Magnetic Bearing Systems
– Design and Industrial Applications

All New Industrial Short Course/Training Program

October 3-5, 2017

Sponsored By: Rotor Bearing Solutions International, Charlottesville, Virginia

Industrial Applications

Compressors, Turbines, Motors, Generators
Energy Storage Flywheels, Turbo Aerators
Refrigeration Motor-Compressors
Waste Heat Turbine Generators
Turbomolecular Vacuum Pumps
Artificial Hearts

Topics

Magnetic Bearing Operating Principles
AMB Design, Magnetic Circuits, Magnetomotive Force,
Airgaps, Magnetic Materials, Wire Sizing,
Load Capacity, Number of Poles,
Amplifiers, Simple Tilt-Translate Controls,
Know Your AMB System,
Digital Controller Specifications, Modern Controls,
Sensitivity Functions, API/ISO Standards,
Auxiliary Bearing Design, Rotor Drop Modeling,
Surge Control, Rotor Identification

New Magnetic Bearing Design Software - MagDes

A detailed RBSI new active magnetic bearing design software MagDes package will be described in this short course and will be available for long term lease by industrial firms or university labs. It will evaluate the magnetic and electrical properties of both radial and thrust bearing geometries based on suitable user inputs. These inputs include shaft diameter, desired bearing length, magnetic material, coil wire size, and required bearing load capacity. The software then evaluates the remaining stator and rotor geometries including lamination dimeter, stator outer diameter, pole configuration, and coil winding geometry. A detailed magnetic circuit model then verifies the design load

capacity through finite element analysis. The software includes both 8 pole and 12 pole (E-core) radial bearing stator designs. The thrust bearing designs are double acting with 2 poles on each side of the thrust disk and a coil in the center of each stator side. The software evaluates the magnetic flux density in the bearing rotor and stator, including both bias flux and control fluxes, and calculates the resulting bearing forces. The magnetic bearing current gain and open loop stiffness values are evaluated, as well as force slew rate, coil inductance, and actuator bandwidth. The results can be easily printed out or plotted for easy evaluation or reporting purposes. The MagDes software will be available for perpetual lease at a one-time cost, yet to be determined. Then a 10% annual maintenance and upgrade fee is available.

Course Description, Objectives, and Lecturers

This magnetic bearing systems short course is intended for engineering staff of companies interested in understanding or using magnetic bearings, and for company employees whose companies use magnetic bearings but do not understand them well. The use of magnetic bearings is increasing in industrial applications but they are often not well understood by mechanical engineers. This course will provide the basic background in electro-magnetic systems and controls. Details of industrial applications of magnetic bearing industrial machines are presented in the course. A number of basic and advanced topics on magnetic bearing design and feedback control are provided but it is not expected that attendees are experts in control theory. New permanent magnet bias bearing designs, recently developed by Rotor Bearing Solutions International, for lowering both the costs and operational power losses of magnetic bearings are presented. Finally, a few additional topics on modern control for flexible shaft-AMB machines such as high pressure compressors and surge control in compressors using magnetic bearings are presented. API/ISO specifications for magnetic bearing supported rotating machines are presented. The details of rotor dynamic analysis of rotor drops on auxiliary bearings are presented for various examples. The use of mathematics in this short course is minimized and, when discussed, is used primarily to indicate technical points of use in the solution.

Lecturers

1. **Paul Allaire, Chief Technical Officer, Rotor Bearing Solutions International Professor, University of Virginia, Retired – Long Time Director of Rotating Machinery and Controls Laboratory, Ph. D. Northwestern University, ASME Fellow**
2. **Brad Nicholas, Senior Engineer, M. S. University of Virginia, Ph.D. August, 2017, University of Virginia**
3. **Jianming Cao, Director of Rotor Dynamics and Manager of China Region, Rotor Bearing Solutions International, Ph. D. University of Virginia**
4. **Tim Dimond, PE, President, Rotor Bearing Solutions International, Ph. D. University of Virginia, Formerly – Principal Scientist, Rotating Machinery and Controls Laboratory, University of Virginia**
5. **Saeid Dousti, RBSI Senior Fellow, Ph. D. University of Virginia**

The course lecturers and contributors have the combined experience and ability to explain rotor-AMB systems making this short course unlike any other short course found in today's world.

Paul Allaire has 48 years of experience in research and teaching rotor dynamics and magnetic bearings. He has taught more short courses on magnetic bearings to engineers in industry than anyone else. He has refined the basic lectures on magnetic bearings over the past 30 years as well as built the largest academic AMB laboratory in existence.

