Mechanical Engineering Department
Texas A&M University

2009/2010

Research Progress Report

Tribology Group

Year XIX

30th Annual
Turbomachinery Research Consortium Meeting

May 2010

Luis San Andrés
Leader

http://rotorlab.tamu.edu

Tribology Group

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In late July 2009, Professor Luis San Andrés initiated a Faculty Development Leave in Asia. He witnessed and learned first hand where the future is made today!

Luis spent five months at the National University of Singapore (NUS) where he taught his Modern Lubrication Course and developed a course entitled Principles of Modern Engineering. The class, tailored to young engineering students, teaches those skills needed to succeed in a global engineering world: communication and business practices across cultures, managing a career and engineering management practices, focuses on the practice of innovation, and instills the work attributes and attitudes to keep a job: how to do more with less and how to do things right the first time. The course was extremely successful and will be offered at TAMU as an elective course in Spring 2011.

While in Singapore, Dr. San Andrés visited Malaysia, Vietnam, Indonesia, Thailand, Cambodia, Japan and China. He lectured at Chiang Mai University in Thailand, Xi'an Jiatong University in China, and attended the World Tribology Conference in Kyoto, Japan.

On January 2010, Dr. San Andrés initiated research work at the Energy Mechanics Center of the Korea Institute of Science and Technology (KIST). While spending three months in cold Korea, Dr. San Andrés visited numerous heavy machinery industries, lectured at Seoul National University, Korea University. He also traveled to Beijing (China) where he lectured at Tsinghua University. While at KIST, Dr. San Andrés taught seminars on rotordynamics and foil bearings and also his Modern Engineering Practices focusing on graduate student needs.

The sabbatical leave was most rewarding for Dr. San Andrés learning Asian culture, history and engineering practices. The fast pace development in Singapore and Korea towards knowledge-based societies is amazing! US scientists, academicians and engineers do not realize how far behind we are in novel technologies and applications. Dr. San Andrés enjoyed the food and music everywhere, got used to live in metropolitan cities where inter connectivity (transport and telecommunications) is far ahead of those in Texas. In Asia, government and industrial funding of university research is at least one order of magnitude larger than in the USA.

Dr. San Andrés resumed work at TAMU on April 1. His sabbatical leave was short two months because an industrial sponsor withdrew its support for his work in Shanghai, China. Currently, Dr. San Andrés is developing a bulk-flow code for annular seals operating with gas in liquid mixtures applicable in oil&gas pumps and compressors. He thanks Dr. Childs, Director of the Turbomachinery Laboratory, for granting him the means to conduct the work.

	2010	2009
Published Journal papers (peer reviewed)	7	6
Conference Proceedings (per reviewed)	8	7
Conference Proceedings (not reviewed) & Magazine	0	2
Total	15	15

In 2009/10, students and Dr. San Andrés published **thirty** technical papers (13 journal and 17 conference). The productivity of the research group continues to exceed normal expectations in a *world class* research & education institution.

While in Asia, Dr. San Andrés reduced his research involvement and student mentoring activities at Texas

A&M University. Lack of funding dictated the outcome. In spite of the difficult economic times, Professor San Andrés and students continued to perform research of the utmost quality, doing more with less! Two TRC proposals were funded; however, Dr. San Andrés declined the work in lieu of current TRC project guidelines. Remnant funds from prior TRC funded projects were used to continue research work in foil bearings: bump-type and metal-mesh type. TRC members clearly benefit from more work without additional funding. Please note that any meaningful research project must tap into various funding sources and combine resources to deliver more and exceed expectations.

