ROMAC NEWSLETTER
November 1991

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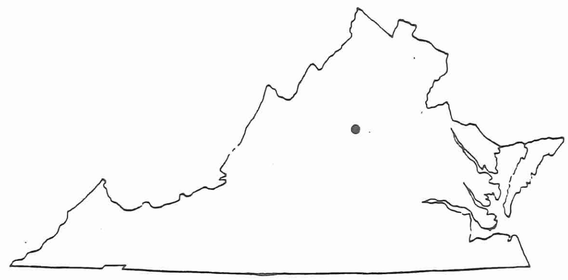
12th ANNUAL ROMAC INDUSTRIAL CONFERENCE

The 12th Annual ROMAC Meeting will be held June 21–25, 1992 at the Omni Hotel, Charlottesville, Virginia. We will be sending out registration materials next Spring, and we look forward to seeing all of you again.



ROMAC INDUSTRIAL COMPANIES

Current list of companies as of November 1, 1991 (* denotes new member).

1. A–C Compressor Corp.
2. Air Products & Chemicals
3. Amoco Corp.
4. * B&W Nuclear Technologies
5. Brush Electrical Machines Ltd.
6. Byron Jackson
7. * Carrier Corporation
8. CentriMarc Corporation
9. CONMEC Group
10. Cooper Industries
11. Cooper Industries – Turbo Compressor Div.
12. Dow Chemical Company
13. Dresser Rand Company
14. Dresser – Pump Div.
15. Dresser Rand – Steam Turbine Div.
16. Duke Power
17. E. I. du Pont de Nemours & Co., Inc.
18. Elliott Company
19. Exxon Chemical Co.
20. General Electric
21. General Motors
22. Glacier Metal Co. Ltd.
23. IMO Delaval
24. Kingsbury Inc.
25. KMC Inc.
26. Mafi–Trench
27. Magnetic Bearings Inc.
28. * Miniature Precision Bearings Co., Subsidiary of the Timken Co.
29. * Mitsubishi Heavy Industries
30. Mobil Research and Development
31. NEI Ltd.
32. NOVA Alberta Corporation
33. Ontario Hydro
34. Orion Corporation
35. Pacific Gas and Electric
36. Petrobras
37. Phillips Petroleum
38. Pratt and Whitney
39. Radian Corporation
40. Shell Development Co.
41. Societe Europeene de Propulsion
42. Solar Turbines International
43. Southwest Research Institute
44. Sundstrand
45. Texaco
46. Tong Yang Cement Corporation
47. * Turbo Components and Engineering
48. Union Carbide Corp., Linde Division
49. Vibrakon Ltd.
50. Washington Public Power
51. Waukesha Bearings

FACULTY/STAFF CHANGES

* **Ted Brockett**, Laboratory Research Engineer
* **William T. Korn**, Programmer/Analyst
* **Paige T. Rohmann**, ROMAC Secretary
* **Sandra F. Maslen**, Conference Coordinator

NEW DIRECTOR

Ron Williams has agreed to serve as ROMAC Director for three years beginning July 1, 1992.

SHORT COURSES

Short courses on rotor dynamics and fluid film bearings will be offered in February and March 1992, respectively. Please see the enclosed flyers for details and registration information.

STUDENT SUPPORT

The ROMAC program currently has 35 graduate students working on various projects. Support for these students is provided by a combination of ROMAC fees, fellowships and contracts, and Center for Magnetic Bearing funds.

NEW STUDENTS

Bill Wakefield, Undergrad w/P. Allaire

Masters
Peter Allan, w/Carl Knospe
Klaus Brun (January), w/R. Flack
Chris Doane, w/R. Flack
Holger Herbert, w/R. Flack
B.J. Lim, w/P. Allaire
Jeanette Smith, w/L. Barrett

MAG '92/Third International Symposium on Magnetic Bearings – July 29–31, 1992

You should have recently received an Announcement and Call for Papers outlining the program for this Conference and Exhibition. Please feel free to pass this brochure to your colleagues who may wish to attend. Thanks.

Magnetic Bearings – Magnetic bearings are becoming more widely accepted in industry for the support of rotating shafts. They can provide the advantages of free operation, no friction losses, long life and enhanced vibration control Magnetic bearings may be applied in many fields.

Magnetic Drives – A magnetic drive is a rotary mechanical device which uses magnetism to couple the drive input and output shafts without physical contact. Sizes up to several hundred Hp are available and "canning" of the drive unit is possible in order to separate the working area from the driving mechanism. With increasing EPA emissions regulations, canned magnetic drives and magnetic bearings together constitute a viable solution to the emissions problem.

Dry Gas Seals – Mechanical dry gas seals have been in existence for about 10 years and are a proven technology. They not only eliminate oil contamination with centrifugal pumps for pipelines, but improve the reliability and efficiency of the seal–bearing system and reduce the risk of fire. They are a natural companion with magnetic bearings in gas pipeline compressors and other applications.

CENTER FOR MAGNETIC BEARINGS

The Center for Magnetic Bearings, which was established by the University School of Engineering and Applied Science and Virginia's Center for Innovative Technology (CIT) in July 1989, received $300,000 from CIT for the period July 1991–June 1992. This is the third year of the Center, and we anticipate some funding from CIT for an additional two years. Our funding from CIT for the first three years is over $1,000,000.