Brad Nichols is a Senior Engineer for RBSI carrying out magnetic bearing design and field installation and on site testing for industrial firms. He will also complete his Ph. D. on magnetic bearing testing of rotor- fluid film bearing systems at the University of Virginia in August, 2017.

Jianming Cao is the Director of Rotor Dynamics as well as Manager of the China Region. He has worked on nonlinear transient rotor dynamics for the past 10 years, including rotor drop modeling of AMB systems. He also designs auxiliary bearings for industrial magnetic bearing systems. He does on site work with magnetic bearing systems for industrial firms. Previously, he received his BS and MS degrees from Harbin Institute of Technology. Also, he has worded in the nuclear industry.

Tim Dimond is the President of RBSI and formerly was the Principal Scientist of the ROMAC Laboratory. He also worked for 9 years as a design engineer at Newport News Shipbuilding. He has now been in magnetic bearings research over the past 10 years and participated in numerous AMB short courses.

Saeid Dousti is an expert on water and other low viscosity lubricated bearings, squeeze film dampers, turbocharger bearing designs, bearing software and magnetic bearing design software. He got his Ph. D. from the University of Virginia.

Additional Training Program Talk Contributors

1. **Simon Mushi, Director of Magnetic Bearings and Controls, Rotor Bearing Solutions International, Ph. D. University of Virginia**
2. **Pablo Yoon, Assistant Professor, University of New Hampshire, Ph. D. University of Virginia**
3. **Arun Kailasan, Magnetic Bearing Specialist, Gardner Denver, Ph. D. University of Virginia**
4. **Christian Klatt, Business Development Specialist, CEROBEAR GmbH**

Day 1 – Tuesday, October 3, 2017

9:00 a.m. -9:20 a.m. – On Site Registration

Session 1 – Introduction to Magnetic Bearings

Time	Talk	Title	Authors
9:20–9:55	1	Introduction to Magnetic Bearings	Paul Allaire
9:55-10:35	2	Initial Levitation Testing and Design of Magnetic Bearings for High Speed Turbo Aerator	Paul Allaire (with Simon Mushi, Tim Dimond, Brad Nichols, Jianming Cao, Kinetic Traction Personnel)
10:35-10:50		Break	

Session 2 –Basic Concepts and Design

Time	Talk	Title	Authors
10:50-11:25	3	Design of Active Magnetic Radial and Thrust Bearings for High Speed Turbo Aerator	Brad Nichols (with Paul Allaire, Tim Dimond, Jianming Cao, Kinetic Traction Personnel)
11:25-12:00	4	Electromagnetic Fields, Flux, and Material Properties	Paul Allaire
12:00-1:30		Lunch (On Your Own)	

Session 3 –Basic Magnetic Bearing Design

Time	Talk	Title	Authors
1:30-2:00	5	Magnetic Actuator Properties	Tim Dimond

Session 4 – Control of Magnetic Bearings and Standards - 1

Time	Talk	Title	Authors
2:00-2:35	6	Design and Tilt-Translate PID Control of Magnetic Bearings in a High Speed Industrial Motor – Part 1	Paul Allaire (with Simon Mushi)
2:35-3:10	7	Design and Tilt-Translate PID Control of Magnetic Bearings in a High Speed Industrial Motor – Part 2	Paul Allaire (with Simon Mushi)
3:10-3:30		Break	

Session 5 – Control of Magnetic Bearings and Standards – 2

Time	Talk	Title	Authors
3:30-4:00	8	Control and Sensitivity Functions for Magnetic Bearings – ISO/API Vibration Standards	Tim Dimond (with Simon Mushi)
4:00-4:30	9	Principles of Digital Electronic Control Hardware	Tim Dimond (with Simon Mushi)

Session 6 – Magnetic Bearing Materials and Load Capacity

Time	Talk	Title	Authors
4:30-5:00	10	Magnetic Bearing Materials and Design	Tim Dimond

Day 2 – Wednesday, October 4, 2017

Session 7 – Auxiliary Bearings

Time	Talk	Title	Authors
8:30-9:10	11	Rotor Drop Analysis and Auxiliary Bearing Design	Jianming Cao
9:10-9:50	12	Rotor Drop Analysis and Auxiliary Bearing System Optimization	Jianming Cao
9:50-10:20	13	Experimental Validation and Improvement of Rotor Drop Analysis	Jianming Cao
10:20-10:40		Break	

