NEW PROPOSAL

MEASUREMENTS OF THE STATIC AND DYNAMIC LOAD CAPACITY OF A POROUS CARBON-GRAPHITE, TILTING PAD AIR BEARING FOR OIL-FREE COMPRESSORS

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SIGNIFICANCE

Compact high power density turbomachinery dispenses oil lubricated bearings to reach high efficiency. Oil free turbomachinery has a smaller foot-print with savings in weight and part count. Externally pressurized porous gas bearings (PGBs), tilting pad type, allow nearly friction free and rotor dynamic stable operation. This bearing type offers a high centering stiffness albeit damping is an issue for any gas lubricated bearing as the fluid viscosity is rather low. In comparison to cylindrical carbon bushings, tilting pad PGBs also provide enhanced stability by eliminating cross-coupling hydrodynamic forces. While PGBs are not a new technology (around since 1950), advances in manufacturing made them available at a low cost. San Andrés et al. [1] show that a rigid rotor supported on tilting pad PGBs produces a large damping ratio ($\zeta = 0.17$) despite the low viscosity of the lubricant: air. In rotor speed coast down tests from 55 krpm (82 m/s), the bearing drag friction coefficient is just $f = 0.007$ → 0.004 as the supply pressure into the bearings increases. In the tests, the rotor operation is nearly friction-free and its dynamic response purely synchronous.

The low-friction feature of the tested PGBs makes them attractive for large size turbomachinery where reduced drag power losses could mean a substantial increase in mechanical efficiency and lower operational costs. OEMs have a particular interest in assessing oil-free bearing types to satisfy ever stringent environmental constrains while improving system efficiency and reliability in machines with a smaller footprint.

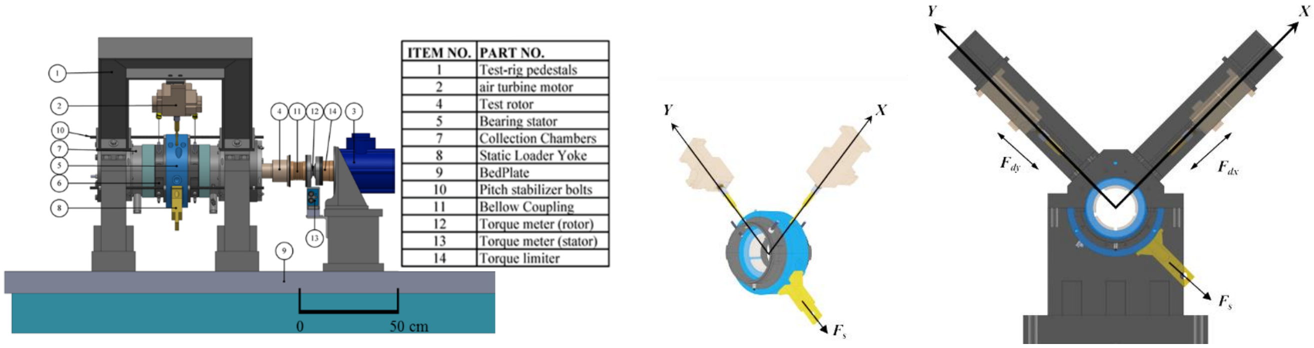
A demonstration of PGB performance at high surface speeds and under high loads (1 MPa) will pave the way for their implementation in commercial systems. This proposal intends to provide the needed experimental verification to further the technology of PGBs by testing one bearing at the Turbomachinery Laboratory.

DESCRIPTION OF TEST RIG

Fig. 1 depicts the test rig for measurement of the dynamic load performance of oil lubricated fluid film bearings and seals. A 65 kW-power air turbine motor drives a rigid 4" shaft through a bellow coupling, a torque-limiter, and a torque meter. Two angular contact ball bearings, oil-mist lubricated and placed in a back-to-back orientation, support the shaft. Two stiff pedestals hold the ball bearings, 406 mm (16") 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 hydraulic loaders and stingers apply dynamic loads along two orthogonal directions, see Fig. 1(b). The rated maximum pull load is 22 kN (5 klb_f), and the shaker loads can be 4.5 kN (1klb_f) max. to 500 Hz. The soft spring (K_s= 0.26 MN/m: 1480 lbf/in) in the static loading system isolates the bearing stator from the static loader. Three pairs of tensioned bolts connect the bearing stator to the pedestals to restrain pitch motions of the bearing housing while allowing alignment of the test floating bearing. 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 many K-thermocouples.

