MEASUREMENTS TO QUANTIFY THE EFFECT OF A REDUCED FLOW RATE ON TILTING PAD JOURNAL BEARING PERFORMANCE – STATIC AND DYNAMIC

Dr. Luis San Andrés, Mast-Childs Chair Professor
Jon Toner, Graduate Research Assistants
May 2018

SIGNIFICANCE

Tilting pad journal and thrust bearings (TPJBs) are commonplace oil lubricated supports in high performance turbomachinery, including multiple stage centrifugal compressors and power generation gas turbines. These bearings' load capacity, power loss and dynamic force coefficients are well documented and certified, both experimental and analytical, both by bearing manufacturers as well as end users.

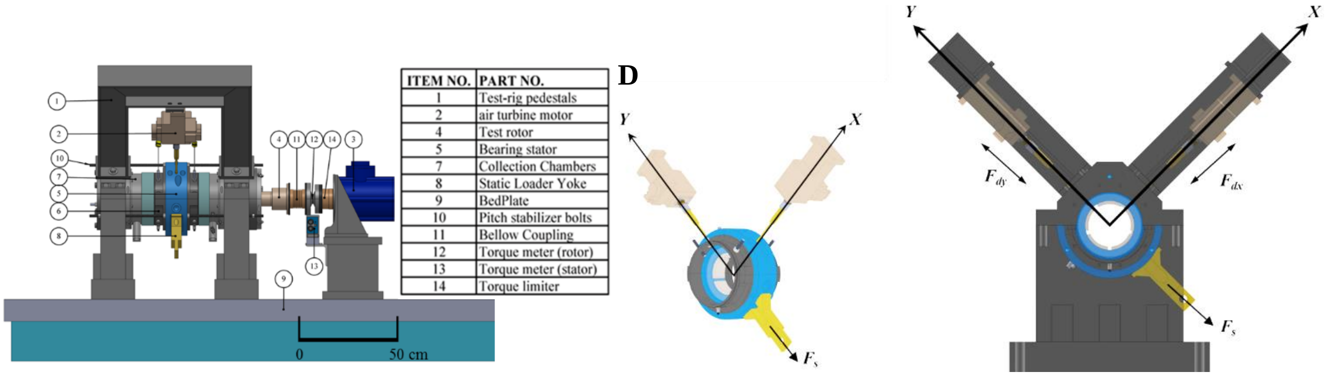
Presently, there is a need to push the performance of TPJBs to their limit by operating them with a reduced flow rate (to decrease pumping costs and oil sump storage volumes) towards enabling lower drag power losses (improve system energy efficiency) within safe and controlled temperature increases in both the bearings pads and oil circulation system. Note that operation with a too low flow rate in evacuated TPJBs, nearly unloaded, can produce the infamous subsynchronous shaft vibrations (SSV hash) [1]. A too low flow rate can also produce a quick raise in pad temperature that could melt the Babitt layer with disastrous consequences as the literature attests.

Incidentally, as per lubrication theory and sound operation, the supplied flow rate into a bearing is surface speed dependent; the higher the rotor speed, the larger the required flow rate. Prior extensive experimental research on TPJBS at the Turbo Lab produced useful results for a myriad of TPJBs (including oil delivery systems [2]) tested at increasing shaft speeds and applied loads. Alas most tests were conducted with a fixed flow rate. Most likely at low shaft speed, the bearings were over flooded with lubricant, while at a high shaft speed, the bearings likely starved of lubricant [3]. The consideration of flow rate has not received serious consideration until the most recent test program sponsored by an OEM.