The current status on the few remaining research projects, the students involved, and the sources of funding follow:

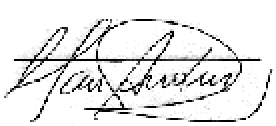
- **Squeeze Film Damper – operation of test rig for high frequency & high load measurements**
  OBJECTIVE: To assess novel SFD designs for aircraft applications.
  STATUS: Test rig operational (500 lbf dynamic force). Measurements and force coefficients identification completed in a 5 inch SFD with central groove. Effect of fluid inertia found to dominate SFD forced response.
  SPONSOR: PRATT & WHITNEY, **$331,000**
  Student: Sanjeev Seshagiri (M.S.), Paola Mahecha (M.S.), James Law (UG)

- **Foil Gas Bearings for Oil-Free Turbomachinery**
  OBJECTIVE: To quantify the performance of bump-type foil gas bearings for micro gas turbines
  STATUS: Completed computational analysis model for thermal management of foil bearings. Measurements of foil bearing performance at high temperatures (max 300 C) currently under way.
  SPONSORS: TRC REMNANT FUNDS USED IN 2009-2010. Cooperation with KIST
  Student: Keun Ryu (Ph.D.)

- **Metal Mesh Foil Bearings for Microturbomachinery**
  OBJECTIVE: identify metal mesh foil bearings rotordynamic force coefficients
  STATUS: High speed (60 krpm) test rig with two orthogonal shaker load excitations constructed and operational. identification of performance and force coefficients in progress.
  SPONSOR : TRC REMNANT FUNDS USED IN 2009-2010
  Student: Thomas Chirathadam (Ph.D.)

- **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: Thirteen selected UG students participated in Summer 2009: two students worked with Tribology Group students. In Summer 2010, two High School teachers will undertake educational research in micro manufacturing.
  SPONSOR: NATIONAL SCIENCE FOUNDATION (2006-2010), **$279,249**
  Investigators: PI: Wayne Hung (Engineering Technology), co-PI: Luis San Andrés

I thank the students for their hard work and progress while I was away. Without their support and patience I could not have enjoyed (and endured) a most rewarding sabbatical leave



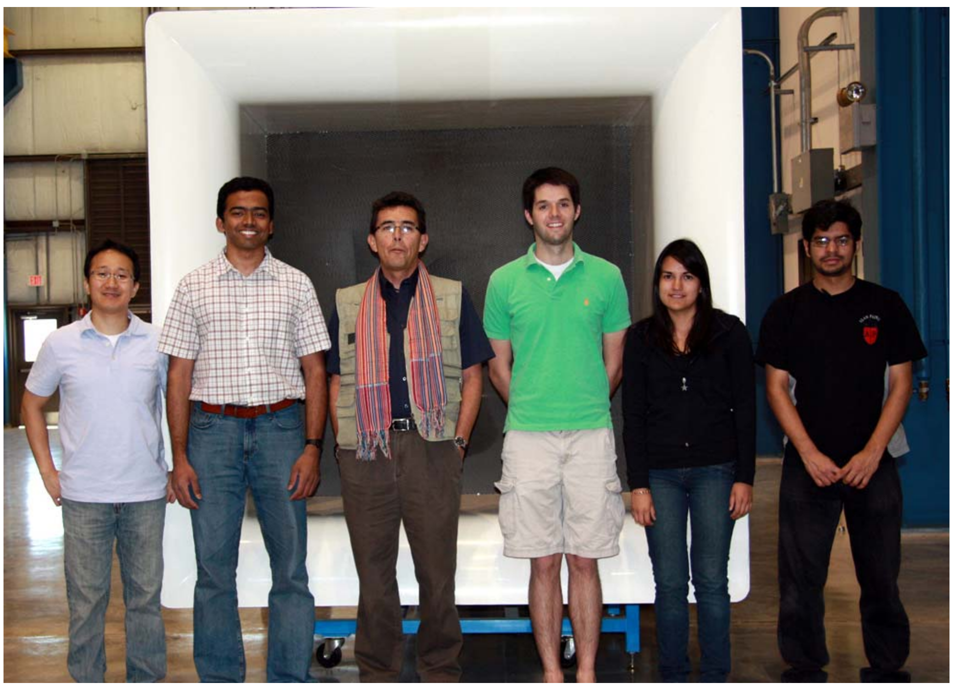
Luis San Andrés, Leader

Tribology Group

Team Members 2009/2010

Name	Research Project	Degree	Graduation date
Keun Ryu	Bump-type Foil Bearings: Measurements of High Temperature Performance	Ph.D .	August 2010
Katherine Janica*+	Nonlinear Force Response of Foil Bearings	B.S.	December 2010
Sanjeev Seshaghiri Paola Mahecha+ James Law	SFD Test Rig & Measurements: Pratt & Whitney	M.S. M.S. B.S.	December 2010 May 2011 May 2011
Thomas Chirathadam	Metal Mesh Foil Bearings: identification of Rotordynamic Force Coefficients	Ph.D.	May 2012

