Mechanical Engineering Department
Texas A&M University

2008/2009
Research Progress Report
Tribology Group

Year XVIII

29th Annual
Turbomachinery Research Consortium Meeting

May 2009

Luis San Andrés
Leader

http://phn.tamu.edu/TRIBGroup

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In 2008/9, Dr. San Andrés managed seven (7) research projects. The Tribology Group remains vibrant and productive in spite of the hard times. We suffered the economy downturn, going down and down and … ! just like everyone else on earth. Industry withdrew its support, without announcement or simply procrastinated in delivering timely the resources to support the students, their only lifeline! We have done more with less, but we cannot do more with nothing.

In 2008/09, students and Dr. San Andrés published **twenty-four** technical papers (10 journal and 13 conference – all peer reviewed). The current status on the various research projects, the students involved, and the sources of funding follow:

	2008	2009*	Total
Journal (peer reviewed)	5	5	10
Conference (peer reviewed)	6	7	13
Conference (NOT peer reviewed)	2	2	4
Accepted/awaiting publication		5P 2A	7
Extended Abstracts	2	4	6
Student posters	4		4

- **Squeeze Film Damper – design & construction of test rig for high frequency & high load**

  OBJECTIVE: To assess novel SFD designs for aircraft applications.
  STATUS: Test rig designed in 2008 (500 lbf dynamic force). Construction started in 2009. Sponsor stopped funds in April (> $60k worth of equipment and instrumentation).
  SPONSOR: PRATT & WHITNEY, **$210,000 reduced to $131,400** **(project stopped)**
  Student: Adolfo Delgado (Ph.D.), Shraddha Sangelkar (M.S.), Sanjeev Seshagiri (M.S.), Anthony Logan (UG)

- **Nonlinear Rotordynamics of Turbochargers**

  OBJECTIVE: To continue advancement of (experimentally validated) virtual tools for prediction of the dynamic forced response of turbocharger rotors supported on (S)FRBs.
  STATUS: Project terminated, sponsor delayed payments for siz months. Industry wants work done for free.
  SPONSOR: HONEYWELL TURBO TECHNOLOGIES**, $105,000** **project terminated** **b/c of delays in payments.**
  Student: Arian Vistamehr (M.S.) – graduates June 2009, moves to University of Austin for Ph.D.

- **Hybrid Brush Seals to Improve Gas Turbine Efficiency**

  OBJECTIVE: Measurements of leakage, power loss and structural parameters in labyrinth seal, brush seal and hybrid brush seals for gas turbine applications
  STATUS: High temperature (300 C) test rig operational. Comparisons of leakage measurements in labyrinth seal, brush seal, hybrid brush seal completed. Tests with novel HALO® seal in progress. Hybrid brush seals have 1/15 less leakage than labyrinth seal and 1/3 less than conventional brush seal.
  SPONSOR: SIEMENS POWER GENERATION (2006-2009) **$75,000,** Seals from ADVANCED TURBOMACHINERY GROUP (ATG)
  Students: Zach Ashton (M.S.) – graduates June 2009 (will work at Rocketdyne), Brian Butler (UG)

- **Foil Gas Bearings for Oil-Free Turbomachinery** **TRC-B&C-2-09**

  OBJECTIVE: To quantify the physical parameters of bump foil gas bearings for micro turbine applications
  STATUS: Computational analysis complete to model thermal management of foil bearings. High temperature test rig (max 400 C) in operation: MiTi Korolon® bearings and Foster-Miller bearings. Cooperation with KIST Korean Institute of Science and Technology).
  SPONSORS: NASA GRC (2007-2009), **$284,577**, TRC, **$40,000** (start date 02/01/09)
  Students: Tae-Ho Kim (Post-Doc), Keun Ryu (Ph.D.), Chun Liu (M.S.), Ramon Silva (UG), Laura Wells (UG)

- **Metal Mesh Foil Bearings for Microturbomachinery** **TRC-B&C-3-09**

  OBJECTIVE: Further development of predictive models anchored to test data for prediction of mechanical parameters of metal mesh foil bearings.
  STATUS: high speed (60 krpm) test rig completed. Measurements of bearing lift off and drag torque during start up and shut down obtained.
  SPONSOR: TRC, **$40,000 (**start date 09/01/09)
  Students: Thomas Chirathadam (M.S.) – graduates June 2009

