Turbomachinery Laboratory

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Founded in 1971, the faculty and staff of the Turbomachinery Laboratory and Texas A&M University continue to address the needs of the pump and turbomachinery industries. We moved into a new building in 1993 that is located a short distance from the George Bush Presidential Library. We are proud to continue Texas A&M's land-grant charter and tradition of attention to industry's needs in the following three areas:

- Continuing Education and Professional Development
- Undergraduate and Graduate Education
- Basic and Applied Research

CONTINUING EDUCATION AND PROFESSIONAL DEVELOPMENT

With respect to continuing education and professional development, the Turbomachinery Symposium was the initial principal activity of the Laboratory. From a modest beginning on the Texas A&M campus, the symposium has become the principle annual meeting for the users and manufacturers of industrial turbomachinery. The attendance for this meeting has grown to more than 2800, with over 200 exhibitors. Because of the continued growth of the Turbomachinery Symposium, the meeting moved to Houston. The papers presented at the symposium are invited by the Advisory Committee from recognized industrial leaders. The high quality and enduring value of these papers have been confirmed by practicing engineers who carefully hoard the symposium *Proceedings* within their professional libraries, and by the frequency of their citation in other transactions.

In 1984, the Turbomachinery Laboratory began a new symposium, the International Pump Users Symposium, which was patterned after the Turbomachinery Symposium, but devoted entirely to pumps. The inaugural Pump Symposium had 520 attendees and more than 50 exhibitors, representing pump manufacturers and users from the petrochemical industry and the utilities. Recent Pump Symposia have shown strong growth and clearly confirm the need for a forum for industrial pump users. The attendance has grown to more than 2500, with over 175 exhibiting companies.

Short courses are offered in advance of both symposia. The Short Courses are offered by experienced turbomachinery and pump users. Some topics covered by recent short course offerings include:

- Basic Pump Hydraulics with a Minimum of Mathematics
- The Relationship of Vibration to Problems in Centrifugal Pumps
- Mechanical Seals—Design and Theory
- Fundamentals of Centrifugal Pump and System Interaction
- Mechanical Seals—Applications and Failure Analysis
- Positive Displacement Pumps
- Flexible Couplings
- Fundamentals of Mixing Technology
- Design of Induction Motors Driving High Load Torque and Inertia Values
- Machinery Failure Analysis
- Turbomachinery Diagnostics and Condition Assessment
- Advanced Gas Turbine Technology
- Dry Gas Seals
- Review of API TP 684
- Reciprocating Compressor Performance Measurement and Condition Analysis

UNDERGRADUATE AND GRADUATE EDUCATION

At Texas A&M University, faculty expertise related to turbomachinery has traditionally provided equal emphasis on performance and reliability. Our undergraduate program provides students with elective options in turbomachinery performance, fluid and thermal science, vibrations, stress analysis, and other related topics. Our M.S. program provides a balance between performance and reliability with more specific electives in turbomachinery performance, rotordynamics, etc. A majority of the M.S. thesis research projects involve experimental validation of theoretical and computational developments. The emphasis on experimental validations of predictions stands in contrast to many graduate programs around the country. Ph.D. students generally concentrate on research topics related to ongoing research programs within the Laboratory.

BASIC AND APPLIED RESEARCH

Faculty and staff of the Turbomachinery Laboratory carry out research activities for both industry and government. Most of the industrial research support is provided through the Turbomachinery Research Consortium (TRC). Currently, 22 industrial firms provide grants of $15,000 per year to support a broad range of industrial research projects. In addition, grants and contracts from government and private agencies provide continuing support for graduate research and education related to performance, rotordynamics, seals, computational fluid dynamics, torsional vibrations, materials, and finite element analysis. Brief summaries are provided below for some of our current research activities.

Turbomachinery Performance

- Development of computational programs for both compressible and incompressible, radial-flow turbomachines.
- Computing the thrust force on shrouded pump impellers in the presence of several leakage mechanisms.