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



Keun Ryu   Thomas Chirathadam   Luis San Andrés   James Law   Paola Mahecha   Sanjeev Seshaghiri

Seminars abroad 2009/2010

During his sabbatical leave, Professor San Andrés presented the following lectures and seminars. In most places, he introduced the Turbomachinery Laboratory research and continuing education activities. He also explained the structure of the Turbomachinery Research Consortium, its objectives and its, members and currently funded research work.

Seoul National University, Seoul, South Korea, "High Temperature Leakage Measurements in Three Types of Gas Seals," March 24, 2010

Doosan Heavy Industries, Pusan, South Korea, "Comparison of Leakage Performance for Three Gas Seal Types Operating at High Temperature," March 17, 2010

Tsinghua University, Beijing, China, "Gas Bearings for Microturbomachinery – an Overview," March 15, 2010

Korea University, Seoul, South Korea, "How to Get the Work Done," March 10, 2010

KAES, Co., Gyeongju, South Korea, "The Turbomachinery Laboratory at TAMU – Overview of Research Capabilities," March 9, 2010

Keyyang, Co., South Korea, "Vehicle Turbocharger Nonlinear Rotordynamics: Modeling and Experiments," February 9, 2010

Korea Institute of Science and Technology, Seoul, Korea

Seminar Series on **Practices of Modern Engineering** tailored to international graduate students

1. Introduction to Modern Engineering Practices – January 21, 2010
2. Engineering Criteria EC 2000 – January 28, 2010
3. The Complete Engineer, February 4, 2010
4. How to get the (graduate) Work Done, February 11, 2010
5. Writing and Reviewing Papers, February 25, 2010
6. Honesty and Integrity, March 4, 2010
7. Ethics in the Workplace, March 11, 2010
8. Intellectual Property and Innovation, March 18, 2010
9. Closure – The Road Ahead, March 25, 2010

National University of Singapore, Singapore

Development of Freshman Seminar on Modern Engineering Practices, December 29, 2009

Advances in sealing technology for power & oil & gas turbomachinery: Comparison of leakage performance for three gas seal types operating at high temperature, November 6, 2009

How to Get the Work Done, October 5, 2009

Chiang Mai University, Chiang Mai, Thailand

Advances in Metal Mesh Foil Bearings for Oil-Free Turbomachinery, November 20, 2009

NASA Glenn Research Center, Cleveland, (delivered from Singapore vie web)

Final Presentation: Thermohydrodynamic Analysis of Bump Type Gas Foil Bearings: A Model Anchored to Test Data," NASA SSRW2-1.3 Oil Free Engine Technology Program, August 26, 2009

Escuela Politécnica Nacional, Quito, Ecuador

Metal Mesh Foil Bearings for Oil-Free Turbomachinery, July 22, 2009

2010 Research Progress Reports

More on Metal Mesh Foil Bearings: Effect of Excitation Frequency on Dynamic Force Co-efficients

TRC-B&C-01-10

Luis San Andrés, Thomas Chirathadam

2010-2011 Research Proposals

	# years	Cost Y1
THRUST FOIL BEARINGS FOR OIL-FREE MICROTURBOMACHINERY	3	$ 44,463
METAL MESH FOIL BEARINGS: PREDICTED & EXPERIMENTAL ROTORDYNAMIC FORCE COEFFICIENTS	2	$ 38,863
MEASUREMENT OF LEAKAGE IN A NOVEL ALL METAL NON-CONTACTING ANNULAR SEAL AT HIGH TEMPERATURES	2	$39,863
AUTOMATED ANALYSIS OF TIME TRANSIENT RESPONSES IN NONLINEAR ROTOR BEARING SYSTEMS	2	$34, 863
COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS	2	$34, 863