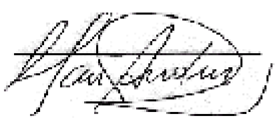
- **Gas Bearings for Oil-Free Turbomachinery** **TRC-B&C-1-09**

  OBJECTIVE: To advance the technology of inexpensive reliable gas bearings for micro gas turbines and micro power systems
  STATUS: Demonstrated reliability of hybrid gas bearings to intermittent shocks and shaker induced excitations into base of test rotor-bearing system.
  SPONSORS: TRC (TURBOMACHINERY RESEARCH CONSORTIUM), **$40,000** **(**start date 11/01/08)
  Personnel: Yaying Niu (M.S.) – graduates June 2009

- **Research Experiences for Undergraduates: Development of Microturbomachinery**

  OBJECTIVE: The REU Summer Program funds 30 junior-level students to conduct hand-on training and research in mechanical, manufacturing, industrial, or materials engineering topics related to technological advances in microturbomachinery.
  STATUS: Seven qualified UGS participated in Summer 2008. Four students worked with Tribology Group students. Thirteen students will initiate further research in June 2009. Read conference paper ASME GT2009-59920.
  SPONSOR: NATIONAL SCIENCE FOUNDATION (2006-2010), **$259,249**
  Investigators: PI: Wayne Hung (Engineering Technology), co-PI: Luis San Andrés

I thank the students for their excellent disposition towards learning and their immense patience. Their work makes me look good, most times!
Off to Singapore!

