■ ROTATING MACHINERY AND CONTROLS LABORATORIES ■

ROMAC

FALL, 1999

Message from the Director

Lloyd Barrett

ROMAC continues to be busy this year. The Annual Meeting in Charlottesville last June was well attended. Our meeting next June will be held in Vermont, and will be hosted by Concepts, ETI. Their staff has been very helpful in making arrangements for the meeting, and we look forward to seeing everyone there.

We want to welcome Crystal Besecker to our staff. She joined us last January as our new office manager. Many of you already met Crystal at our last Annual Meeting. She is working hard on organizing the next Annual Meeting.

Work has continued during the past year in making improvements to the Shell and Editors for ROMAC computer programs. Our new stability and forced response program is being released, and it will allow us to more easily add additional analysis capability. Concepts, ETI demonstrated the improvements to the RotorLab™ program they are developing for ROMAC. We plan to use it and other ROMAC software in a Rotor Dynamics Short Course we plan to offer next May. Unlike previous short courses, we plan to integrate the use of ROMAC software in the course to illustrate rotor dynamic phenomena and help our industrial members users use our software more effectively.

If you have any comments, suggestions, or questions about these efforts or about any of the projects described in this newsletter, please contact the faculty member in charge or me.

We look forward to seeing you in next June in Vermont.

ROMAC Annual Meeting 2000

Fairlee, VT - June 18-22

The 2000 Annual Meeting will be held in Fairlee, Vermont at the Lake Morey Inn and Resort. The meeting will begin with registration and a reception during the evening of Sunday, June 18 and will end with lunch on Thursday, June 22. Sessions and lunches will be held at the hotel ~~which is just north of Charlottesville with a tour of the ROMAC facilities one afternoon.~~

There were many positive comments about the 1999 meeting at Charlottesville. We endeavor to schedule the Annual Meeting sessions to best accommodate the interests and schedules of our industrial members. At the 1999 Annual Meeting, we expanded the scope of the research overviews at the beginning of the meeting for those attendees who could not attend all sessions. Many of our members tell us that one of the most significant benefits of attending the ROMAC Annual Meeting arises from the interactions that occur among members from different organizations. We encourage this interaction and hope that all attendees will take advantage of this opportunity.

Registration materials will be sent to our members in March, 2000. Mark your calendars and plan to join us in June.

ROMAC Programs now available on CD-ROM!

Call the ROMAC Office or send e-mail to jose@virginia.edu to request a copy of the ROMAC CD-ROM with the latest version of all ROMAC programs.

José Antonio Vázquez is the ROMAC Theoretical Lab Engineer. He is responsible for liaison with industrial members on technical issues with our programs. He works directly with graduate students and faculty in finding answers to your questions. If you have any questions concerning ROMAC programs, please call José at 804-924-6234 or contact him via e-mail at jose@virginia.edu.

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ROMAC Computer News

José Antonio Vázquez

ROMAC ON-LINE

ROMAC offers a variety of services through our online service. All ROMAC programs are available via FTP (File Transfer Protocol). Our FTP address is:

Romac.mae.virginia.edu

Users need an account on the ROMAC server in order to have access to the programs. ROMAC is also on the World Wide Web. Members have access to information about ROMAC, ROMAC programs, latest programs and script releases, faculty, staff, students and much more. The address is:

http://www.virginia.edu/romac

Electronic mail (e-mail) is an especially useful tool for providing technical support. All ROMAC faculty, staff and students may be reached using e-mail. ROMAC also maintains a distribution list for notification of program updates. Members that have e-mail but are not included in our mailing list should send e-mail to:

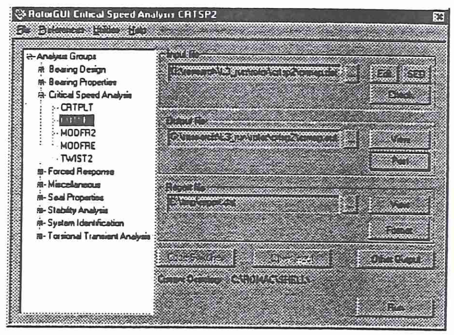
romac@virginia.edu

ROMAC User Interface Suite

ROMAC Shell Software

José Antonio Vázquez

The "ROMAC shell" is a collection of support programs that provides an easy interface to the ROMAC analysis codes. The program Rotorgui is the main component and provides a link to the scripted editor (SEDWIN), the analysis codes, ASCII editors and viewer, rotor geometry plotter (RotorVal) and post-processing capabilities using Tecplot® or other plotting packages to produce final plots.

