MEASUREMENTS OF ROTOR LIFT-OFF AND BREAK UP TORQUE IN A METAL MESH FOIL BEARING FOR USE IN AUTOMOTIVE TURBOCHARGERS

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Abstract

Gas bearings enable the commercial success of high speed microturbomachinery operating at high temperatures and virtually friction free. Metal mesh gas foil bearings are a low cost alternative to replace oil-lubricated bearings in passenger vehicle turbochargers. However, during rotor start up and shut down, the rotor operates in contact with the foil bearings thus demanding of a large break-up torque to overcome the dry friction. Early rotor lift-off in the bearings enables nearly friction free operation. Measurements of break-up torque on a metal mesh bearing as a function of shaft speed and static load are obtained in an existing turbocharger driven test rig. Bearing performance characteristics such as power loss and ultimate load capacity are experimentally determined. The bearing experiences the highest torque at low shaft speeds, dropping significantly once the rotor lifts off. Increases in static load lead to an increase in bearing break-up torque and delay rotor lift off to a higher speed.

Terminology

Gas bearing – compliant, self-acting film bearing uses air as the working lubricant.[1]

Break-up torque – Applied shaft torque to overcome dry-friction (contact) and allow shaft rotation with gas film.

Lift-off speed – Rotor speed at which thin gas film evolves to support load acting on bearing and without rubbing.

Load (*W*) capacity – The maximum load that the bearing can withstand at a particular speed until sliding contact occurs with sudden rise in drag torque [1].

Power loss – The mechanical loss of energy caused by the sliding friction between the top foil and test rotor.

μ_b – Break-up friction coefficient

μ_g – Gas film friction coefficient (idem)

$$\mu = \frac{Torque}{\frac{D}{2} W}$$

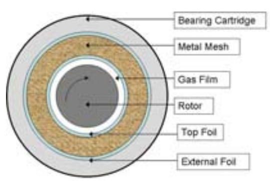
Metal Mesh Gas Bearings

Gas Bearings

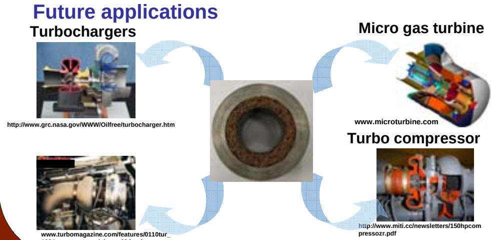
- eliminate oil and remove pumping and sealing systems
- reduce drag power and heat generation
- allow weight reduction
- improve overall system efficiency & reliability
- enable higher and lower temperature capability

Metal Mesh Foil Gas Bearings

- readily available at low cost
- material compactness provides control of stiffness
- enable high temperature operation



Future applications



Research Objective

Rotordynamic measurements of a metal-mesh gas foil bearing mounted on a turbocharger rotor

- Lift-off speed and torque during start-up and shut-down
- Drag torque for increasing rotor speed and static loads
- Ultimate load capacity
- Rotor temperature for increasing static load

Acknowledgment

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Experimental Facility

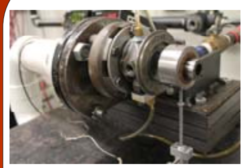


Figure 1. Turbocharger test rig [2]

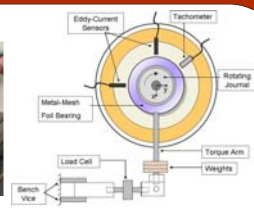
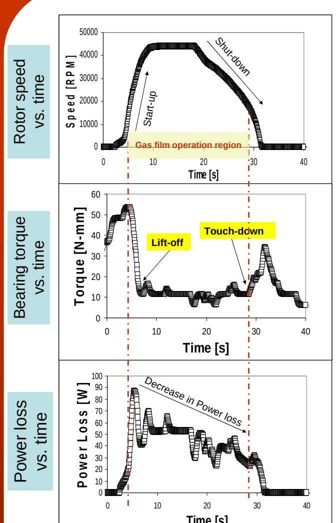


Figure 2. Schematic view of test rig [2]