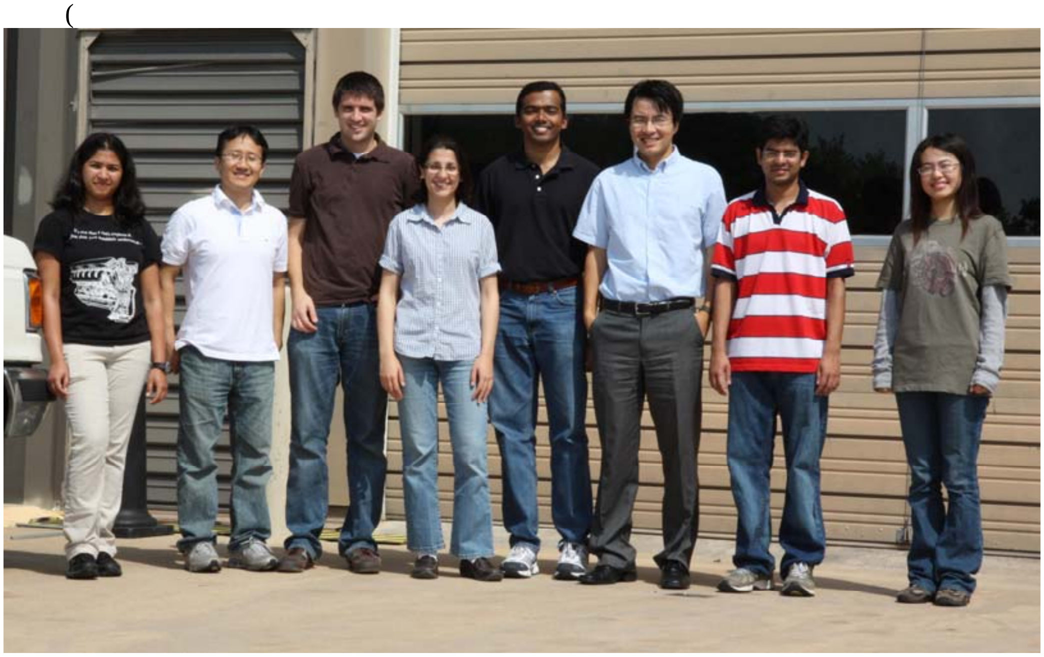


Luis San Andrés, Leader

Tribology Group

Team Members 2008/2009

Name	Research Project	Degree	Graduation date
Arian Vistamehr[+]	**Nonlinear Rotordynamics of Turbochargers**	**M.S.**	**June 2009**
Tae-Ho Kim, **Keun Ryu** **Chun Liu[+]** Ramon Silva[+]	**Gas Foil Bearings – Computational Analysis & High Temperature Test Rig**	**Post-Doc** **Ph.D** **M.S.** B.S.	**December 2007** **May 2010** **August 2010**
Laura Wells[*+]	**Nonlinear Force Response of Gas Foil Bearings**	**B.S.**	**May 2010**
Yaying Niu	**Flexure Pivot Gas Bearings for Oil Free TM**	**M.S.**	**June 2009**
Zach Ashton Brian Butler	**High Temperature Seal Tester: labyrinth seal & brush seals**	**M.S.** B.S.	**June 2009**
Adolfo Delgado[+]	**Identification of Force Coefficients in SFDs Hybrid Brush Seals for Gas Turbines**	**Ph.D.**	**December 2008**
Shraddha Sangelkar[+] **Sanjeev Saghiri** Anthony Logan	**Developmemt of SFD Test Ring for Pratt & Whitney**	**M.S.** **M.S.** B.S.	**August 2010** **December 2010**
Thomas Chirathadam	**Metal Mesh Foil Bearings & High Speed TC Driven Test Rig**	**M.S.**	**June 2009**



L-R: Shraddha Sangelkar, Keun Ryu, Zach Ashton, Arian Vistamehr, Thomas Chirathadam, Dr. Tae Ho Kim, Sanjeev Sechagiri, Chunliu Mao
missing: Yaying Niu, Dr. Adolfo Delgado,

(*) undergraduate student,
(+) minority student (female, Hispanic, Asian, African-American)

2009 Research Progress Reports

Dynamic Response of a Rotor-Air Bearing System due to Base Induced Periodic Motions

Luis San Andrés, Yaying Niu,

TRC-B&C-1-09

Measurements of Rotordynamic Performance in a Hot Rotor-Gas Foil Bearing System

Luis San Andrés, Keun Ryu, Tae Ho Kim,

TRC-B&C-2-09

Measurement of Bearing Drag Torque, Lift Off Speed and Identification of Structural Stiffness and Damping in a Metal Mesh Foil Bearing

Luis San Andrés, Thomas Chirathadam

TRC-B&C-3-09

2009-2010 Research Proposals

Gas Bearings for Oil-Free Turbomachinery
(continuation V)

Identification of Squeeze Film Damper Force Coefficients – Off-Centered Operation
(new)

PROGRESS REPORTS – EXECUTIVE SUMMARIES

TRC-B&C-1-09 DYNAMIC RESPONSE OF A ROTOR-AIR BEARING SYSTEM DUE TO BASE INDUCED PERIODIC MOTIONS

Oil-free microturbomachinery (MTM) are inevitably subjected to base or foundation excitations: passenger and commercial transportation vehicles experiencing intermittent excitation from road conditions, and (multiple) periodic load excitations from internal combustion (IC) engines in turbochargers, for example. Too large base excitations can produce severe damage, even failure, due to hard collision or rubbing contact between a rotor and its bearings. Therefore, it is paramount to evaluate the reliability of rotor-air bearing systems to withstanding base load excitations.

In 2008, intermittent shock load excitations, up to 30 g (pk-pk), were introduced to a test rig consisting of a small rotor (0.825 kg) supported on two hybrid flexure pivot tilting pad gas bearings (FPTPBs). The experiments demonstrated the reliability of the hybrid gas bearings to withstanding external transient load excitations. Presently, a shaker delivers periodic load excitations to the base plate supporting the rotor-bearing test rig. The whole system, weighing 48 kg, is supported on two soft coil springs and its lowest natural frequency is just ~5 Hz. The rod connecting the shaker to the base plate is not affixed rigidly to the test rig base. The rod merely pushes on the base plate and hence the induced based motions are intermittent with multiple impacts and frequencies. As with most practical conditions, the base motion frequencies (5-12 Hz) are low respective to the operating speed of the rotor-bearing system.