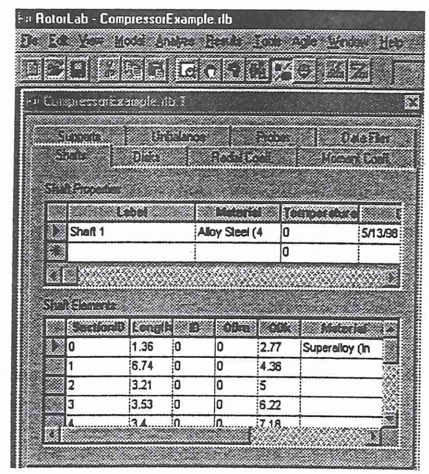


RotorLab™

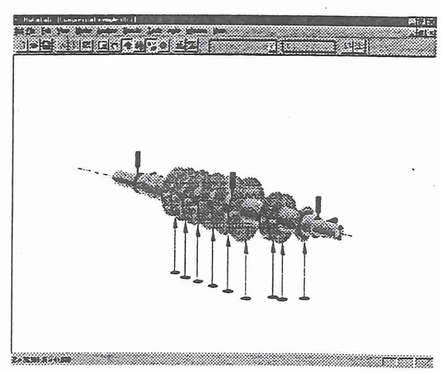
Mike Platt (Conecepts ETI) and Lloyd Barrett

As part of the software development being performed by Concepts ETI for ROMAC under the agreement reported at last year's Annual Meeting, CETI has been developing an integrated software package, RotorLab, which combines the tasks of design, modeling, analysis, postprocessing, and data management into a consistent user interface. The analysis is performed by the standard ROMAC analysis software available to all industrial members. The first version of RotorLab was demonstrated at the last Annual Meeting in San Antonio, and ROMAC and CETI are developing plans for updating and improving this program. The analysis packages currently supported are CRTSP2, RESP2V3, and ROTSTB. Some of the features of RotorLab include

- Flexible model generation and automatic meshing
- Consistent model definition for a full range of rotordynamic analyses
- Definition of bearing, disk, and support locations by dimension rather than station numbers
- Interactive insertion and movement of elements
- 2D cross-sectional and 3D rendered solid views of rotor assemblies



A survey of the industrial members was taken at the Annual meeting to help us determine new features that you want included in future versions of RotorLab.



ROMAC SED File Releases (Script Files)

BRGOPT.SED
Version 1.00 (05/12/99) James Byrne
Script file that creates the input file for BRGOPT.

FORSTAB.SED
Version 4.30b (05/12/99) José A. Vázquez
Script file for FORSTAB. This script generates input files for FORSTAB and can import files from ROTSTB and RESP2V3.

TORTRAN2.SED
Version 1.00 (10/14/99) José A. Vázquez
Script file that creates input files for TORTRAN2.

Updated ROMAC Programs

RESP2V3
Version 3.01 (11/20/98) update by José A. Vázquez
The program checks that the unbalance locations and output locations are in ascending order. If they are not in ascending order, the program reorders them. Before this update, the program ignored the unbalance locations out of order and produced an error if the output locations were not in ascending order.

FRESP2
Version 3.00 (December 02, 1998) update by José A. Vázquez
Added command line options.
Replace the Geograf plots with Tecplot plots.

CRTSP2
Version 2.77 (04/13/99) update by José A. Vázquez
Added a calculation of zero frequency modes. Zero frequency modes are present when a single rotor is in a free state, with no bearings attached to it. These modes are needed to represent the rotor in modal space. CRTSP2 calculates zero frequency modes when the system is composed of a single rotor with no external bearings. The speed range selected for the search of critical speeds does not affect the calculation of the zero frequency modes.