NewWay® Air Bearings (NWB), a TRC member, has designed (will construct at no cost) a PGB for testing in the current test rig facility, see Fig. 2. The gas bearing has four arcuate pads (50% offset and no preload) and (Bellville) spring pivots. When assembled the bearing pads have an interference with the shaft (spring preload); and upon external pressurization (max 10 bar), the pads retract to form a minute gap. Note that these bearings demand of a very small air flow rate (same magnitude as a human breath). Upon shaft spinning, the bearing can withstand an applied load. The critical design consideration is the pivots' elastic spring system as the bearing load capacity is proportional to the spring stiffness since the air film is likely too stiff.

Gas bearings have very little torque; hence, the current air turbine will likely be replaced by a VFD motor (18 krpm) and one end of the test rotor modified to accommodate a direct quill shaft connection to the driver.



(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.

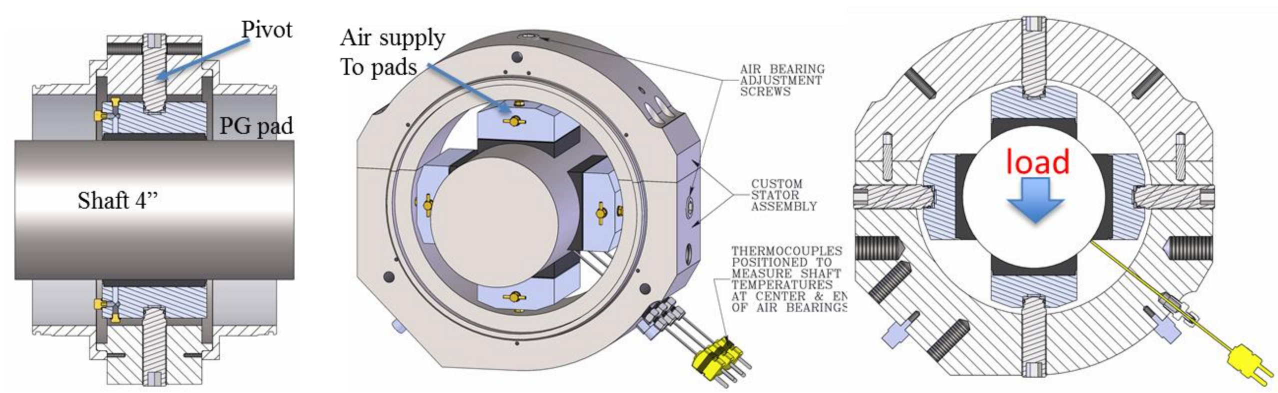


Fig. 2 4-pad porous Carbon-Graphite tilting pad gas bearing designed for ready test in existing facility.

PROPOSED WORK (2018-2019)

The main objective is to measure the static load capacity, drag torque, pad temperature, and force coefficients of a porous Carbon-Graphite four-pad pivoted air bearing, shown in Fig. 2. The pads are 60º with a null preload and 50% pivot offset. OD=101 mm (4”), *L/D*=0.6. The nominal *cold* clearance = 0 mil. The tasks are:

(a) Design and manufacture bearing and custom stator assembly to fit in existing test rig.

(b) Assemble one bearing pad in ad-hoc jig and measure pivot spring stiffness. Determine pad lift off pressure as function of air supply pressure and pivot spring preload.

(c) Assemble bearing into cartridge and align bearing to shaft, record nominal (opening) gap as a function of supply pressure.

(d) For air supply pressure (max. 100 psi), conduct static load measurements at three shaft speeds, 6, 9 and 12 krpm (64 m/s) and an increasing static load (max. 1,000 lb_f [445 kg_f]). Measure supplied air flow, and shaft and pad temperatures. Apply dynamic loads and identify bearing stiffness and damping force coefficients.

(e) Prepare a technical report detailing design procedure and installation, measurements procedure and results.

The experimental program will deliver (independent) test results demonstrating the applicability of PGBS, tilting type, to high speed – high load rotating machinery.

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
Supplies: bearing parts and rig ancillary parts	$ 4,627
Total BUDGET	**$ 50,000**

REFERENCES

[1] San Andrés, L., Jeung, S.-H., Rohmer, M., Devitt, D., 2015 “Experimental Assessment of Drag and Rotordynamic Response for A Porous Type Gas Bearing,” STLE Annual Meeting, Dallas, TX May 17-21.