Rotor speed coast down tests evidence the rotor-bearing system natural frequency when the gas bearings are supplied with feed pressures increasing from 2.36 to 5.08 bar (ab). The shaker excitations move the rig base plate, which transmits forces into the rotor-bearing system. The recorded rotor response, relative to the bearing housings, contains the main input frequency (5-12 Hz) and its super harmonics; and because of the intermittency of the base motions, it also excites the rotor-bearing system natural frequency. The motion amplitudes at the natural frequency are smaller than the components synchronous with rotor speed. The excitation of the rotor-bearing system natural frequency does not mean the system exhibits rotordynamic instability.

With base induced motions, the rotor motion amplitude at the system natural frequency increases as the gas bearing feed pressure decreases, as the rotor speed increases, and as the shaker input excitation frequency increases (5-12 Hz). Hence, the test rotor-air bearing system is highly sensitive to base motions, intermittent in character, that excite its natural frequency, in particular when the gas bearings are supplied with a low feed pressure.

Predicted rotor motion responses obtained from XLTRC^2® and an analytical rigid rotor model, both including the (measured) periodic base motions, show good correlation with the measurements.

The research results demonstrate further the applicability of gas bearings into oil-free high speed MTM.

TRC-B&C-2-09 MEASUREMENTS OF ROTORDYNAMIC PERFORMANCE IN A HOT ROTOR-GAS FOIL BEARING SYSTEM

The TRC project co-sponsors a NASA GRC funded program on the development of computational models, experimentally benchmarked, for prediction of gas foil bearing performance at high temperature operation. Implementation of gas foil bearings (GFBs) into gas turbines requires careful thermal management and demands reliable performance measurements and predictions.

In 2009, measurements of bearing and rotor temperatures and shaft motions are obtained in a hot rotor supported on a pair of 2nd generation GFBs (uncoated top foils). A high speed AC motor (9.5 kW at 65 krpm) replaces the inexpensive router motor (1.5 kW at 25 krpm) used earlier. An inexpensive electric cartridge (max. 360°C), loosely installed inside the hollow rotor, is a heat source warming (unevenly) the rotor and its bearings. A shop air stream (max. 300 L/min & 23°C) forced axially into the bearings can be regulated to determine its effectiveness in cooling the rotor and bearings. A cover with layers of ceramic paper insulates the test rig from ambient conditions.

In rotor speed coast downs from 25 krpm and with a cold rotor, the amplitudes of rotor synchronous motion are proportional to the added imbalance masses. For operation with a hot shaft, the amplitude of rotor motion drops while crossing a (rigid body mode) critical speed. Large elapsed times (50~70 s) for rotor speed coast downs demonstrate airborne operation with little viscous drag, as is typical with gas bearings support systems.

In extended time tests, at 20 minute intervals, the rotor speed is set at 10 krpm, then at 20 krpm, and lastly at 29.3 krpm. The recorded bearing cartridge and rotor surface temperatures steadily increase with operating time. For operation without or with 50 L/min axial cooling, the temperatures of the bearing cartridges are almost identical. Note that the free end rotor surface shows the largest temperature raise as operation time and rotor speed increase. There is a significant axial thermal gradient (up to 50°C) from the rotor free end towards its drive end. The measurements show that the rotor has a temperature path paralleling that of the heater. The temperatures on the bearing cartridges, on the other hand, increase steadily with time.

In further tests, at a rotor speed of 29.3 krpm, a cooling gas stream, with increasing strength, controls the temperatures in the bearings and rotor. First, the peak temperature of the heater surface drops from 360ºC (without cooling) to 165ºC for a 150 L/min flow rates into each bearing. Since the heater power is limited, the rotor surface temperature quickly drops as the cooling flow advects heat from the whole test rig. The effect of a cooling flow, if turbulent in character, is most distinctive at the highest heater temperature (360°C). For operation at ambient or a lower heater temperature condition, however, the cooling flow stream demonstrates a very limited effectiveness.

In a gas turbine, gas bleed-off from the compressor is readily available to cool an oil-free hot rotor-GFB system. However, a too large cooling stream will reduce the engine efficiency. Therefore, later developments must focus on the determination of the minimum cooling stream needed for adequate thermal management.

To date the foil bearings remain operational, in spite of the severe rotor vibrations and large thermal gradients introduced into the test system. Future experiments will replace the bearings with *MiTi* Kololon® coated foil bearings able to support (higher) temperatures akin to those found in gas turbine engines.