DESCRIPTION OF TEST RIG

The test rig for measurement of the dynamic load performance of oil lubricated fluid film bearings and seals will become available in September 2018 for further commercial use. This rig, having undergone major revamping in 2017 (cost ~$90,000), offers unique features to test oil lubricated bearings to speeds as high as 17 krpm and specific loads to 2.5 MPa (250 psi). The test rig, see Fig. 1(a), consists of a main test-section and ancillary equipment (not shown) for lubrication and cooling. A 65 kW-power air turbine motor drives a rigid test shaft through a high-speed bellow coupling, a torque-limiter, and a state of the art electronic torquemeter. The AISI 4140 shaft has diameter of 101.590 mm (3.9996 in.) at the test bearing section. Two high precision angular contact ball bearings placed in a back-to-back orientation support the shaft. Two stiff pedestals hold the ball bearings, 406 mm (16 in) in span. A pneumatic cylinder, soft spring and cable, connected to the bearing stator through a pulley and yoke, applies a static load along the (-) *y*-direction; and a pair of (refurbished) hydraulic loaders and stingers apply dynamic loads along both *x* and *y* directions, as shown in Fig. 1(b). The rated maximum pull load is 22 kN (5 klbf), and the shaker loads can be 4.5 kN (1klbf) max. to 500 Hz. The soft spring (K_s= 0.26 MN/m) in the static loading system isolates the bearing stator from the static loader. Note that three pairs of tensioned stabilizer bolts connect the bearing stator to the pedestals. These bolts restrain pitch motions of the bearing housing while allow precise alignment of the test floating bearing section.

The test rig is fully instrumented with a tachometer, four pairs of eddy current sensors, a strain-gauge torque meter, pairs of load cells and accelerometers on the bearing cartridge, and no less than 40 thermocouples (and dedicated data logger) for measurement of pad temperatures and oil inlet and exit temperatures. A turbine-type flow meter measures the oil flow rate delivered to the bearing. Presently, the test rig has a dedicated DAQ for data recording as well as automated controls for its operation, including emergency shutdown procedures.



(a) Side view of complete test rig **(b) isometric and axial views with load systems**

Figure 1. Schematic views of fluid film bearing test rig.

PROPOSED WORK 2018-2019

The main objective is to quantify the effects of reduced (or higher than) nominal flow rate on the performance of a tilting pad bearing. Fig. 2 shows the test four-pad TPJB, OD=101 mm (4"), *L/D*=0.6, and spherical pivots. The pads are 72º with a 0.30 preload and 50% pivot offset. The nominal *cold* clearance = 4.65 mil.

Fig. 2 4-pad bearing with spherical pivots and single orifice oil feed

(a) Produce predictions of bearing performance, based on model in [4], for (flooded) sealed ends TPJBs: nominal flow rate vs. shaft speed.
(b) Check bearing thermocouples and repair any broken leads or install new wires. Assemble bearing into cartridge and measure installed *cold* clearance.
(c) Conduct static load measurements at two shaft speeds, 6 krpm and 12 krpm, for increasing specific loads (2.0 MPa max) and while varying the flow rate, 150% above and 50% below nominal (25% if possible). Measure drag torque (power loss), oil exit temperature, and pad (sub surface) temperatures.
(d) Perform dynamic load measurements and identify the test bearing stiffness, damping and virtual mass coefficients.
(e) Correlate measurements against predictions and prepare a technical report addressing to the main question: <u>how low is a low flow rate</u> enough for safe and cost efficient bearing operation?

BUDGET FROM TRC 2018-2019

Support for graduate student (20 h/week) x $ 2,200 x 12 months	$ 26,400
Fringe benefits (2.4%) and medical insurance ($422) x 12 months	$ 5,698
Tuition & fees three semesters (24 ch)	$ 13,275
Conference travel and registration	$ 1,800
Supplies: bearing parts and rig ancillary parts	$ 2,827
Total BUDGET	**$ 50,000**

REFERENCES

[1] DeCamillo, S.M., He, M., Cloud, C.H., and Byrne, J.M., 2008, "Journal Bearing Vibration and SSV Hash," *Proc. 37th Turbomachinery Symposium*, Houston, TX, September 7-11.

[1] Coghlan, D.M., 2014, "Static, Rotordynamic and Thermal Characteristics of a Four Pad Spherical-Seat Tilting Pad Journal Bearing with Four Methods of Directed Lubrication." M.S. Thesis, Texas A&M University, College Station, Texas.

[3] Abdollahi, B., and L. San Andrés, 2018, "ON THE PERFORMANCE OF TPBs: A NOVEL MODEL FOR LUBRICANT MIXING AT OIL FEED PORTS WITH IMPROVED ESTIMATION OF PADS' INLET TEMPERATURE AND ITS VALIDATION AGAINST EXPERIMENTAL DATA," II Asia Turbomachinery and Pump Symposium, Singapore, March 13-15.

[4] San Andrés, L., Koo, B., and Hemmi, M., "A Flow Starvation Model for TPJBs and Evaluation of Frequency Response Functions: a Contributions towards Understanding the Onset of low Frequency Shaft motions," ASME Paper GT2017-64822.