Version 2.78 (09/02/99) update by José A. Vázquez
Added the running speed and bearing coefficients to the critical speed maps generated by CRTPLT and CRTSP2. The rotor running speed and bearings characteristics are added to the input file and plotted in the critical speed maps. These modifications do not affect the results of the program.

CRTPLT
Version 1.02 (09/02/99) update by José A. Vázquez
Added the running speed and bearing coefficients to the critical speed maps generated by CRTPLT and CRTSP2. The rotor running speed and bearings characteristics are added to the input file and plotted in the critical speed maps. These modifications do not affect the results of the program.

MODFR2
Version 3.00 (03/01/99) update by José A. Vázquez
Added plotting capabilities with Tecplot. The plot file is to the plot file (option -p). Only mode shapes are generated because MODFR2 uses only one speed case and critical speed maps have no meaning.
Added command line options. The new options are:

-i inFile use *inFile* as the input file name

-o outFile use *outFile* as the output file name

-p plotFile use *plotFile* as the plot file name (used for Tecplot)

-m modFile use *modFile* as the output modal file name.

-g display the entries in the romac.org file necessary to run this program

-? show the command line options and exit.

@rspFile use *rspFile* as the response file for MODFR2

Switches can be preceded by "-" or by "/" and can be either upper or lower case (processing is not case sensitive).

THPAD
Version 2.67 (07/15/98) updated by Lloyd E. Barrett & José A. Vázquez
Added a check to the value of the Stiffness and Damping coefficients before the calculation of the dimensionless damping ratios. This check fixes a division by zero error that occurred under certain circumstances.

ROTSTB
Version 7.15 (08/27/98) updated by José A. Vázquez
Corrected the print out of the coefficients of THBRG bearing files. The Kxy, Kyx, Cxy and Cyx were mixed. This error only affected the print out of the coefficients. It DID NOT affect the operation of the program.

Version 7.16 (10/07/98) updated by José A. Vázquez and Peter Weber
Changed the format of the ratio of Young Modulus when written to the modal file. This corrected a problem writing the Modal file. The same format change was done on MODEPLT.

Version 7.17 (10/04/99) updated by José A. Vázquez
Added sorting of the eigenvalues by frequency with overdamped eigenvalues at the end.
Added a frequency range for the calculation of mode shapes. Only the mode shapes of the eigenvalues inside the frequency range are calculated or plotted. This optioncan be turn on and off in the input file.

Version 7.18 (10/07/99) updated by José A. Vázquez and James Byrne
Added at special case to the sorting of eigenvalues.

MODEPLT
Version 7.31 (10/07/98) updated by José A. Vázquez and Peter Weber
Changed the format of the ratio of the young modulus in the modal file. This change corrected a problem when a ratio of young modulus was supplied. This change is consistent with ROTSTB 7.16
Removed the Geograf subroutines and compiled the program as a 32 bits code.
Version 7.33 (10/04/99) updated by José A. Vázquez
Added the rotor spin speed in the mode shape files
Version 7.34 (10/07/99) updated by José A. Vázquez
Modified the location of the print out of Tecplot Headers. This modification fixed the special case when the first speed case did not have mode shapes in the range of interest.

Modified Script Files

CRTSP2.SED
Version 3.33 (09/02/99) updated by José A. Vázquez
Added the running speed and bearing coefficients to the critical speed maps generated by CRTPLT and CRTSP2. The rotor running speed and bearings characteristics are added to the input file and plotted in the critical speed maps. These modification do not affect the results of the program.
The new version of the script allows the importation of the direct stiffness coefficients from RESP2V3, ROTSTB and THBRG bearing files.
RESP2V3.SED
Version 2.4 (11/18/98) update by José A. Vázquez
Added a check for the number of speed cases used of the external bearings for the unbalanced rotor. If the number of external bearings is zero, do not write the speed case information. This modification solves a problem that occurred for dual rotor systems where the unbalanced rotor did not have external bearings.
ROTSTB.SED
Version 4.7 (10/04/99) updated by José A. Vázquez
Added the frequency range for the mode shape calculation.