TRC-B&C-3-09 MEASUREMENT OF BEARING DRAG TORQUE, LIFT OFF SPEED AND IDENTIFICATION OF STRUCTURAL STIFFNESS AND DAMPING IN A METAL MESH FOIL BEARING

Metal mesh foil bearings (MMFBs) are a promising low cost gas bearing technology for high speed oil-free microturbomachinery. Elimination of complex oil lubrication and sealing system by installing MMFBs in rotorcraft gas turbine engines offer distinctive advantages such as reduced system overall weight, enhanced reliability at high rotational speeds and extreme temperatures, and extended maintenance intervals compared to conventional engines. MMFBs for oil-free rotorcraft engines must demonstrate adequate load capacity, reliable rotordynamic performance, and low frictional losses in a high temperature environment. The report presents the measurements of MMFB break-away torque, rotor lift off and touchdown speeds, temperature at increasing static load conditions, and identified stiffness and equivalent viscous damping coefficients. The experiments, conducted in a test rig driven by an automotive turbocharger turbine, demonstrate the airborne operation (hydrodynamic gas film) of the floating test MMFB with little frictional loses at increasing loads. The measured drag torque peaks when the rotor starts and stops, and drops significantly once the bearing is airborne. The estimated rotor speed for lift-off increases linearly with increasing applied loads. During continuous operation, the MMFB temperature measured at one end of the back surface of the top foil increases both with rotor speed and static load. Nonetheless, the temperature rise is only nominal ensuring reliable bearing performance. Application of a sacrificial layer of solid lubricant on the top foil surface aids to reduce the rotor break-away torque. The measurements give confidence on this simple bearing technology for ready application into oil-free turbomachinery.

Impact loads delivered (with a soft tip) to the test bearing, while resting on the (stationary) drive shaft, evidence a system with large damping and a structural stiffness that increases slightly with frequency (max. 125 Hz). The system damping ratio decreases from ~ 0.94 to 0.47 as the frequency increases. In general, the viscous damping in a metal mesh structure is of structural type and inversely proportional to the frequency and amplitude of motion.

CIATEQ A.C., a TRC member, donated two aluminum foam bearings; their viability for use in turbomachinery is not recommended due to delicate integrity of the stiff metal foam.

PROPOSALS –SUMMARIES

Gas Bearings for Oil-Free Turbomachinery

NASA funding ends in August 2009. TRC support is sought to continue the experimental work to benchmark the completed computational model.

a) Experiments will be conducted in the GFB test rig with two *MiTi* Korolon® coated foil bearings for cartridge heater temperatures to 400 °C (752 ºF) and with rotor speed to 50 krpm. Rotordynamic measurements will determine rotor lift off and touch down speeds, load capacity and drag power, synchronous speed force coefficients, and regimes of stability and limit cycle operation. Perform comparisons with predictions.

b) Conduct dynamic load tests in KIST bearings to identify their structural stiffness and damping coefficients and correlation with predictive tool.

c) Install automatic open/close valve to operate multiple start & stop cycles in turbocharger driven gas bearing test rig. Install KIST bearings to determine their lift off and touch down speeds, load capacity and drag power.

The products of the research, codes and test data, will enable the reliable application of gas foil bearings into high temperature turbomachinery. The research will educate mechanical engineering students applying gas bearing technology to oil-free turbomachinery.

Identification of Squeeze Film Damper Force Coefficients – Off-Centered Operation

The proposed work will continue to use the TRC-SFD vertical test rig with dynamic loads of multiple frequency for excitation of an **off-centered** SFD to simulate operating conditions in multi-spool gas turbine engines. The tests with lubricant thru flow (open ends) will be conducted for ranges of frequency excitations including the test rig natural frequency. The identified force coefficients will be presented as a function of excitation frequency and amplitude of motion. The ultimate goal is for the experimentally derived coefficients to aid, in conjunction with a rotor-bearing model, to reproduce the complicated orbital patterns typical of multi-spool engines.

The proposed research is of interest for SFD applications in gas turbines, semi-floating ring bearings in turbochargers, hydrodynamic bearings in compressors, etc. Since 1990, TRC sponsors the SFD research program with many practical advances derived from planned experiments and computational analysis. The TAMU SFD research program is the most renown in the world.

