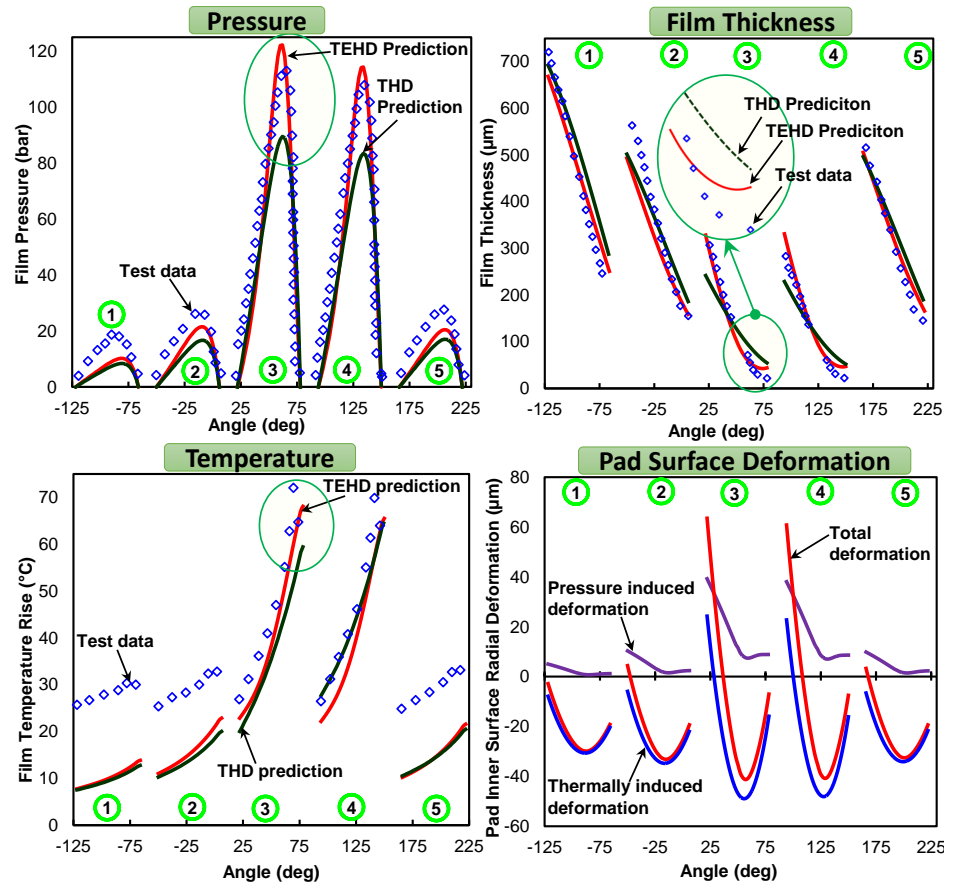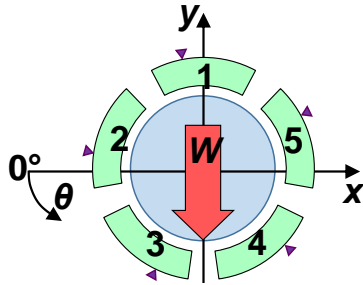
PROPOSED WORK 2016-2017 (YEAR VI)

Available groove thermal and flow mixing models are substantially simple and reliant on a mixing coefficient (λ). Brito et al. [2] have conducted tests and physically modeled this groove mixing phenomena in plain journal bearings for more than a decade. The goal is to extend a realistic model for feeding groove in TPJBs. Namely, to modify XLTPJB® to model the lubricant feeding condition, with dimensions of the groove, energy transport and fluid mixing in the groove region. A thermal mixing model that includes (1) heat flow due to inlet and outlet lubricant flows in the groove boundary, (2) convection with the pads and bearing housing, (3) accounts for the groove geometry.

Another important modification to improve predictions is the ability to impose the actual inlet flow; in particular when a bearing operates either as over-flooded or in a starved condition. The film temperature rise is inversely proportional to the amount of lubricant supplied. Thus, enforcing a known flow rate will aid to better predictions of static and dynamic force performance.

XLTPJB® will continue to assist TRC members in modeling accurately TPJBs for commercial turbomachinery; i.e. high specific load and high rotor speed. The model and GUI reduce the burden on the unseasoned user by calculating actual operating (*hot*) clearances, minimizing the specification of empirical parameters, and considering sound boundary conditions for a proper analysis with thermal energy transport effects.

BUDGET FROM TRC FOR 2016-2017

Support for graduate student (20 h/week) × $ 2,400 × 12 months	$ 28,800
Fringe benefits (2.5%) and medical insurance ($360/month)	$ 4,995
Travel to (US) technical conference	$ 1,200
Tuition & fees three semesters ($363 credit hour × 24 h/year)	$ 9,090
	Total Cost: **$ 44,085**

REFERENCES

[1] Hagemann, T., Kukla, S., and Schwarze, H., 2013, "Measurement and Prediction of the Static Operating Conditions of a Large Turbine Tilting-Pad Bearing Under High Circumferential Speeds and Heavy Loads," ASME Turbo Expo 2013: Turbine Technical Conference and Exposition, pp. V07BT30A019–V07BT30A019.

[2] Brito, F. P., Miranda, A. S., Claro, J. C. P., Teixeira, J. C., Costa, L., and Fillon, M., 2014, "Thermohydrodynamic Modelling of Journal Bearings Under Varying Load Angle and Negative Groove Flow Rate," Proc. IMEchE, Part J: J. of Engineering Tribology, **228**(9), pp. 955-973.