

Short Course (6 CE hours)

BEARINGS FOR OIL-FREE ROTATING MACHINERY

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Gas bearings (GBs) are an efficient alternative for load support of high speed (microturbo) machinery (< 400 kW, +1000°F, +3M DN). Hydrodynamic bearings, often with a compliant surface as foil bearings, use ambient air as the working fluid media. Oil-free systems have lesser part count, footprint and weight and are environmentally friendly and (nearly) maintenance free, thus saving costs and resources. Current commercial applications include air cycle machines, cryogenic turbo expanders, blowers, and micro gas turbines. Other upcoming applications include auxiliary power units, automotive turbochargers, compressors for A/C units, and aircraft gas turbine engines for regional jets.

Successful implementation of GBs in commercial rotating machinery involves a three-tier effort with (a) selecting and designing bearing structural components and solid lubricant coatings to improve the bearing load carrying capacity with reduced friction, (b) having accurate performance engineering prediction models anchored to dependable (non commercial) test data, and (c) integration with secondary flow, operating profile, and the rotor-bearing dynamic system.

The short course provides practicing engineers with a comprehensive review of existing gas bearing technologies including their principle of operation, analysis and experimental verification, comparison amongst other gas bearing types, as well as the integration of gas bearings, foil bearings in particular, into actual rotor-bearing systems (hot and cold). The course also includes an introduction to magnetic bearings and their applications.

CONTENTS

MORNING: Luis San Andrés, Texas A&M University
GAS BEARINGS AND APPLICATIONS
00 Oil-Free Bearings for microturbomachinery: needs, hurdles and issues
01 About gas bearings: ultimate load capacity
MAKING A FOIL BEARING: the basics
02 How to make a foil bearing details on making bump foil strips and top foils.

03 Regimes of operation and the rule of thumb for load capacity A map to reality
CHARACTERIZATION OF FOIL BEARINGS
04 Structural dynamic stiffness and damping in a bump-type foil bearing: effect of load orientation and assembly preload. Is damping viscous? How FBs dissipate mechanical energy? Evaluation of Drag torque and friction coefficient.
DYNAMIC RESPONSE OF A ROTOR-FOIL BEARING SYSTEM
05 Nonlinear dynamics of rotor-foil bearing systems: Foil bearings are prone to sub synchronous whirl, is this behavior a rotordynamic instability or something else?
OTHER TYPES OF GAS BEARINGS
06 Metal mesh foil bearings: simple & cheap alternative. Comparison to bump type foil bearing
07 Flexure pivot tilting pad bearings: a stable gas bearing with predictable performance
08 Thrust foil bearings: Light Load vs Large Load Performance
09 Carbon-graphite gas bearings: a bearing with no friction and tight clearances. Can serve as an effective seal too. The road ahead: hurdles and expected outcomes for oil-free machinery in an ever changing engineering field.
AFTERNOON: Mr. Daniel Lubell, Oil-Free Machinery, LLC
10. IMPLEMENTATION OF FOIL GAS BEARINGS IN A MICRO GAS TURBINE SYSTEM.
A Gen. III foil bearing for a mass production microturbine. A perspective from a successful commercial application of oil-free technology in microturbines from 30 kW up to 200 kW as well as development testing with blowers, compressors, air cycle machines, and more. Experience-based lessons on what-to-do and what-not-to-do related to implementation at the design level, including recommended operating spaces for the least risk. Expectations for bearing performance and assembly at the mass production level. Discussion of common failure modes.\
11. INTRODUCTION TO MAGNETIC BEARINGS FOR SMALL AND LARGE SIZE TURBOMACHINERY SYSTEMS
A review of the components and operating principles of Active Magnetic Bearings (AMBs). Additional discussion of expected performance and associated challenges with integrating AMBs into next-generation turbomachinery.
12. FOIL BEARINGS IN ALTERNATE GASES
A practical review of direct experience with foil bearings used in Freon, Helium, and more. Applicable to the growing HVAC market and the Hydrogen Economy

Who Should Attend

The course is designed around the needs of every job function related to integrating oil-free foil bearings into rotating machinery products. This includes design engineers interested in making their next generation machines or improving current machines with a hybrid oil-lubed and foil bearing system. Additionally, consumers of oil-free machines will benefit from understanding the technology's unique characteristics. This course will include material relevant to oil-free compressors, industrial and aerospace gas turbines with hot section bearings, air cycle machines, and more. The course will give enough information to rationally select foil bearings by understanding their (current) practical limits and planning for further qualification and standardization. The short course will dispel several myths related to GFB performance and stress its unique features.

Why You Should Attend

Foil bearings are an enabling technology that benefits from a novel approach for effective integration into an oil-free rotating machine based on the bearing unique characteristics. The course is taught by engineers with practical, analytical, experimental and commercial experience with oil-free gas turbines and state of the art laboratory modeling and testing.

The course will utilize common rotordynamics, hydrodynamics, and other physics principals already familiar to the community and show how they apply to foil bearing equipped machines from a theoretical and practical point of views. In addition, the instructors' practical experience will prepare the designer for common pitfalls including gauging realistic performance expectations and typical operational failures, streamlining future projects.

This course was offered at TPS in 2014, 2016, and 2018 with outstanding success. Attendees' reviews compliment the presentations and acknowledge the quality and practicality of the knowledge learned.



THE PRESENTERS

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Luis San Andrés is a renowned analyst and experimentalist in the fields of gas and liquid film lubrication and rotordynamics. Dr. San Andrés has performed research on the analysis and experimental verification of gas foil bearing performance for high temperature oil free turbomachinery, squeeze film dampers for aircraft jet engines, and *wet* seals for subsea compression and pumping systems. His computational codes, benchmarked against test data, are standards in the rotating machinery industry. Dr. San Andrés and his students have published over 200 journal papers, several earning best paper awards. Dr. San Andrés is a

fellow of ASME, STLE and GPPS, a member of the Advisory Committees for the Turbomachinery and Pump Symposia. He is also an Associate editor for Tribology Transactions, Lubricants and the GPPS Journal.

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Daniel Lubell, the developer of Oil-Free Machinery™, specializes in oil-free turbomachinery with over 25 years of related experience, including over 10 years with Oil-Free Machinery, LLC. Daniel's previous experience includes several years at Calnetix Technologies as the Manager of Rotating Machinery and +12 years with Capstone Turbine with diverse roles that included Manager of Turbomachinery Rotating Systems and Principal Engineer of Oil-Free Bearing Technology. His responsibilities included bearing and rotordynamic design integration and testing for all Capstone

products as well technical and commercial lead for all outside foil bearing programs. Prior small turbomachinery experience includes APU's and small thrust jets with Sundstrand Aerospace (now part of Pratt and Whitney) and air cycle machines with Honeywell Aerospace. Daniel has a Master of Science degree in Mechanical Engineering which he earned at the Texas A&M University Turbo Lab in College Station, Texas. Prior to that, he earned a Bachelor of Engineering Science degree from Trinity University in San Antonio, Texas. Daniel is an ASME member and active participant in conferences and journals and has published papers on squeeze film dampers and foil bearing developments for micro gas turbines.