MORE MEASUREMENTS ON THE EFFECT OF A REDUCED FLOW RATE ON THE PERFORMANCE OF A LOP TILTING PAD JOURNAL BEARING WITH EVACUATED ENDS

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SIGNIFICANCE

Tilting pad journal and thrust bearings (TPJBs) are common oil lubricated supports in high performance turbomachinery, including multiple stage centrifugal compressors and power generation gas turbines. TPJB load capacity, drag power loss and dynamic force coefficients are well documented and certified, 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 toward enabling low drag power losses and keeping safe temperature increases in both the bearings pads and oil circulation system. A reduced flow decreases pumping costs and oil sump storage volumes, and improves system energy efficiency. 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 may also produce a quick raise in pad temperature that could melt the Babbitt 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 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; whereas at a high shaft speed, the bearings likely starved of lubricant [3]. The consideration of flow rate has not received serious consideration until a recent test program sponsored by an OEM.

WORK IN 2018-20 (YEARS I AND II)

In 2018 and 2019, TRC funded a program to quantify the effects of reduced (or higher than nominal) flow rate on the performance of a TPJB (load in between pads [LBP] and with a flooded configuration (2019) and with evacuated ends (2020). Fig. 1 shows the test four-pad bearing, OD=101 mm (4"), *L/D*=0.6, and spherical pivots. The pads are 72^o with a 0.30 preload and 50% pivot offset. The nominal *cold* clearance = 4.5 mi (0.115 mm). ISO VG46 oil at a constant temperature of 60 ^{o}C (140 ^{o}F) flows into the bearing at a (user) set flow condition. A 60kW air motor spinning to a maximum 16 krpm drives the shaft supported on two precision ball bearings.

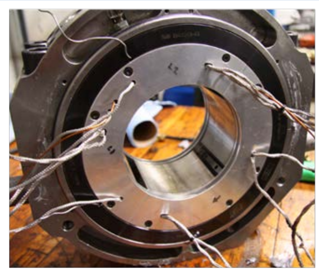

Fig. 1 A 4-pad bearing with spherical pivots and single orifice oil feed.

The test bearing in Year I had its ends flooded with lubricant as it had end seals. The test bearing test in Year II had its ends evacuated or open to ambient (end seals removed).

The tests comprise operation at two shaft speeds (6 and 12 krpm) corresponding to shaft surface speeds = 32 and 64 m/s, and three applied loads = 345, 1,034, and 2,068 kPa (50 psi to 300 psi) while the supplied flow rate varies from 120 % nominal flow to a low magnitude, a minute fraction of nominal (2% - 5% with a flooded configuration). Note the nominal flow rate is mainly a function of shaft speed, ~ 14 LPM and 29 LPM for the low and high shaft speeds.

For a set shaft speed and applied load, the measurements include journal eccentricity, [drag torque], pad sub-surface temperatures and oil exit temperature as the flow rate supplied varied from high to low (<< nominal). Dynamic load excitations permit the identification of bearing force coefficients (stiffness, damping and inertia) over a certain frequency range.

Fig. 2 presents the outcome of the measurements conducted at 6 krpm. Find (similar results) for operation at 12 krpm in the accompanying technical presentation. In brief, both evacuated and flooded ends bearing show the same performance (eccentricity, pad temperatures and force coefficients) for nominal or overflow conditions. A moderate changes (to 75%) in flow rate does not produce major changes in both pad temperatures and force coefficients.

A larger reduction in flow rate, well below 10 LPM, produces an increase in eccentricity and direct stiffness (K_{YY}) for the bearing with evacuated ends. The viscous damping (K_{YY}) also increases as the film thickness is very thin. On the other hand, the bearing with end seals shows a drop in both direct stiffness and damping coefficients.

The cartridge holding the test bearing is a relative thin shell structure with an annular groove on its OD for oil distribution into the pads. For a too low supplied flow rate, temperatures in the bearing OD annulus are quite distinct and unsteady. At this condition, flow and oil inlet temperature controls are difficult.