PROPOSALS –SUMMARIES

THRUST FOIL BEARINGS FOR OIL-FREE MICROTURBOMACHINERY

The widespread deployment of oil-free microturbomachinery (MTM) supported on gas foil bearings (GFB), radial and axial, relies on overcoming intermittent contact and damaging wear at rotor start up and shut down, temporary rubs during normal operating conditions; and most importantly, with engineered thermal management to ensure GFB performance in high temperature environments. Although, gains have been made in specific loading; high-temperature material limits, coating endurance and stability, and adequate thermal management still restrict application of GFBs into high power density gas turbines. Poor thermal management, eminently empirical and costly, due to inefficient cooling techniques and/or inadequate coatings can lead to catastrophic failure of the entire rotor-bearing system.

An ongoing research program at Texas A&M University, funded by NSF, NASA GRC, turbomachinery manufacturers and end users, has been instrumental in developing engineering design tools, experimentally validated, for prediction of radial GFB performance. The next step is to undertake similar research in thrust foil bearings (TFBs). A three-year research program, analytical and experimental, is proposed to the TRC[1]. The tasks are:

- Development of a computational model for prediction of TFB forced performance, static and dynamic.
- Measurements of TFB forced performance in a revamped high speed test rig for code validation. Tests will evaluate rotor lift and break away torque, touchdown speed and stall torque, TFB axial load versus minimum film thickness and drag power losses, and identification of axial force coefficients (stiffness and damping) over a range of speeds and excitation frequencies

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.

TRC members will benefit from an existing water lubricated thrust bearing test rig ($220,876 in capital equipment) to conduct (gas) thrust bearing load capacity tests at high speeds (30 krpm).

MESH FOIL BEARINGS: PREDICTED & EXPERIMENTAL ROTORDYNAMIC FORCE COEFFICIENTS

Metal Mesh Foil Bearings (MMFBs) are simple and inexpensive gas bearings that provide low friction, long operating life, and material damping for mechanical energy dissipation into high speed rotor bearing systems. Engineered MMFBs will aid to improve system efficiency, raise power density, and lower carbon foot-print when compared to oil-lubricated bearing systems.

The main objective of the MMFB research at TAMU is to develop low cost and reliable gas bearings using commercially available metal meshes. In the next two years, 2010-12, the research tasks include:

a) Measurement of MMFB forced response due to shaker-load excitations and identification of rotordynamic force coefficients for increasing rotational speeds to 70 krpm.
b) Similar measurements conducted on a bump-type foil bearing, first generation. Comparison of static and dynamic load performances.
c) Development of FORTRAN program and EXCEL GUI for prediction of MMFB rotordynamic force coefficients, ready for integration into XLTRC[2]. Predictions will be benchmarked against test data.

[1] A comprehensive proposal with same objective is pending support from National Science Foundation. As in past instances, Dr. San Andrés will combine TRC and federal funds to complete the work.

The results of the research will characterize, both qualitatively and quantitatively, a novel (non proprietary) gas bearing technology of low cost, simple in construction, and suitable for operation at high and low temperatures.

MEASUREMENT OF LEAKAGE IN A NOVEL ALL METAL NON-CONTACTING ANNULAR SEAL AT HIGH TEMPERATURES

Parasitic secondary flows (seals leakage) in centrifugal compressors and gas and steam turbines represent a substantial loss in efficiency and power delivery with an increase in specific fuel consumption. Labyrinth seals (LBS) are the most common and inexpensive means of reducing secondary leakage, albeit wearing out with operation and thereby penalizing performance and even affecting rotordynamic stability. Presently, there are other seal types that can perform better in terms of leakage reduction and low drag power losses.

The HALO™ seal [Hydrostatic Advanced Low Leakage] is an all metal compliant seal engineered to close its clearance as pressure differentials increase. Laboratory measurements show an impressive reduction in leakage, 33% of that in a hybrid brush seal and 14% of the flow in a labyrinth seal! Industries seeking to increase efficiency by reducing (parasitic) secondary leakage losses will benefit greatly from a change in seal technology.