Tribology Group - Funded Research **2008-2009**

TOTAL funds 08/09: **$ 350,000**

External NEW funds (08/09) $ 210,000 (-80,000)

NEW

Sponsor Project #	Amount	Project	Dates(GS support)
PRATT & WHITNEY	$210,000 reduced to **$131,400 Stopped**	Squeeze Film Damper – design of test rig for high frequency & high load operation	07/01/08 – 12/31/09 (2) **04/02/09**

ON GOING

Sponsor Project #	Amount	Project	Dates (GS support)
NASA - Glenn RC 32525/39600/ME	**$ 284,577**	Prediction of Foil Bearing Performance: A Computational Model Anchored to Test Data	09/01/07-08/26/09 (2)
Honeywell Turbocharging 32525/6865AA/ME	**$ 438,160** Terminated No on time payment	A Virtual Tool for Nonlinear Rotordynamics of Turbochargers	01/15/03 05/31/09 (1) 12/31/08
Siemens Power Generation 32525/34650	**$ 182,943**	Hybrid Brush Seals to Improve Gas Turbine Efficiency	12/09/05 6/31/09 (1)
National Science Foundation 32525/35430/ME	**$ 259,249**	Research Experiences for Undergraduates: Development of Microturbomachinery	10UG/year 04/24/06 05/31/10

Internal, $120,000 (TRC) - note differing start dates

Sponsor	Amount	Project	Dates
TRC 32514/1519B4/ME	$40,000	Gas Bearings for Oil-Free Turbomachinery	11/01/08 10/31/09
TRC 32514/1519C4/ME	$40,000	Rotordynamic Performance of Foil Gas Bearings: High Temperature Tests and Analysis	02/01/09 01/31/09
TRC 32514/1519S7/ME	$35,000	Metal Mesh-Top Foil Gas Bearings for Oil-Free Turbomachinery: Test Rig for Prototype Demonstrations	09/01/08 08/31/09

DONATION

Korean Institute of Science and Technology	~$15,000	Three pairs of foil bearings and rotor for high temperature test rig	01/01/2009

Research Expenditures Fiscal Year 2008: ~ $ 549,860.

Source: TEES portal 01//31/09

Tribology Group Publications 2008/2009

	2008	2009*	Total
Journal (peer reviewed)	5	5	**10**
Conference (peer reviewed)	6	7	**13**
Conference (NOT peer reviewed)	2	2	**4**
Accepted/awaiting publication		5P 2A	**7**
Extended Abstracts	2	4	**6**
Student posters	4		**4**

P- in print, A: accepted
(*) to May 15, 2009

below in bold face- student co-author

2009

Journal publications (peer reviewed)

5 **Delgado, A.,** and San Andrés, L., 2009, "Nonlinear Identification of Mechanical Parameters on a Squeeze Film Damper with Integral Mechanical Seal," ASME Journal of Engineering for Gas Turbines and Power, Vol. 131 (4), pp. 042504 (ASME Paper GT2008-50528

4 San Andrés, L., and **Kim, T.H.,** 2009, "Analysis of Gas Foil Bearings Integrating FE Top Foil Models," Tribology International, **42**(2009), pp. 111-120.

3 San Andrés, L., **Baker, J.,** and **Delgado, A.,** 2009, "Measurements of Leakage and Power Loss in a Hybrid Brush Seal," ASME Journal of Engineering for Gas Turbines and Power, 131(1), pp. 012505. (ASME Paper GT2008-50532)

2 Kim, T. H., and San Andrés, L., 2009, "Effect of Side End Pressurization on the Dynamic Performance of Gas Foil Bearings – A Model Anchored to Test Data," ASME Journal of Engineering for Gas Turbines and Power, 131(1), pp. 012501. (ASME Paper GT2008-50571)

1 San Andrés, L., and **Kim, T.H.,** 2009, "Analysis of Gas Foil Bearings Integrating FE Top Foil Models," Tribology International, **42**(2009), pp. 111-120.