CONTACT LIST UPDATES

Enclosed with this Newsletter you will find a copy of the most recent Contact List. This list is used to send out not only this Newsletter but also invitations to Annual Meetings and any other ROMAC mailings. Please make additions, deletions and/or corrections and return as soon as convenient to Paige Rohmann by E–Mail (romac@virginia.edu), FAX (804–982–2037 or U.S. mail.

COMPUTER NEWS – Toby Korn

We are endeavoring to make your life easier by making ROMAC programs more user friendly and to allow more flexibility.

We are currently developing a scripted editor which will allow data files to be interactively edited and also to allow for automatic transfer of data from one ROMAC program to another. This will eliminate the painstaking task of lining up data in the proper rows and columns manually and also of retyping data created by one program into the file format of another program.

We will be creating a shell program to manage ROMAC programs and data files which will work closely with the scripted editor.

Another exciting development is that ROMAC codes will be available as Microsoft Windows 3.0 applications. This will allow us to run larger models than before as well as allow multitasking.

Many of the updated ROMAC codes will have the added feature of accepting command line arguments. We have used command line arguments to input data file names and parameters to redirect output. This will allow batch processing.

In order to make access to ROMAC programs easier for ROMAC members, we are making programs available over the INTERNET network and are looking into using a MODEM dial–in line. Please be sure to let us know if you have an INTERNET connection or a MODEM at your disposal.

The following ROMAC programs have recently been upgraded:

MODFR2 Version 2.31
Units of measure options were added for English units, SI units, and non–unit.

THBRG Version 2.0 (Lyle Branagan)
Two major changes were implemented. First, the position iteration search was revamped to fix an inconsistency. As a result, a relaxation factor [RELAX: range 0–1, default 1.0] and a perturbation factor [FACT: range > 1.0, default 1.0] are now used in the position update. Note, versions 1.2 and following include the option to defeat any position iteration. Second, several changes in the standard output can be seen, including increased significant digits (for smaller bearings), a turbulence check, a check for a 360 degree bearing, and a crude prediction of heat rise (deltaT * GPM). In addition, the program now accepts the data file name on the command line.

THPAD Version 2.11, 10/30/91
Version 2.0 Update (Lyle Branagan): Four major changes were implemented. First, the position iteration search was revamped to fix and inconsistency. As a result, a relaxation factor [RELAX: range 0–1, default 1.0] and a perturbation factor [FACT: range>1.0, default 1.0] are now used in the position update. Note, versions 1.2 and following include the option to defeat any position iteration. Second, the thermal deformation model was enlarged to allow for separate thermal coefficients of expansion for the journal, pads, and shell and to allow for the inclusion of a reference temperature (at which 'cold' clearances are set). Third, the pivot rotational degrees of freedom are modified to allow for a rotational stiffness [KTHETA] and an initial set angle [DEL0]. Fourth, several changes in the standard output can be seen, including increased significant digits (for smaller bearings), a check for a 360 degree bearing, and a crude prediction of heat rise (deltaT * GPM). In addition, the program now accepts the data file name on the command line.
Version 2.1 Update:
THPAD can now create a Tilting–Pad Bearing Coefficient file for use with ROTSTB Version 4.xx. Command line options have been added for input file name, output file name, and output to a printer.

SIF 'Scripted Interactive Filter': Input screens are available for THPAD and THBRG using SIF (Lyle Branagan).

TWIST

TWIST2 Version 2.0

TWIST2 Ver. 2.1 (Expected January 1, 1991) – Torsional Critical Speed and Forced–Response Analysis. TWIST2 Version 2.1 will be an upgraded version of TWIST2 Version 2.0. It will automatically scale the modeshape and forced–response output for rotors in the model not running at the reference speed.

ROTSTB Version 4.1

ROTSTB Ver 4.1 – Lateral Stability of Single Spool Rotor ROTSTB has been updated to include tilting–pad bearing models represented by their (NP+2) x (NP + 2) stiffness and damping matrices, (NP = Number of pads). ROTSTB now operates in double precision and should give significantly more accurate results. In addition, a more accurate method of iterating to the damped natural frequencies has been implemented. The modeshape calculations have been changed to reflect the coordinate system used at ROMAC and not Lund's coordinate system. The rotor cross–section plots have also been enhanced and modeshape plots are possible.

FLEXCOP Version 1.1

Translated from CDC version.

FSTB3 Version 1.2 PC

Version with better precision than older versions. PC Version has smaller dimensions than the original CDC Version in order to fit under DOS. If you have trouble running larger models, the Windows 3.0 version W1.21 solves this problem.

FSTB3 Version W1.21

Microsoft Windows Version

We were able to increase the dimensions to the original CDC sizes.

PTEMP Version 1.1

Translated from CDC version. Command line arguments added for file name input.

MAGDES–2 Version 1.0

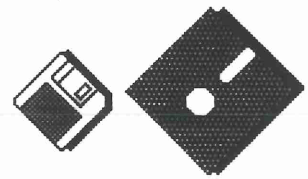
See ROMAC report #321

FRESP2 Version 2.2

The maximum number of couplings was increased from 15 to 30. The GEOGRAF plotting options menu was simplified. NOTE: This larger program requires more memory than the previous version. DOS 5.0 is recommended.