A two-year research program is proposed with the following tasks:

a) Revamp test rig for operation at higher rotor speeds to reach a tip surface speed of 120 m/s (15 krpm). Modifications include replacing the drive motor, stiffening the rotor and implementing gas bearings. Sealing of the bearing compartments at high temperature will be particularly difficult.

b) Perform clearance and leakage measurements with a three teeth labyrinth seal and the HALO™ seal operating with pressure ratios as high as 5 bar, temperatures to 300ºC, and tip surface speeds to 120 m/s.

c) Compare the labyrinth seal measured leakage with XLLABY® predictions at high temperatures. The benchmarking is essential to trust, modify or discard current predictive models.

The research product –a reliable leakage data base- will enable the application of state of the art sealing technology that increases system efficiency by reducing leakage and that extends maintenance intervals by eliminating wear of components.

TRC members will readily benefit from an existing high temperature seal test rig fully instrumented ($75,000 cost in capital equipment) to conduct (short seal) seal leakage measurements up to 300ºC. Labyrinth seals are an outdated technology.

AUTOMATED ANALYSIS OF TIME TRANSIENT RESPONSES IN NONLINEAR ROTOR BEARING SYSTEMS

XLTRC^2© is a comprehensive GUI tool for the prediction of the dynamic response of realistic rotor-bearing systems (RBS). The tool includes linear analyses such as generation of critical speed maps, prediction of eigenvalues (critical speeds and damping ratios) and imbalance response, rotor static and synchronous motion deflected shapes, and generation of reports as per API 610 requirements. The nonlinear tool, presently incorporating a few simple nonlinearities that include the short length journal bearing model, integrates the equations of motion of the rotor-bearing system and calculates the RBS time response for a variety of loads: mass imbalance, maneuver and User specified. XLTRC^2© outputs the predictions in tabular form and graphs depicting the rotor motion, at specified stations, versus time. The amount of data generated in a transient time response case is exceedingly large, i.e. tens of thousands of data points revealing little of the desired features expected when performing a nonlinear analysis. These features include the frequency content of the rotor motions and the mode shapes at selected frequencies. Furthermore, XLTRC^2©is constrained to single speed (range) operation which forestalls its use as an analysis tool generating waterfall plots, for example.

A two year project is proposed to develop GUIs integrated into XLTRC^2 nonlinear analysis feature to perform automated (point & click)

a) Multiple case rotor speed transient RBS responses with efficient data storage.
b) **Post-processing:** worksheet for FFT analysis of predicted RBS motions with generation of waterfall graphs and display of rotor motion amplitudes versus whirl frequency and rotor speed(s) (see Fig. 2)
c) Generation of 3D rotor operating deflected shapes within specified frequency ranges to verify modal conditions and strain energy distribution.
d) Upgrading XLTRC^2 Finite Element code XL_PressDam_TH®, released in 2009, into an impedance model for prediction of instantaneous bearing reaction forces as a function of journal center position (X,Y) and velocities (V_X,V_Y). XL_PressDam_TH® models radial bearings with multiple pads (offset and preload) and pressure dam bearings. A squeeze film damper option, i.e. without journal or bearing rotation, will be built into the updated code. This feature will enable modeling semi-floating ring bearings.

The products of the research will enable TRC members to use efficiently XLTRC^2 for frequency domain analysis of the time response of nonlinear RBS. The research is of immediate applicability into high speed RBS such as turbochargers, for example.

TRC members will benefit from the vast experience accumulated during nine years of work funded by a major TM OEM.

COMPUTATIONAL MODEL FOR TILTING PAD JOURNAL BEARINGS

Accurate prediction of the static and dynamic forced performance of tilting pad journal bearings is necessary to design, troubleshoot and predict the dynamic response and stability of rotor-bearing systems. XLTRC^2 software suite includes a computational code for prediction of tilting pad bearings static operation and frequency reduced stiffness and damping force coefficients.