Peer reviewed Conference publications

(J accepted for journal publication)

ASME Turbo Expo 2009, June 2009, Orlando, FLA

7J San Andrés, L., Delgado, D., and Baker, J., "Rotordynamic Force Coefficients of a Hybrid Brush Seal: Measurements and Predictions," ASME Paper No. GT2009-59072

6J San Andrés, L., Maruyama, A., Gjika, K., and Xia, S., "Turbocharger Nonlinear Response with Engine-Induced Excitations: Predictions and Test Data, " ASME Paper No. GT2009-59108

5J San Andrés, L., and Kim, T.H., "Thermohydrodynamic Analysis of Bump Type gas Foil Bearings: A Model Anchored to Test Data," ASME Paper No. GT2009-59919

4 San Andrés, L., and Ryu, K., "Dynamic Forced Response of a Rotor-Hybrid Gas Bearing System Due to Intermittent Shocks," ASME Paper No. GT2009-59199

3J San Andrés, L., Chirathadam, T. A., and Kim, T.H., "Measurements of Structural Stiffness and Damping Coefficients in a Metal Mesh Foil Bearing," ASME Paper No. GT2009-59315

2J Delgado, D., and San Andrés, L., "Identification of Squeeze Film Damper Force Coefficients from Multiple-Frequency, Non-Circular Journal Motions," ASME Paper No. GT2009-59175

1 San Andrés, L., Kim, T.H., Ryu, K., Chirathadam, T. A., Hagen, K., Martinez, A., Rice, B., Niedbalski, N., Hung, W., and Johnson, M., "Gas Bearing Technology for Oil-Free Microturbomachinery – Research Experience for Undergraduate (REU) Program at Texas A&M University," ASME Paper No. GT2009-59920

Conference Proceedings - Not Peer Reviewed

2 San Andrés, L., Kim, T.H., **Chirathadam, T.A., and Ryu, K**., 2009, "Measurements of Drag Torque, Lift-Off Journal Speed and Temperature in a Metal Mesh Foil Bearing," American Helicopter Society 65th

Annual Forum, Grapevine, Texas, May 27-29, 2009.

1 San Andrés, L., and Kim, T.H., 2009, "Thermohydrodynamic Model Predictions and Performance Measurements of Bump-type Foil Bearing for Oil-Free Turboshaft Engines in Rotorcraft Propulsion Systems," American Helicopter Society 65th Annual Forum, Grapevine, Texas, May 27-29, 2009.

Extended Abstracts

4 San Andrés, L. and **K. Ryu,** 2009, "Experimental Structural Stiffness and Damping in a 2nd Generation Foil Bering for Increasing Shaft Temperatures, ASME/STLE International Joint Tribology Conference, IJTC2009, October 19-21, 2009, Memphis, Tennessee, USA

3 Kim, T.H., L. San Andrés , J. Nourse, J.L. Wade, and D. Lubell, 2009, "Modeling of a Gas Foil Bearing for Microturbine Applications: Predictions versus Experimental Stiffness and Damping Force Coefficients," World Tribology Congress 20009, Kyoto, Japan, September 6-11, 2009

2 **Delgado, A.,** and L. San Andrés, 2009, "Identification of Force Coefficients in a Squeeze Film Damper with a Mechanical Seal: Large Seal Contact Force," World Tribology Congress 20009, Kyoto, Japan, September 6-11, 2009

1 San Andrés, L., **Ashton, Z., and Delgado, A**., 2009, "Comparison of Leakage Performance in Three Types of Gas Annular Seals Operating at High Temperature", 2009 STLE Annual Meeting & Exhibition, May 17-21, 2009, Disney's Coronado Springs Resort, Orlando, Florida, USA

2008

Journal publications (peer reviewed)

5 San Andrés, L., and **Ryu, K.,** 2008, "Hybrid Gas Bearings with Controlled Supply Pressure to Eliminate Rotor Vibrations while Crossing System Critical Speeds," ASME Journal of Engineering for Gas Turbines and Power, Vol. 130(6), pp. 062505-1-10 (ASME Paper GT2008-50393)

4 San Andrés, L., and **Kim, T.H.,** 2008, "Forced Nonlinear Response of Gas Foil Bearing Supported Rotors," Tribology International, **41**(8), pp. 704-715.