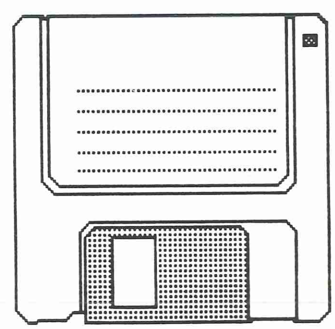
VERTPB1 Version 1.1

Upgraded to obtain input and output file names or output to printer option from the DOS command line.



NOTE TO ROMAC MEMBERS:

Do you have a Compuserve account? If so, please furnish us your user ID. You are able to access E–Mail over Internet.

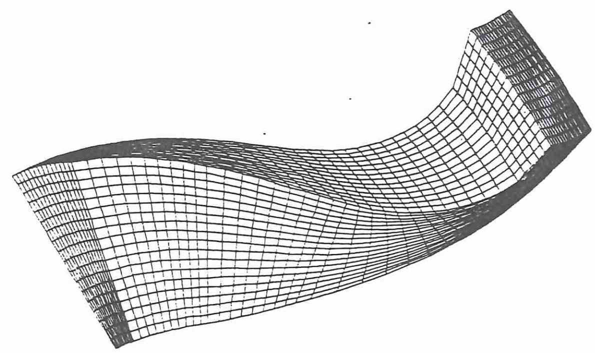


CURRENT LABORATORY RESEARCH PROJECTS

FLUID FLOWS

A Numerical Simulation of Flow Separation in Centrifugal Diffusers – Gerry O'Leary, Graduate Student, R.J. Ribando, Advisor

Experimental results in vaned centrifugal diffusers have shown that maximum pressure recovery occurs when the flow is just on the verge of separating from the vane surfaces. To assist in designing for this maximum–performance condition, a numerical simulation of the flow is being developed with special emphasis on the flow separation phenomena. The numerical scheme makes use of recent advances in interactive boundary–layer theory, and includes an adaptation of the existing ROMAC potential flow code "POT2D." A quasi–simultaneous viscous–inviscid interaction scheme has been developed to allow a marching solution of the boundary–layer equations through the region of flow separation, without the need for time–consuming under–relaxation algorithms. Results from the new scheme compare favorably with results from full Navier–Stokes solutions of several sample cases of separating flow found in the literature. A numerical method has recently been developed to model the wake region formed as the separating flow leaves the centrifugal–diffuser guide–vane. Subsequent solution of the potential–flow, incorporating the updated boundary–layer and wake, has required additional development to accurately specify the new boundary conditions and circulation. Such specifications are complicated by the unusual geometry of this application and by the existence of a wake in a continuously decelerating flow. Incorporation of a simple mixing–length turbulence model will follow resolution of the potential–flow difficulties.



3–D Viscous Flow Simulations in Rotating Impeller Channels having Complex Geometries – Qingping Shi, Graduate Student, R.J. Ribando, Advisor

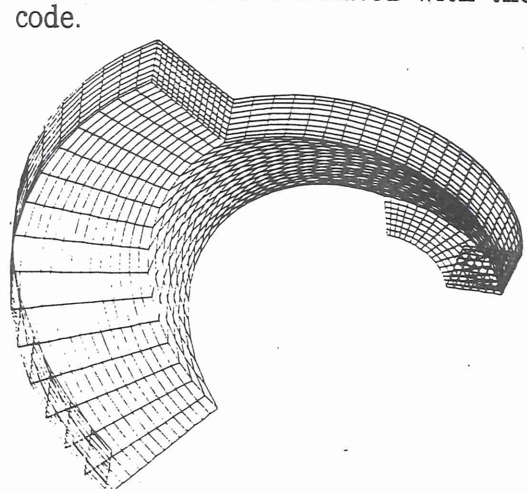
Three–dimensional viscous flow simulations in rotating impeller channels are undergoing development. The numerical techniques involved are as follows:

(1). The parabolized transport equations and curvilinear coordinate systems are used to handle internal flow field with complex geometries.

(2). A Coriolis–modified numerical procedure developed by Shi is applied. This scheme includes the influence of the Coriolis force on pressure correction. Also the partially parabolic numerical algorithm is involved to introduce the elliptic effect of pressure field.

(3). Turbulence K–ϵ models as well as their Coriolis–modified forms are employed in the simulations.

The 2–D results were reported at the Wintergreen meeting and some 3–D results at San Francisco meeting. The geometry and the flow conditions of the radial discharge impeller tested by Eckardt are used for the simulations. Rotation rate as high as 14000 RPM have been successfully run. The impeller flow field tested by Miner and Flack is also simulated with the 3–D code.



Plexiglas Pump – Willy de Ojeda, Graduate student, R.D. Flack, Advisor

As indicated at the Annual Meeting, the Plexiglas pump was modified. Previously, the rig was a single volute/single discharge design. The rig can now handle a double volute/single discharge. Static pressure taps were installed in the volute and pressures were collected for both geometries. Two different double volute geometries were tested. By comparison of the sets of data, quantitative comparison of the static pressure forces was possible. Integration of the pressures indicated the pressure radial force was much lower for the double volute geometries. LV data is also currently being taken in the double volute/single discharge configuration and compared to the previous data for the single volute/single discharge pump. The work is being done by Willy de Ojeda.