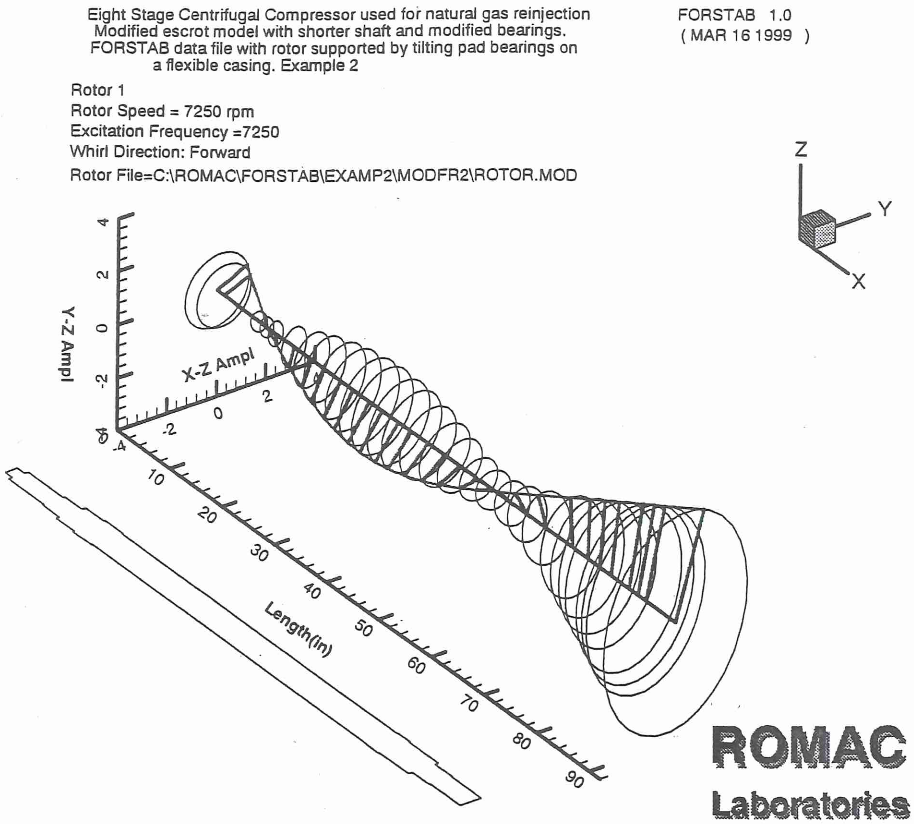
TECPLOT ® Interface

ROMAC is using Tecplot®[1] as a plotting interface to some of the ROMAC engineering codes. This interface consists of a post-processor to the engineering codes that generates the Tecplot® input data file and a macro file. The macro file contains functions that simplify the navigation inside Tecplot. With the macros, the user does not need to know how to use Tecplot in order to generate plots. This interface is intended to be used through the post-processing capabilities of the ROMAC shell but it can be used independently if needed.

New Tecplot Macros

Brgopt.mcr
Version 1.00 (05/12/99) by James Byrne.
This macro formats the bearing performance plots in a 3D format. Figure 3.1 shows an example of this type of plots.
Brgopt2.mcr
Version 1.00 (05/12/99) by James Byrne
This macro formats the bearing parameter plots in 2D. These plots include bearing geometry, power loss, minimum film thickness, specific load, maximum film temperature, eccentricity ratio, attitude angle, lubricant flow and orientation angle versus the clearance for each bearing. Figure 3.2 shows the bearing geometry versus the clearance for each bearing. Figure 3.3 shows the power loss versus the clearance in each bearing. Figure 3.4 shows the minimum film thickness. Figure 3.5 shows the specific load. Figure 3.6 shows the plot of the maximum film temperature versus the bearing clearance. Figures 3.7, 3.8 and 3.9 shows the plots of eccentricity ratio and attitude angle, lubrication flow and orientation angle respectively.
Version 1.01 (05/20/99) by José A. Vázquez
Fixed a scaling problem introduced by a redefinition of some macro variables in Tecplot 7.5
Fresp2.mcr
Version 1.00 (12/03/98) by José A. Vázquez
This macro formats forced response plot from FRESP2. It includes macro functions to help in the navigation of Tecplot. Figure 3.10 shows an example of the plots produced with FRESP2.
Version 1.01 (05/20/99) by José A. Vázquez
Fixed a scaling problem introduced by a redefinition of some macro variables in Tecplot 7.5
Forstab_stb2D.mcr
This macro formats stability mode shapes plots in 2D view. This kind of plot if generated by stability calculations in FORSTAB. A plot of the rotor is included if the information was available in the rotor mode shape files. Figure 3.11 shows an example of stability mode shapes in 2D view.
Version 1.00 (05/27/97) by José A. Vázquez
This macro:
-Resize the plot screen
-Create new zones for all the stations in the file
-Change the fonts of the axis titles and labels
-Creates and display the legend
-Change the symbols and color for all maps
-Creates functions to be run from the quick macro function tool
-Clots the logo (romac3.mcr) on the plots.
Version 1.01 (05/01/98) update by José A. Vázquez
Changed the location of the tick marks to make space for the rotor geometry drawing