Childs and students have conducted measurements of rotordynamic force coefficients for a number of industrial type tilting pad journal bearings, including a flexure pivot configuration. In general, predicted force coefficients, stiffness and damping, correlate well with the measurements for small to moderate specific loads (up to 150 psi [10 bar]). The measurements evidence the bearing stiffness force coefficients to be strongly frequency dependent, best represented with a **K**-**M** model. Damping coefficients are adequately represented with magnitudes not depending on frequency. In a heavily loaded condition, poor correlation of predictions to measured force coefficients is evident. Rationale for the significant discrepancies lies on the model not accounting for the bearing' pads pivot stiffness. The model assumes an ideal pivot configuration without friction and infinitely rigid along the radial direction. Furthermore, the computational model does not calculate the effective film clearance, which is affected by both mechanical and thermal deformations under heavy loaded conditions.

A two-year project is proposed to enhance an existing computational tool for accurate prediction of tilting pad bearing force coefficients for heavily loaded operating conditions. The upgraded model will include pivot flexibility, typically nonlinear, for a number of pivot type configurations, with specification of sliding or rolling contact conditions. In addition, the model will include simple formulations for estimation of the operating clearance as a function of local thermal expansion and mechanical deformation.

The upgraded computational program will enable TRC members to model accurately realistic tilting pad configurations. The computer code will be integrated into XLTRC^2 for ready use. A technical report detailing the model enhancements as well as comparisons to the test data of Childs et al. will be delivered at the end of the project. The GUI will be revamped for more expedite computational predictions with physically reasonable starting initial *guesses* to reduce the burden on the unseasoned user.

Tribology Group - Funded Research **2009-2010**

External NEW funds (09-10) $ 153,509+$ 20,000

Sponsor Project #	Amount	Project	Dates(GS support)
PRATT & WHITNEY	$185,577+ **$153,509**	Squeeze Film Damper – design of test rig for high frequency & high load operation	07/01/08 – 12/31/10 (2)

Sponsor Project #	Amount	Project	Dates (GS support)
National Science Foundation 32525/35430/ME	$ 259,249 + **$20,000**	Research Experiences for Undergraduates: Development of Microturbomachinery	2 HS teachers 2010

Internal, $0,0 (TRC) - funding for projects declined and used remnant funds from past years

Sponsor	Amount	Project	Dates
TRC 32514/1519B4/ME	$0	SFD – Multiple Frequency Excitation	declined
TRC 32514/1519C4/ME	$0	Rotordynamic Performance of Foil Gas Bearings: High Temperature Tests and Analysis	Declined

Sponsor	Amount	Project	Dates
TAMU	**$8,000**	Faculty Development Leave – Travel Expenses	07/09-04/10

Research Expenditures Fiscal Year 2009: ~ $ 459,736.

Source: TEES portal 01/02/2010

Tribology Group Publications 2009/2010

	2010	2009	2008	2007	2006	2005
Published Journal papers (peer re-viewed)	**7**	**6**	**5**	14	6	2
Conference Proceedings (per reviewed)	**8**	**7**	**6**	6	6	7
Conference Proceedings (not reviewed) & Magazine	**0**	**2**	**2**	1+1	2	4
Total	**15**	**15**	**13**	**22**	**14**	**13**

+ 7 in print journal papers (2010)

below **bold face**=student co-author

2010

Journal publications (peer reviewed)

1 San Andrés, L., and **Ashton, Z.,** 2010, "Comparison of Leakage Performance in Three Types of Gas Annular Seals Operating at (300ºC) High Temperature, STLE Tribology Transactions, Vol. 53(3), pp. 463

2 San Andrés, L., **Delgado, D.,** and **Baker, J.,** 2010, "Rotordynamic Force Coefficients of a Hybrid Brush Seal: Measurements and Predictions," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042503** (ASME Paper No. GT2009-59072)

3 San Andrés, L., and **Kim, T.H.,** 2010, "Thermohydrodynamic Analysis of Bump Type Gas Foil Bearings: A Model Anchored to Test Data," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042504** (ASME Paper No. GT2009-59919)