Rotordynamics and Reliability

- Identification of force coefficients from measurements of the imbalance response in a test rotor supported on series tilting pad bearings and integral squeeze-film dampers.
- Identification of rotordynamic performance of squeeze-film dampers and heavily loaded hydrodynamic bearings subject to natural air entrainment.
- Measurements of responses to imbalance (100,000 rpm) and shock loads in a test rotor supported on gas bearings for oil-free turbomachinery.
- Experimental characterization of the rotordynamic (nonlinear) performance of automotive turbochargers supported on floating and semifloating ring journal bearings.
- Effects of air/oil bubbly mixtures and air entrainment on the performance of squeeze film dampers.

- Experimental tests for identification of rotordynamic coefficients in fluid film bearings, gas damper seals, and brush seals.
- Effect of shrink fits on threshold speeds of rotordynamic instability.
- Experimental evaluation of a Met-L-Flex bearing damper in a high speed test rig.
- Development of high temperature magnetic bearings.
- Flywheel stress and vibration.
- Computational transient (linear and nonlinear) response of turbocharger rotors supported on floating-ring bearings. Identification of limit cycle amplitudes and whirl frequency ratios.
- Application of fiber-optic strain gauges to accurately measure dynamic forces with magnetic bearings for parameter identification.
- Measuring rotordynamic coefficients for tilting-pad bearings.

Seals

- Computational analysis of process fluid hydrostatic/hydrodynamic thrust bearings: effects of collar misalignment and prediction of moment-angle coefficients.
- Computational bulk flow analysis of Lomakin bearings for cryogenic turbopumps.
- Computational bulk flow analysis of labyrinth seals for cryogenic turbopumps.
- Computational analysis of gas tilting pad bearings, spiral-groove face seals and herringbone bearings for oil-free turbomachinery.
- Annular, honeycomb, labyrinth, and hole-pattern gas seals—analysis and high-pressure (70 bar supply pressure) testing for leakage and rotordynamic coefficients.
- Labyrinth seals—analysis and testing for leakage and rotordynamic coefficients.
- Three-dimensional finite difference solution approaches for flow in labyrinth seals and calculation of seal forces.
- Three-dimensional LDA measurement of fluid flow, currently applied to flow in labyrinth seals and flowmeters.
- CFD based rotordynamic coefficients for labyrinth seals and impeller shroud leakage paths.
- Rotordynamic effects of damper seals.
- Measurement of static and dynamic characteristics of high-pressure, laminar, oil bushing seals for centrifugal compressors or pumps.

ROTORDYNAMICS SOFTWARE

The TL staff has developed the integrated rotordynamics-software suite, *XL*TRC^2. The structural-dynamics code uses a finite-element/real-component-mode synthesis approach to achieve accurate and speedy analyses. *XL*TRC^2 can perform steady-state response calculations for synchronous or nonsynchronous excitation, stability analysis, and time-transient nonlinear calculations. The finite-element base means that multirotor systems can be handled readily, e.g., flexible-rotor/flexible-housing vertical pumps, dual-rotor/flexible-housings, etc. The basic code is supported by an extensive support library for calculation of bearings, gas seals, liquid seals, impeller stages, etc. The time-transient feature can be used to examine nonlinear response, e.g., blade loss, bearing-dead-band effects, etc. The code is highly efficient and runs on a range of operating systems. A torsional code is presently being integrated into *XL*TRC^2. This code is only available to members of the Turbomachinery Research Consortium.

FUTURE PROGRAMS

Several of the following programs are being planned for the future.

- LDV measurement capability for compressible and incompressible flow fields (compressors and pumps).
- Visualization of the flows around blade surfaces and tips.
- Visualization of bubbly flows (air entrainment) in squeeze film dampers.
- Use and improvement of magnetic bearings for parameter identification in centrifugal compressors.
- Leakage measurements in brush seals.