Torque Converter–Kevin Gruver, Graduate Student, R.D. Flack, Advisor

Laser velocimeter measurements are proceeding in the Plexiglas torque converter. An oil (Shellflex) with an index of refraction within 0.005 of that of Plexiglas is being used. The index of refraction matching makes the torque converter essentially invisible so that refraction and reflection of the light beams are insignificant. Full sets of data have been acquired in the stator, pump and turbine for two flow conditions. In the next phase two different pumps and two different turbines will be tested to determine the effect of different designs on the interaction of pump and turbine. Although this application is specific to a torque converter, the same methods can be applied to other oil pumps. This work is being done by Kevin Gruver.

Animation of Flow Through Torque Converter – Sharif Nahas, Graduate Student, R.J. Ribando, Advisor

Sharif Nahas, a second year M.S. student in MAE, is currently creating a three–dimensional, time–dependent animation of laser doppler velocimeter (LDV) measurements of flow through the GM torque converter. The new Silicon Graphics IRIS–4D on which the work is being done belongs to the Computer Science Department. This workstation implements a set of graphics and utility routines which provides high– and low–level support for graphics. The graphics library interfaces well with either FORTRAN or C in a UNIX environment. The ultimate goal of the project is to utilize time–dependent LDV data for the pump, turbine and stator to create a 3D animation of flow through the entire torque converter. The display will be manipulated with a "mouse" to provide different viewpoints of the torque converter, different subsets of data, or other user–specified features. The program will serve as a tool to help engineers visualize torque converter flow to aid them in the design process.

This project is not funded by ROMAC (Sharif is supported as a teaching assistant), but will greatly add to ROMAC data analysis and visualization capabilities. We are looking forward to using this advanced capability on both numerical and experimental data.

Cross–Coupling Forces in a Whirling Centrifugal Impeller – Amish Thaker, Graduate Student, H.G. Wood, Advisor

The project to compute the hydrodynamic stiffness matrix has been modified to compute the stiffness matrix for a whirling pump in addition to the flow field. Preliminary values have been obtained for simulation of a 4–bladed pump. Calculations are being performed to model a 5–bladed pump which has been studied experimentally at Cal Tech. Comparisons will be made between the predicted and measured results.

Numerical Simulation of Radial and Mixed–Flow Pumps.– Avichal Mehra, Graduate Student, H. Haj–Harriri, Advisor

A finite–difference code which can quantify the effect of secondary flows on forces and flow rate for mildly curved blade channels of a centrifugal pump has been developed. The essence of the code is to correct the potential–flow solution for the effects of viscosity, so that the stiffness coefficients obtained from potential–flow analyses can be used to estimate the true stiffness coefficients. Currently the code is being modified to handle sharper blade geometries by suitable velocity transformations.

Preliminary work has also begun on formulation of a finite–element simulation of flows in mixed–flow type pumps. Effects of turbulence, tip leakage, whirl, and blade geometry will be investigated. Results from such a study can help give the designer the guidelines for geometry modifications to achieve the required specifications. The code is being developed for implementation on workstations.

EXPERT SYSTEMS
David Lewis

This work has produced software that can aid in diagnosing rotating machinery problems. A user friendly editor has been written to expedite the addition of rules. This topic has been voted down somewhat so that at the present time we are not supporting any further work in the area.

Surprisingly, one company has picked up the software ROMEX and finds it to be extremely useful. The only problem is that they are so happy with it, and have used the inbuilt rule editor so much, that they do not wish to talk about it any further. We are pleased that ROMEX has served the purpose for which it was written.

Bearing Test Rig – Brian Pettinato/Holger Herbert, Graduate Student, R.D. Flack, Advisor

Brian Pettinato is continuing with more bearing tests. He is currently running a parametric study to determine which forced orbits are best to provide the data with the smallest uncertainties. He also is currently performing a series of tests to determine the best method of aligning the rig for the no load condition. When these studies are completed, three lobe bearings with different preload and offset factors will continue. Data will be reduced as non–dimensional dynamic coefficients vs Sommerfeld number for different speeds to determine any thermal effects. Eccentricity measurements will be compiled. Pressure profiles will also be prepared for evaluation and comparison to predictions. A new graduate student, Holger Herbert, is also assisting with these measurements and will continue to work when Brian graduates.

Seals – Brad Williams, Graduate Student, R.D. Flack, Advisor

Brad Williams is working on improving the prediction of rotordynamic coefficients for labyrinth seals. He is generating a new computer code LABY3 which, in addition to correcting a convergence problem in LABY2 and other numerical problems, will hopefully serve as a better predictor of rotordynamic coefficients. He has been performing parametric studies to determine the dependence of the coefficients on various parameters such as mass flow rate, rotor speed and inlet circumferential velocity (preswirl). The results of these studies are then compared to published experimental data to determine the accuracy of the computer model. Three areas of possible improvement in the prediction of coefficients are in the mass flow calculation, shear stress model, and the circumferential flow model. The sensitivity of rotordynamic coefficients to these three areas are being studied and more accurate models will be investigated.