4 **Delgado, D.,** and San Andrés, L., 2010, "Identification of Squeeze Film Damper Force Coefficients from Multiple-Frequency, Non-Circular Journal Motions," ASME J. Eng. Gas Turbines Power, Vol. 132 (April), p. **042501** (ASME Paper No. GT2009-59175)

5 **Kim, T. H.,** and San Andrés, L., 2010, "Thermohydrodynamic Model Predictions and Performance Measurements of Bump-Type Foil Bearing for Oil-Free Turboshaft Engines in Rotorcraft Propulsion Systems," ASME Journal of Tribology, Vol. 132(January), p. **011701**

6 San Andrés, L., **Maruyama, A.,** Gjika, K., and Xia, S., 2010, "Turbocharger Nonlinear Response with Engine-Induced Excitations: Predictions and Test Data," ASME J. Eng. Gas Turbines Power, Vol. 132(March), p. **032502** (ASME Paper No. GT2009-59108)

7 San Andrés, L., **Chirathadam, T. A.**, and Kim, T.H., 2010, "Measurements of Structural Stiffness and Damping Coefficients in a Metal Mesh Foil Bearing," ASME J. Eng. Gas Turbines Power, Vol. 132(March), **032503** (1-7) (ASME Paper No. GT2009-59315)

Peer reviewed Conference publications

(J accepted for journal publication)

1J Hung, W., San Andrés, L., and Leon, V.J., 2010, "Research Experiences for Undergraduates in Micro-manufacturing", Paper AC 2010-2373, ASEE Annual Conference and Exposition, Louisville, KY, June

2 San Andrés, L., and **Vistamehr, A.,** 2010, "Nonlinear Rotordynamics of Vehicle Turbochargers: Parameters Affecting Sub Harmonic Whirl frequencies and Their Jump," Proc. of the 8th IFToMM International Conference on Rotordynamics, September, Seoul, Korea, Paper P-1115

3 San Andrés, L., **Camero, J., Muller, S., Chirathadam, T.,** and **Ryu, K.,** 2010, "Measurements of Drag Torque, Lift Off Speed, and Structural Parameters in a 1st Generation Floating Gas Foil Bearing", Proc. of the 8th IFToMM International Conference on Rotordynamics, September 2010, Seoul, Korea, Paper P-1113.

ASME Turbo Expo 2010, June 2010, Glasgow, Scotland

4J San Andrés, L., **Ryu, K.,** and Kim, T-H, "Thermal Management and Rotordynamic Performance of a Hot Rotor-Gas Foil Bearings System. Part 1: Measurements", ASME paper GT2010-22981

5J San Andrés, Kim, T-H, and **Ryu, K**., "Thermal Management and Rotordynamic Performance of a Hot Rotor-Gas Foil Bearings System. Part 2: Predictions Versus Test Data," ASME paper GT2010-22983

6J San Andrés, L., and **Chirathadam T.A.,** "Identification of Rotordynamic Force Coefficients of a Metal Mesh Foil Bearing Using Impact Load Excitations," ASME paper GT2010-22440

7J Howard, S., and San Andrés, L., "A New Analysis Tool Assessment for Rotordynamic Modeling of Gas Foil Bearings," ASME paper GT2010-22508

8 San Andrés, L., **Niu, Y.,** and **Ryu, K,** "Dynamic Response of a Rotor-Hybrid Gas Bearing System Due To Base Induced Periodic Motions," ASME paper GT2010-22277

2009

Journal publications (peer reviewed)

1 **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)

2 **Kim, T.H**., **Breedlove, A.,** and San Andrés, L., 2009, "Characterization of Foil Bearing Structure at Increasing Temperatures: Static Load and Dynamic Force Performance," ASME Journal of Tribology, Vol. 131(3), pp. 041703-(1-9)

3 **Kim, T.H.,** and San Andrés, L., 2009, "Effects of a Mechanical Preload on the Dynamic Force Response of Gas Foil Bearings - Measurements and Model Predictions," Tribology Transactions, Vol. 52, pp. 569-580

4 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)

5 **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) **2009 Best PAPER Rotordynamics IGTI Structures and Dynamics Committee**

6 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

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

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