[1] Tecplot is a registered trademark of Amtec Engineering, Inc.



Lowered the location of the legend to make space for the name of the program and date

Version 1.02 (10/15/98) update by José A. Vázquez

Added a print button to the macro panel

Forstab_stb3D.mcr

This macro formats stability mode shapes plots in 3D view. This kind of plot if generated by stability calculations in FORSTAB and selecting 3D plots in PLOTSTB. Supplying a setup file to PLOTSTB creates animated 3D mode shapes. Figure 3.12 shows an example of a stability mode shape in 3D view.

Version 1.00 (07/04/97) by José A. Vázquez

This macro includes tools for the animation of a single mode shape or for the cycling through the different mode shapes available.

Version 1.01 (05/01/98) update by José A. Vázquez

Resized the plot in order to make space for the names of the input file names, output file names and plot names

Changed the location of the axis reference in order to make room for the version number and date of FORSTAB.

Forstab_force.mcr

This macro formats FORSTAB unbalance response plots. This kind of plot is generated by unbalance response analysis in FORSTAB. Only the stations were output is requested are plotted. Figure 3.13 shows an example of this kind of plot

Version 1.00 (05/27/97) by José A. Vázquez

This macro:

-Resizes the plot screen

-Creates new zones for all the stations in the file

-Changes the fonts of the axis titles and labels

-Creates and display the legend

-Changes the line type to splines.

-Changes the symbols and color for all maps

-Sets the problem for all bearings

-Creates functions to be run from the quick macro function tool

-Plots the logo (romac3.mcr) name on the plots.

Version 1.01 (06/16/97) by José A. Vázquez

Added the drawgraphics cut off instruction. This feature improves the speed of the macro and avoids the multiple repainting of the screen before the macro have finished.

Corrected the autoscaling for the first plot drawn in the screen

Version 1.02 (06/16/97) by José A. Vázquez

Added 10% to the vertical axis 1. This helps to make room for the amplification factor

Version 1.03 (06/17/97) by José A. Vázquez

Fixed a problem when only one zone was present.

Version 1.04 (12/10/97) by José A. Vázquez

Added the print command in the tools/macro palette

Version 1.05 (05/20/99) by José A. Vázquez

Fixed the scaling problem introduced by a redefinition of some macro variables in Tecplot Version 7.5.

Forstab_Unb2D.mcr

This macros formats unbalance response mode shapes plots in 2D view. This kind of plot if generated by unbalance response calculations in FORSTAB. A plot of the rotor is included if the information was available in the rotor mode shape files. Figure 3.14 shows an example of unbalance response mode shapes in 2D view.

Version 1.00 (05/27/97) by José A. Vázquez

This macro:

-Resizes the plot screen

-Creates new zones for all the stations in the file

-Changes the fonts of the axis titles and labels

-Creates and display the legend

-Changes the symbols and color for all maps

-Creates functions to be run from the quick macro function tool

-Plots the logo (romac3.mcr) on the plots.

Version 1.01 (05/01/98) update by José A. Vázquez

Changed the location of the tick marks to make space for the rotor geometry drawing.