Analysis of Thrust Bearings – Ted Brockett, Graduate Student, L. Barrett, Advisor

Ted Brockett, who recently completed his MS thesis (see the ROTOR DYNAMICS section), intends to develop a hydrodynamic thrust bearing analysis for his Ph.D. dissertation. We are just in the beginning stages of defining the project, so there is little to report at this time. However, we would welcome any input from industrial members on what should be included in the analysis and on any problems that should be addressed.

Groove Temperature Mixing in Tilted Pad Bearings – Carol Demas, Graduate Student, H.G. Wood, Advisor

This project analyzes the fluid dynamics in the lubricant supply groove of a tilted pad bearing. Accurate mixing temperatures at the inlet to a downstream pad cannot be obtained without a through understanding of the mixing mechanisms involved. A full 3–d Navier–Stokes analysis including turbulent effects via the $k-\epsilon$ model and heat transfer effects in the groove is performed. A series of numerical experiments with varying inlet conditions and increasingly accurate geometries is planned. The results will provide insight into the mixing mechanism. Simplified models will be deduced from the numerical results. These models will be suitable for supplying information to THD bearing studies involving the fluid film.

Misalignment and Other Film Thickness Effects in Fluid Film Bearings – Manuel Grau, Graduate Student; L. Barrett, Advisor

Manuel Grau completed his MS degree in August. He examined modeling of shaft misalignment effects in fixed geometry journal bearings using assumed axial pressure functions as is done in TEMBRG and THBRG. Besides developing the capability to calculate stiffness and damping coefficients for bearings with misalignment (there are now 32 coefficients instead of 8) this project was undertaken to evaluate the solution methods before applying them to bearings with arbitrary, or non–standard, axial film thicknesses. This will be the subject of a future MS thesis. Manuel's work has already proved useful in misalignment studies with the hydrodynamic bearing rig.

Manuel has developed two programs based on TEMBRG. One, TMSBRG–2D, incorporates a complete two–dimensional finite element analysis of misaligned bearings into TEMBRG, bypassing the analytic axial solution. The other program, TMSBRG–1D, uses the assumed axial pressure solution including misalignment that Manuel developed for his thesis. Both programs will be available some with accompanying manuals. His thesis will also be available as a ROMAC report.

Bearing Optimization for Flexible Rotor Stability – Deb Dhar, Graduate Student; L. Barrett and C. Knospe, Advisors

Deb Dhar, one of our laboratory engineers and a Ph.D. candidate, is nearing completion of his dissertation on a method for determining optimum bearing stiffness and damping characteristics for stability of flexible rotors operating through several modes. This work is intended to aid in designing both tilting pad and magnetic bearings. It is a supplement to his MS degree work which resulted in a method to optimize tilting pad and magnetic bearings for unbalance and other forced response stimuli. His work is a difficult extension of previous ROMAC work in optimizing bearings for the first critical speed.

The computer program he has developed requires the user to define acceptable stability limits over frequency ranges, frequency bands in which a damped critical speed cannot lie, and upper and lower bounds on acceptable bearing coefficients. The program then optimizes bearing coefficients within these constraints. There is work currently in progress to make the program "user friendly" since user interaction is required.

Incorporating Rotor Casing Models into Rotor Stability Analyses – Karl Wygant, Graduate Student; L. Barrett, Advisor

Karl Wygant is nearing completion of his MS degree. He is developing a method of including casing dynamics into ROTSTB. As in Ted's work, he is utilizing dynamic condensation techniques. A complicating factor is the fact that the shaft interacts with the casing at numerous points, which adds an additional level of iteration into the analysis. However, Karl's work will be extremely useful in incorporating the effect of non–colocated magnetic bearing sensors into a ROTSTB type analysis method. His efforts are also laying th groundwork for including experimentally obtained dynamic information into more of our rotor dynamic analysis programs.

Reduced Order Models for Improved Rotor Dynamic Analysis – Sriram Srinavasan, Graduate student; L. Barrett, Advisor

Sriram Srinavasan, also a Ph.D. student, is working on a method for determining reduced order models for rotor dynamic analysis. These models will be useful in increasing the number of rotor mass stations included in simulation analyses while reducing the number of equations retained in the solution algorithms. This work will be extremely useful in bearing optimization, expert systems, and in the magnetic bearing controls area, particularly in regard to the digital controls efforts.

The scope of the work has been extended to develop a technique to quickly determine the relative acceptability of bearing location on rotor stability. This ties in nicely with Deb's program. The intent is to be able to quickly refine rotor geometry and bearing location before utilizing Deb's program to perform the actual bearing optimization.

Bearing Optimization for Force and Vibration Transmission Reduction – Sungwon Lee, Graduate Student; L. Barrett and D. Lewis, Advisors

Sungwon Lee, also a Ph.D. student, has nearly completed his dissertation in optimizing bearings to minimize force and vibration transmission to supporting structures. He is particularly interested in he application to shipboard mounted machinery. He is using frequency response function techniques similar t those used in the FRESP programs. Sungwon has developed a forced response program similar to FRESP2 that determines the static bearing loads for multi–shaft rotors with more than two bearings per shaft. The program also includes laterally and angularly misaligned plain journal bearings in the analysis.