3 San Andrés, L., and **K. Ryu,** 2008**,** "Flexure Pivot Tilting Pad Gas Bearings: Operation with Worn Clearances and Two Load-Pad Configurations," ASME Journal of Engineering for Gas Turbines and Power, Vol. 130, pp. 042506-1-10.(ASME Paper No GT2007-27127)

2 San Andrés, L., and **A. Delgado**, 2008, "Squeeze film Damper with a Mechanical Seal: Experimental Force Coefficients Derived from Circular Centered Orbits," ASME Journal of Engineering for Gas Turbines and Power, Vol. 130, pp. 042506-1-8. (ASME Paper No GT2007-27436)

1 **Kim, T.H.,** and L. San Andrés, 2008, "Heavily Loaded Gas Foil Bearings: a Model Anchored to Test Data," ASME Journal of Engineering for Gas Turbines and Power, Vol. 130(1), pp. 012504-1-8. (ASME Paper GT 2005-68486)

Peer reviewed Conference publications

ASME Turbo Expo 2008, June 2008, Berlin

6J **Kim, T.H.,** and San Andrés, L., 2008 "Effect of Side Pressurization on the Performance of Gas Foil Bearings – A Model Anchored to Test Data," ASME Paper GT2008-50571

5J San Andrés, L., **Baker, J.,** and **Delgado, A.,** 2008, "Measurements of Leakage and Power Loss in a Hybrid Brush Seal," ASME Paper GT2008-50532

4J San Andrés, L., and **Ryu, K.,** 2008, "Hybrid Gas Bearings with Controlled Supply Pressure to Eliminate Rotor Vibrations while Crossing System Critical Speeds," ASME Paper GT2008-50393

3J **Delgado, A.,** and San Andrés, L., 2008, "Nonlinear Identification of Mechanical Parameters on a Squeeze Film Damper with Integral Mechanical Seal," Paper GT2008-50528

2 **Kim, T.H.,** San Andrés, L., and **Breedlove, A.,** 2008, "Characterization of Foil Bearing Structure for Increasing Shaft Temperatures: Part II – Dynamic Force Performance," Paper GT2008-50570

1 **Kim, T.H., Breedlove, A.,** and San Andrés, L., 2008, "Characterization of Foil Bearing Structure for Increasing Shaft Temperatures: Part I – Static Load Performance," Paper GT2008-50567

Conference Proceedings - Not Peer Reviewed

2 San Andrés, L., Phillips, S., and Childs, D., 2008, "Static Load Performance of a Hybrid Thrust Bearing: Measurement and Validation of Predictive Tool," 6th Modeling and Simulation Subcommittee / 4th Liquid Propulsion Subcommittee / 3rd Spacecraft Propulsion Subcommittee Joint Meeting. December 8-12, Orlando, Florida, JANNAF-120 Paper (Paper of restricted distribution – Joint Army, Navy, Nasa, Air Force Interagency Propulsion Committee)

1 Kim, T. H., and San Andrés, L., 2008, "Gas Foil Bearings for Oil-Free Microturbomachinery: Effect of Mechanical Preloads on the Rotordynamic Performance," *US-Korea Conference (UKC) 2008 on Science, Technology, and Entrepreneurship*, San Diego, CA.

Extended Abstracts

2 **Kim, T.H.,** and L. San Andrés, 2008, "Effect of Mechanical Preloads on the Dynamic Performance of Gas Foil Bearings", Paper IJTC2008-71195, STLE/ASME International Joint Tribology Conference, Miami, Fla, October 2008

1 San Andrés, L., Baker, J., and Delgado, A., 2008,"Measurement of Leakage and Identification of Structural Force Coefficients in a Hybrid Brush Seal," STLE Annual Meeting & Exhibition, Cleveland, OH, May 19-21.

Student Poster presentations

Four student posters prepared by NSF—Microturbomachinery REU Summer 2008 Program
Students: Alex Martinez (TAMU), Kathleen Hagen (TAMU), Brian Rice (UVA), Nick Niedbalski**,** (Gonzaga University

PUBLICATIONS OF BOOKS OR AUTHORITATIVE REFERENCES

Encyclopedia of Tribology
Squeeze Film Dampers,
Cryogenic Fluid Film Bearings,
Edited by Q. Jane Wang & Yip-Wah Chung, Springer Science+Business Media, LLC, New York, 2009

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