Session 8 – New Low Cost, Permanent Magnet Bias, Magnetic Bearings

Time	Talk	Title	Authors
10:40-11:20	14	New Permanent Magnetic Bias, Low Cost Thrust AMB Design	Brad Nichols (with Paul Allaire and Tim Dimond)
11:20-12:00	15	New Radial Permanent Magnet Bias, Low Cost AMB Design	Brad Nichols (with Paul Allaire and Tim Dimond)
12:00-1:15		Lunch (On Your Own)	

Session 9 – Understanding Your AMB System

Time	Talk	Title	Authors
1:15-1:40	16	Power Losses in Magnetic Bearings	Brad Nichols
1:40-2:20	17	Design of High Load Capacity Magnetic Bearing	Tim Dimond
2:20-3:00	18	Design and Characterization of Flexible Rotor on Active Magnetic Bearings	Paul Allaire (with Simon Mushi)
3:00-3:15		Break	

Session 10 – Energy Storage Flywheel Design

Time	Talk	Title	Authors
3:15-4:00	19	High Speed Energy Storage Flywheel Design – Composite Rotor, AMB Support System, Motor-Flywheel-AMB System Design	Paul Allaire (with Arun Kailasan)

Session 11– RBSI Magnetic Bearing Design Code Examples

Time	Talk	Title	Authors
4:00-4:30	20	Use of RBSI Magnetic Bearing Design Code - MagDes	Brad Nichols (with Saeid Dousti)
4:30-5:00	21	Input and Output Files for Magnetic Bearing Design Code - MagDes	Saeid Dousti (with Brad Nichols)

Day 3 – Thursday, October 5, 2017

Session 12 – Other AMB Applications

Time	Talk	Title	Authors
8:30-9:10	22	Magnetic Bearings for Human Artificial Hearts	Paul Allaire
9:10-10:00	23	Measurement of Compressor Rotor/Tilting Pad Bearing Stability and Bearing Starvation with AMB Excitation	Brad Nichols

Session 10 – Test Rigs

Time	Talk	Title	Authors
10:00-10:45	24	Test Rigs for Magnetic Bearings	Brad Nichols

Session 12 – Surge Control

Time	Talk	Title	Authors
10:45-11:20	25	Test Rig with Magnetic Bearings in Centrifugal Compressor	Paul Allaire (with Pablo Yoon)
11:20-12:00	26	Surge Control with Magnetic Bearings in Centrifugal Compressor	Paul Allaire (with Pablo Yoon)
12:00-1:30		**Lunch (On Your Own)**	

Session 13 – Modern (Advanced) Control of Flexible Rotors

Time	Talk	Title	Authors
1:30-2:10	27	Modern Control of Flexible Rotors	Paul Allaire (with Simon Mushi)
2:10-3:00	28	Advanced Control of Compressor Flexible Rotor With Destabilizing Cross Coupled Stiffness	Paul Allaire (with Simon Mushi)

Session 14 – Optional Session – Custom Design of Your Magnetic Bearings and Control System

Time	Talk	Title	Authors
3:00-5:00		**Individual Company Meetings with RBSI Staff – As Desired**	

End of Course

- Small Agenda Changes May Occur In the Final Short Course Talks and Notes

Registration and Fees

Advanced registration for the short course should be sent to Dr. Tim Dimond at tim.dimond@rotorsolution.com or Rotor Bearing Solutions International (RBSI), 3277 Arbor Trace, Charlottesville, Virginia, 22911. Additional information is given on the Rotor Bearing Solutions International website at www.rotorsolution.com. The RBSI telephone number is 434-632-8469 or 434-284-1850 (cell).

The fee for the course for the first person from a company is $1,000, with advanced registration or $1,100 on site. The fee for the second or third person from the same company is $750 per person with advanced registration or $850 on site. Seating for the short course is limited so early registration is recommended. On-site registration payments can be made with cash or credit card. If requested in advance via a purchase order, billing to an individual company will be accepted.

Lecture Materials and Continuing Education Credit

The material for all talks will be provided to attendees on a memory stick. Detailed questions on the course topics in particular and magnetic bearings in general will be answered. Certificates for 17 PDHs (professional development hours) will be provided for attendees of the short course.

Conference Hotel

A conference hotel in Charlottesville will be booked soon. The lectures will be held at the hotel conference room and guest rooms reserved in the hotel. The attendees are responsible for registering at the hotel on their own. More detailed information about the hotel and room reservation information will be available soon on the RBSI website.