Laser-Induced Fluorescence (LIF) Imaging Studies of the Oil-Film Thickness in a Thrust Collar

Continuation Proposal

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June 2022

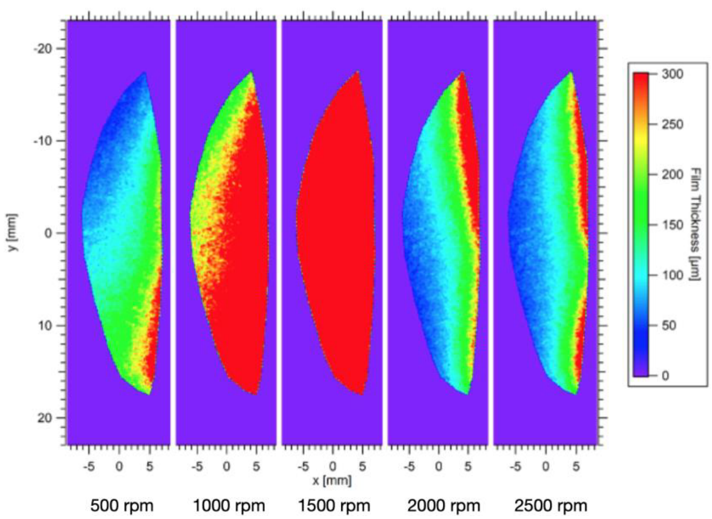
Introduction

Integrally geared compressors (IGCs) offer higher thermal efficiency and a smaller footprint when compared to traditional single-shaft multistage centrifugal compressors [1]. The axial load produced from the impellers and the force from the geared connection create an axial load on the pinion shaft that must be balanced to ensure reliable operation. Thrust collars (TCs) provide a way to transmit the axial load from the pinion shaft to the bull gear (BG) shaft, on which resides a large diameter thrust bearing to react the total IGC thrust load. Increasing the power density of IGCs could expand their application range to higher flows and compressor ratios. However, the increase in efficiency and capacity result in additional load and higher speed requirements on the TCs.

The Turbomachinery Laboratory developed a test rig based on a typical IGC. Fig. 1 details the thrust collar test facility (TCTF) which resembles a single-pinion IGC. The pinion and bull wheel shafts are independently controlled with VFDs and can spin up to 20,000 and 3,600 rpm, respectively. The TC is made of acrylic and has two windows which allow for visualization of the oil film.

Status

The cavitation and turbulence of the TC film was captured with a high-speed camera [2], and quantitative 2D measurements of the OFT were recently conducted through laser-induced fluorescence (LIF) imaging. LIF involves adding a molecular tracer to the oil film to generate a fluorescent signal that is governed by the Beer-Lambert law of absorption. A novel calibration device was used to quantify the LIF that seals an oil film between two acrylic windows was used to quantify the LIF signal at different film depths. The initial LIF experiments were conducted at axial loads of 0, 500, and 600 N for the starved lubrication testing and 0, 500, and 1000 N for the full lubrication testing. The film thickness map shown in Fig. 4 was imaged at an axial load of 1000 N at various running speeds ranging from 500 to 2500 rpm.



Film thickness map at 600 N for TC speeds of 500, 1000, 1500, 2000, and 2500 rpm (left to right)

The film thickness first increases with running speed up to 1500 rpm, then decreases with running speed at speeds greater than 2000 rpm. This transition is correlated to the velocity of the oil inlet to the surface velocity of the TC. Further tests are required to evaluate the effect of oil inlet velocity on the film thickness behavior. Additionally, further tests are required to identify the optimal dye concentrations and laser intensities to measure films at various film thickness ranges up to ~ 400 microns.

Proposed Work

Year 3:

The proposed year two testing will extend the LIF OFT measurements to a wider test matrix that focuses on the effect of differing oil inlet speeds on the film thickness. The testing will be split into load testing and starvation testing. Load testing will start at a given speed, and the load will be increased steadily until the film collapses, or the load is at its maximum capacity. Starvation testing will proceed in a similar manner to determine the minimum supply rate before scoring occurs.

To accurately measure OFT across the expanded test matrix, additional calibration device designs and tests will be required. Deeper groove depths are necessary to extend the calibrations to thicker films, and additional tests are necessary to determine the optimal the laser intensity and the dye concentration to ensure that the fluorescent signal remains linear over a given OFT range.

Year 4:

The proposed year three testing involves Particle-Image-Velocimetry (PIV) measurements of the lubricant film. In PIV, tracer particles are added to the flow field and correlated between two successive frames to determine the velocity field. The only experimental change required to implement PIV at the TCTF is to replace the dyed oil with fresh oil seeded with tracer particulates; the same optics, camera, and laser can be used from the OFT experiments. These experiments can provide transient velocity and turbulence measurements of the LA flow field. These experiments can assist original equipment manufacturers in developing more accurate TC models, which can lead to improved designs and increased TC power density.

Budget

Budget	
Graduate Student Payroll, 12 months @ $2200/month	$ 26,400
Fringe Benefits	$ 5,755
Tuition and fees	$ 13,275
Computer and Software	$ 4,570
Total	$ 50,000

References

[1] U.Fingerhut,E.Rothstein,andG.Sterz,"Standardized integrally geared turbomachines tailor made for the process industry," in Proceedings of Twentieth Turbomachinery Symposium, pp. 131–144, Texas A&M University, Turbomachinery Laboratories, 1991.

[2] T. Kerr, Experimental and Numerical Study of Oil Lubrication on a Thrust Collar for Use in an Integrally Geared Compressor. PhD thesis, Texas A&M University, August 2020.