Parameter Estimation and Experimental Models – Ping Zhong, Graduate Student; L. Barrett, Advisor

Ping Zhong, a Ph.D. student, has recently joined ROMAC. Ping has a background in modal analysis, and is interested in developing techniques for generating analytic models from experimental data. This work will be useful in estimating parameters such as bearing coefficients, from test data, and creating and refining rotor and casing models based on test measurements. This work is just underway.

Including Complete Tilting Pad Bearing Models in Rotor Stability Analyses – Ted Brockett, Graduate Student; L. Barrett, Advisor

Ted Brockett, an MS student, has completed his work on including complete tilting pad bearing representations into the ROTSTB stability program. He utilized a dynamic condensation technique similar to that used by Jim Bielk in FTSB3, to include the pad dynamics without explicitly retaining the pad degrees of freedom in the analysis. As a consequence of his work, we have further verified calculations of tilting pad bearing coefficients made by ROMAC bearing programs. His work is also relevant to the incorporation of casing dynamics in ROTSTB and to including magnetic bearing and controls models into our rotor dynamic programs.

Ted has made a number of enhancements to ROTSTB to improve calculation efficiency and include graphical output of the rotor dynamic programs.

Ted is now employed as a laboratory research engineer, and will be replacing Deb Dhar in that capacity when Deb graduates. Ted has been working closely with Toby Korn, our new computer programmer / analyst, and with many of the industrial members on the ROMAC programs.

Optimized Tilting Pad Bearing Design – Jeannette Smith, Graduate Student; L. Barrett and C. Knospe, Advisors

Jeannette Smith has recently joined ROMAC as a MS student. She has been working with Deb Dhar and has developed a graphical display for the bearing optimization program. For her thesis project, Jeannette will be developing a methodology for designing tilting pad bearings. The methodology will involve the use of Deb's optimization program, so there is ongoing work in ROMAC to go beyond just analyzing rotors into design.

MAGNETIC BEARINGS

Digital Control of Magnetic Bearings – John D'Addio, Joe Keith, and Steve Fedigan, Graduate Students; R. Williams, Advisor

The effort to develop digital control for magnetic bearings continues this year with an increased emphasis on practical control implementations. This work within ROMAC has moved away from independent axis PID control and toward more powerful and flexible algorithms. This digital control research includes the development of specialized computing hardware, integrated power switching amplifier modules and a real–time operating system specifically tailored to control applications.

Hardware for the new control computer that will serve as a powerful laboratory controller is complete, and all of the system boards (CPU, input, output) have been successfully tested. This controller is based upon a floating point digital signal processor, and it is approximately two orders of magnitude more powerful than the typical personal computer when compared in terms of floating point operations per second.

True simultaneous sampling of all analog input channels simplifies multiple output (MIMO) control algorithms, and sampling rates of up to 50,000 samples per second per axis are anticipated. Although the controller will initially provide control for five magnetic bearing axes, the machine can easily be expanded to handle additional input and/or output channels as required by future rotor bearing systems. The power switching amplifier modules that directly interface to the new controller have been assembled and tested.

The real–time operating system (RTOS) is designed to insulate users from many of the tedious hardware details embodied in the new digital controller while allowing easy user access to both sensor input and actuator output information. The RTOS handles many of the difficult tasks associated with the real–time implementation of control algorithms, thus freeing users to concentrate on the development and testing of the actual algorithms. Multitasking capabilities provided by the RTOS are particularly useful when developing MIMO and adaptive control algorithms. Since both the controller hardware and operating system are designed and implemented by ROMAC faculty and staff, future modifications to accommodate changing user needs can be handled in a quick, straightforward manner.

Magnetic Actuator Design – B.J. Lim, Graduate Student; P. Allaire, Advisor

We have started work on a magnetic bearing finite element analysis code that will conduct an automatic modeling of typical geometries of magnetic bearing actuators. It will resemble fluid film bearing codes in that the finite element mesh will be generated automatically within the code employing isoparametric finite elements for the mesh generation. The code will calculate the two dimensional magnetic flux in the actuator, the fringing and leakage, force, stiffness and damping (with input of control system transfer function).

Magnetic Actuator Design – Patrick Depret–Guillaume, Graduate Student; D. Lewis, Advisor

We now have acquired a 3–D software package for analyzing magnetic circuits. This software will give the ability to model the high temperature radial bearing (500 lb load capacity) with more accuracy. The 3–D model will allow the designer to look at the effects of non–uniform pole structures and axial fringing effects. These types of models should yield better correction factors for the planned analytical codes for sizing the actuators. The goal is to produce a design code that will yield an optimal actuator based on the maximum force to weight ratio.