Difficulties encountered included (a) sharing the test rig for experiments with a porous-gas bearing and which proved remarkable difficult to achieve; (b) an apparent failure of the torque meter which could not be timely resolved until it fixed on its own; (c) persistent delay in preparation of technical documentation (TRC reports); and a global health emergency (COVID19). **To complete the work as proposed a second graduate student is urgently needed!**

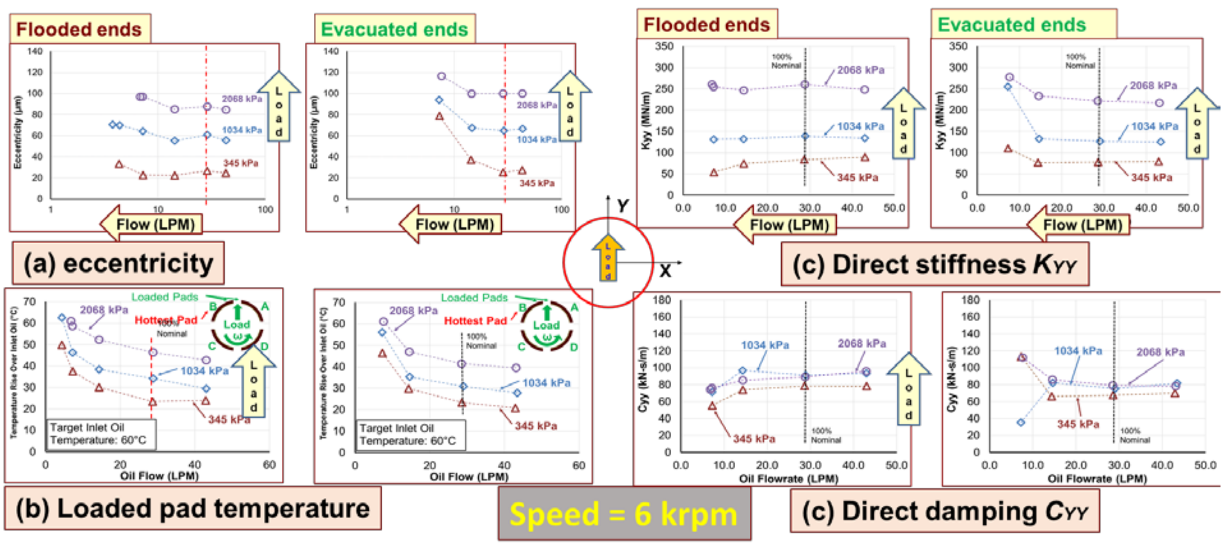

Fig 2. Effect of flow rate on performance of test bearing (LBP): Flooded Ends vs Evacuated Ends. A peek to test data acquired at 6 krpm and three static loads (nominal flow 14.4 LPM).

PROPOSED WORK 2020-2021 (YEAR III)

On Year III, concerted work will continue to evaluate the effect of (low) flow rates on the performance of an evacuated bearing (no end seals) and also operating under a load on pad (LOP) orientation. Specific tasks include:

(a) Install bearing w/o end seals → evacuated configuration (LBP → LOP)

(b) Conduct measurements at shaft speed=6 krpm and 12 krpm, and three static loads (50 psi to 300 psi =0.344 MPa), and decreasing flow rate to limit determined by (a) excessive pad temperatures (above 121ºC=250 ºF), or (b) onset and persistence of SSV, (c) inability to control set flow and oil inlet temperature.

(c) Perform dynamic load measurements to extract bearing stiffness, damping and virtual mass coefficients.

(d) Produce predictions of bearing performance for (flooded & evacuated) TPJBs and correlate measurements against predictions.

(e) Complete technical reports (2019, 20 & 21) with engineering answers to the main question: how low is a low flow rate enough for reliable and cost efficient bearing operation?

BUDGET FROM TRC 2020-2021

Support for graduate student (20 h/week) x $ 2,200 x 12 months	$ 26,400
Fringe benefits (3%) and medical insurance ($206) x 12 months	$ 3,264
Tuition & fees three semesters (24 ch)	$ 16,728
PC for Data Acquisition	$ 1,200
Supplies: bearing parts and rig ancillary parts	$ 2,408
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.