Table 1. Main parameters of MMFB bearing and test rig

	Parameter	Value
Bearing	Mass [g]	278.2 ($W_{BEARING}$=2.73 N)
	Cartridge length [mm]	35.9
	Cartridge outer diam. [mm]	54.2
	Cartridge inner diam. [mm]	42.2
	Mesh length [mm]	30.5
	Mesh thickness [mm]	8
	Top foil diam. [mm]	28.1
	Top foil thickness [mm]	0.127
Test Rig	Journal diam. [mm]	28.05
	Speed range [rpm]	0 - 70,000
	Pressure range [psi]	0 - 125
	Torque Arm Length [mm]	119.2

Experimental Results

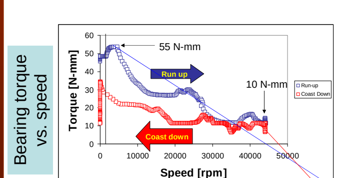


Air supply pressure into turbine is manually increased until rotor overcomes the dry friction and begins to rotate freely. Rotor runs up to 40 krpm and then coasts down.

Drag torque is large and peaks at rotor speed of ~2 krpm. A sharp drop in torque indicates rotor lift-off, while sharp increase evidences touch-down.

Maximum power loss due to friction occurs at start-up and gradually decreases as lifted rotor speeds up.

Figure 3. Rotor start-up/shut-down cycle over a 40 second interval, 13 N static load (vertical).



Drag torque is maximum at low rotor speed, prior to rotor lift-off. The bearing torque at top speeds, > 40 krpm, drops to 18% of the torque at start-up.

Figure 4. Bearing torque versus speed under a 13 N static load.

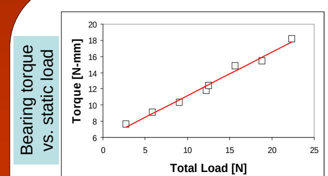
Friction coeff.

μ_b = 0.31

μ_g = 0.055

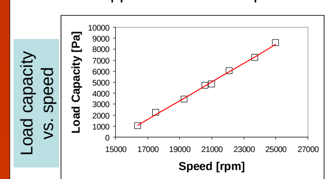
Once rotor lifts-off, operation with a gas film reduces friction 82 % **(~ 6 times)**

Experimental Results (cont'd)



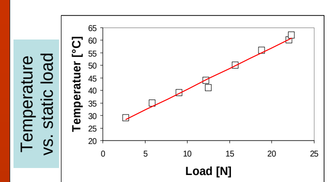
Bearing drag torque increases linearly with applied load (includes the bearing weight) at a speed of 40 krpm (rotor lifted off).

Figure 5. Bearing torque versus applied load at 40 krpm



Rotor runs up to 40 krpm and is statically loaded. Rotor decelerates by closing air supply into turbine. **Ultimate load capacity** determined from sudden increase in torque at a rotor speed that is proportional to applied load.

Figure 6. Bearing ultimate load capacity versus rotor speed



Rotor temperature is proportional to applied load in gas film operating region.

Figure 7. Temperature of rotor free end versus applied load. Operation at 40 krpm

Conclusions

1) During a rotor start-up/shut-down cycle, bearing torque drops significantly at rotor lift-off and raises sharply at touch-down. Break-up torque during start-up is ~ 34% larger than that at shut-down.
2) Once rotor lifts, torque decreases as rotor speed increases demonstrating operation in cushion of gas film. Within 30-40krpm, torque is a minimum.
3) Friction coefficient reduced by ~ six times once rotor lifts as opposed to operation with rubbing contact.
4) Gas film operating torque and rotor temperature increase linearly with respect to applied static load.
5) Ultimate load capacity increases proportionally as rotor speed increases.

Metal mesh foil bearings perform best at high speeds where the gas film can support higher loads and no dry friction occurs. At low speeds metal mesh foil bearings show high friction. The challenge is to design a bearing that reduces both break-up torque and drag torque during gas film operation. Further research on solid lubricant coatings could achieve the goal.

References

[1] DellaCorte, C., 1997, "A New Foil Air Bearing Test Rig for Use to 700 °C and 70,000 rpm," NASA TM-107405.

[2] San Andrés, L., and Kim, T.H., 2008, "Measurements of Structural Stiffness and Damping in a Metal Mesh Bearing and Development of a Test Rig for Foil Gas Bearings," TRC-B&C-5-08.