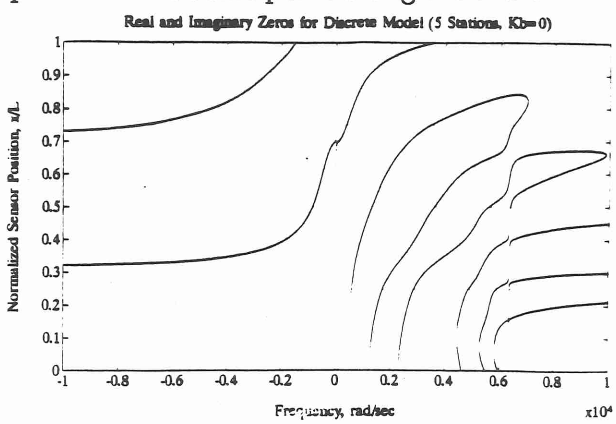
Bearing/Sensor Noncollocation – P. Allaire

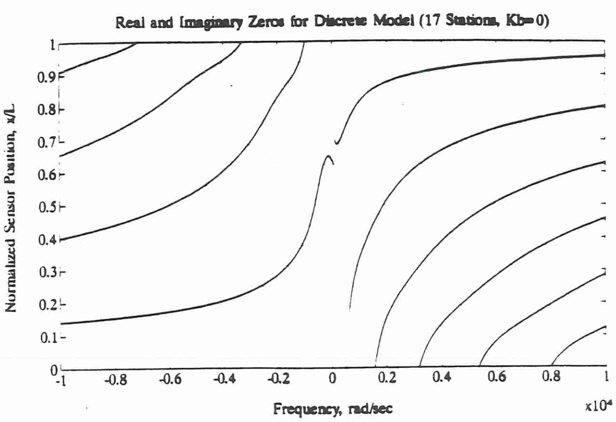
P. Allaire has started an investigation of the effects of noncollocation of magnetic bearing and sensor in magnetic bearing supported rotors. This will involve the study of some industrial machines that have experienced problems as well as some machines that will have magnetic flux in the actuator, the fringing and leakage, force, stiffness and damping (with input of control system transfer function).

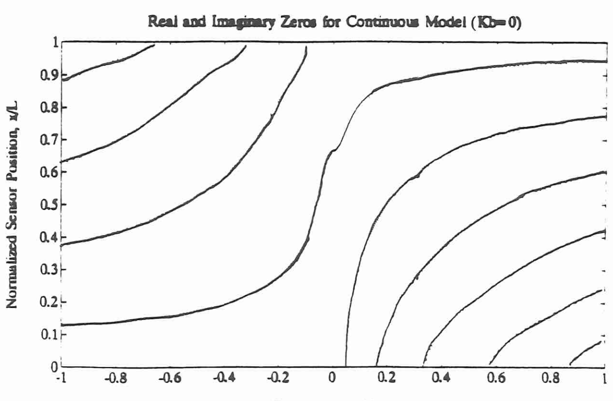
Noncollocation –
Vincenzo LeFante, Graduate Student
E. Maslen and P. Allaire, Advisors

Vinnie Lefante is completing his Master's Degree examination of the theoretical issues surrounding sensor–actuator noncollocation. His research has revealed some surprising properties of beam transfer functions which have strong implications for multi–variable control. Particularly, discrepancies between the properties of finite element models and the fundamental behavior of beams suggest that the number of mass stations required for MIMO design may be substantially larger than would be expected on the basis of accurate eigenvalues (critical speeds.)

Vinnie's work makes clear the modeling issues which must be resolved in designing stable magnetic suspensions for systems where the sensor and actuator cannot be placed at the same point along the shaft.







Proximity Sensors – Daniel Maurer, Graduate Student; E. Maslen, Advisor

Daniel Maurer (M.S.) has made substantial progress in the last year toward implementing a practical proximity sensor for use in magnetic bearing systems. The primary thrust of his research has concentrated on a robust phase detection based scheme which provides a direct digital measurement of the gap. The sensor he has constructed and is testing provides a 10 bit digital gap measure with sensitivity comparable to that obtained with commercial eddy current probes in conjunction with 12 bit A/D converters. Noise in this sensing scheme is an important issue and he will be quantifying the signal–to–noise performance of the probe in the next months. A phase locked loop noise enhancement scheme has been proposed and Dan will compare the signal–to–noise performance of the probe with and without the phase locked loop enhancement. This probe is inductive rather than eddy current based, so it promises the ability to "see" through stainless steel cans for application to canned pumps.

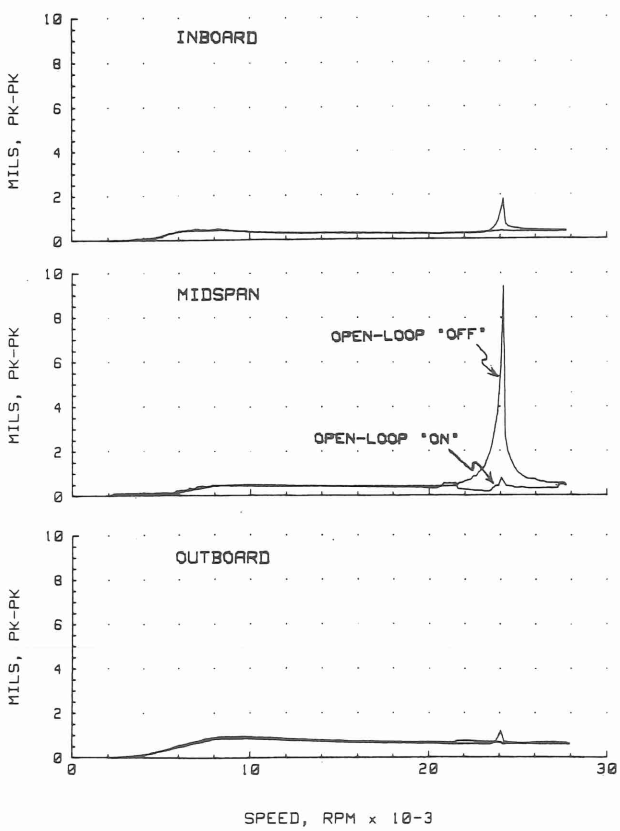
Once the performance of this probe is fully documented and the theoretical model has been validated, Dan plans to explore a competing bridged scheme which permits distributed sensing with less sensitivity to shaft imperfections and negligible sensitivity to thermal growth. This design is similar to what appears to be supplied to some commercial magnetic bearing vendors, although we believe that some details of our bridging scheme are unique. (It is difficult to accurately assess the commercial technology because it is almost exclusively proprietary.)

Synchronous Vibration Reduction Using Magnetic Bearings –
Subra Sundaram, Graduate Student; C. Knospe and R. Humphris, Advisors

Work has continued on applying open loop control methods with magnetic bearings to the suppression of rotating machinery unbalance response. The open loop control produces a rotating magnetic field on the shaft which acts to counter the rotor's vibration in much the same manner as conventional balancing.

We have demonstrated the open loop control method on two magnetic bearing rigs at the University. Among other results we have shown that

(1) reductions in synchronous shaft vibration of over 100 fold are easily achievable.
(2) unbalance response at higher critical speeds can be virtually canceled.
(3) vibration transmitted to the foundation can be greatly reduced.
(4) vibration at harmonics of the operating speed can also be reduced.



Vibration amplitudes vs. speed with and without open loop control; control adjusted to minimize midspan vibration at the third critical speed, 24050 rpm

Work has also progressed on adaptive digital algorithms for executing the open loop control over the entire operating speed range of a typical machine. A theoretical study and simulation is being completed at this time. When the new digital controller becomes available these algorithms will be tested on magnetic bearing rigs at the University.

Load Capacity Based Design –
Matthew Stewart, Graduate Student; E. Maslen, Advisor

Matt Stewart (M.S.) is completing construction of a small magnetic bearing test rig with many objectives. The rig has been designed to be small enough to be easily transported and set up for demonstration purposes. It has an induction motor at its midspan to allow us to experiment with magnetic support of electric motors and to have a rig with no drive coupling. The control electronics have been designed to be fairly compact – not as compact as could perhaps be achieved commercially, but far more so than our usual "laboratory test devices". Finally, the bearings were sized based on algorithms developed previously by ROMAC for matching the bearing load capacity to the shaft dynamics and expected levels of mass unbalance; the performance of this rig will help to validate that design procedure.

Matt had hoped to have this test rig running in time for the annual meeting, but the inevitable delays intruded, and early January now looks more realistic.

Microgravity Vibration Isolation – Dave Hampton, Bibhuti Banerjee , Graduate Students; C. Knospe, and P. Allaire, Advisors

The University is continuing its research in microgravity vibration isolation with NASA Lewis Research Center. Our work has focused on the development of control strategies and actuators to achieve the very low frequency, high attenuation vibration isolation needed for microgravity science experiments.

Research is continuing on vibration isolation through the feedback control with magnetic supports. Dave Hampton is currently finishing study of the application of modern control theory to a one degree–of–freedom vibration isolation problem. Soon, an investigation of the six degree–of–freedom isolation problem will begin. The one degree of freedom test rig at the University to demonstrate microgravity vibration reduction is currently nearing completion.

The long stroke Lorentz linear actuator for the isolation rig has been designed, built, and tested. There is a good agreement between test results and finite element predictions. Linearity with respect to both stroke and control current has been verified. The actuator will soon be incorporated into the microgravity isolation rig.

The laboratory is very interested in expanding its research in magnetically supported vibration isolation platforms for conventional machinery.

MAGBEDD – Magnetic Bearing Diagnostic Device – Bob Humphris

Sounds like another computer design program, but it is not. We've been using a cumbersome collection of various commercial and homemade instruments and circuits to provide perturbation diagnostic signals for our magnetic bearings. Finally, we are in the process of constructing a small portable dedicated package which will permit the measurement and determination of certain properties of rotating machinery using magnetic bearings.

The device will have a white noise generator, a variable frequency, variable amplitude sine wave and square wave output and will generate a ramped frequency "rotating" electronic signal to simulate rotor speed run up. System dynamic properties, such as critical speeds, stiffness, damping, maximum and optimum clearances, rub angle locations, amplification factors, log decrements, structure resonances, cross coupling, etc., can be determined. Also, dynamic balancing using open–loop control may be manually achieved on a rotating rotor at a single speed, and is effective over a range of speeds. A key–phasor reference signal is required, as well as a means of connecting the device to the power amplifier of the magnetic bearings. We hope to have this ready for our June '92 meeting for "show and tell".