Lowered the location of the legend to make space for the name of the program and date

Version 1.02 (10/15/98) update by José A. Vázquez
Added a print button to the macro panel

Forstab_Unb3D.mcr
This macros formats unbalance response mode shapes plots in 3D view. This kind of plot if generated by unbalance response calculations in FORSTAB. A plot of the rotor is included, if the information was available in the rotor mode shape files. Supplying a setup file to PLOTSTB creates animated 3D mode shapes. Figure 3.15 shows an example of unbalance response mode shapes in 3D view.

Modified Macros
These macros have been updated to fix a scaling problem introduced with Tecplot 7.5. The new version of Tecplot redefines some of the macro variables that were used in the older version of these macros. In consequence, some of these macros did not worked as originally intended. The modified versions of the macros work under Tecplot versions 7.0 and 7.5.

Crtsp2_m.mcr
Version 1.10 (05/20/99) by José A. Vázquez

Resp2v3.mcr
Version 1.01 (05/20/99) by José A. Vázquez

Seal3.mcr
Version 1.01 (05/20/99) by José A. Vázquez

Thbrg.mcr
Version 1.10 (05/20/99) by José A. Vázquez

Thpad.mcr
Version 1.10 (05/20/99) by José A. Vázquez

ROTSTB.mcr
Macro for eigenvectors calculated using ROTSTB (the plotting is done in X-Y coordinates)
Version 1.01 (05/01/98) updated by José A. Vázquez
- Changed location of tick marks to make space for rotor geometry drawing.
- Lowered location of legend to make space for name of program, date, and version number.

3dROTSTB.mcr
Version 1.01 (05/01/98) updated by José A. Vázquez
- Resized plot in order to make space for names of input file, output file and plot file.
- Changed location of axis reference in order to make room for version number and date of ROTSTB.

ROMAC3.mcr
Version 1.01 (06/02/98) updated by José A. Vázquez
Added some variables to make it easier to change name displayed in logo. There are two lines available. User may use this macro or a template to create a logo.

New Computer Programs

BRGOPT
Version 1.00 (05/12/99) by James Byrne and Paul Allaire
BRGOPT finds optimal fixed geometry bearing configurations within a range of user specified parameters. BRGOPT uses THBRG as the solution engine for the fixed geometry bearings designs. The programs varies the bearing length, clearance and other design parameters to obtain user defined load capacity, power loss and rigid rotor stability while maintaining a desired minimum film thickness.

FORSTAB
Version 1.01 (05/12/99) by José A. Vázquez and Lloyd E. Barrett
FORSTAB combines the capabilities of the ROMAC programs ROTSTB and RESP2V3 and add new features such as multiple level rotors, seals, flexible supports, relative and absolute responses and unbalance response mode shapes. While ROTSTB and RESP2V3 use the transfer matrix method to generate the equation of motion of the system, FORSTAB uses a finite element formulation with built in modal reduction to reduce the number of equations that need to solve. This makes FORSTAB easier to modify and to add capabilities.

PLOTSTB
Version 1.00 *(05/12/99) by José A. Vázquez*
PLOTSTB is a companion program for FORSTAB. It reads the plot file generated by FORSTAB and creates Tecplot input files. The plotting capabilities include unbalance response plots, unbalance response mode shapes in 2D and 3D and stability mode shapes in 2D and 3D views.

Program Development

Continuing enhancements to FORSTAB – José A. Vázquez and Lloyd E. Barrett

FORSTAB is ROMAC's new unbalance response and stability program. FORSTAB uses modal reduction to reduce the number of equations to be solved. Because the program is modally based, models for various components can be developed using existing critical speed programs or finite element programs or can be measured experimentally. FORSTAB can use transfer function descriptions for bearing supports and casings. This feature permits the use of experimental data in the modeling of these components.
Presently the program includes:

1. Multiple rotors and structures
2. Foundations (modal description)
3. Flexible supports (8-coefficient models)
4. Flexible supports and casings described using transfer functions
5. Tilting pad journal bearings
6. Magnetic journal bearings
7. Fixed geometry journal bearings
8. Fixed geometry thrust bearings

CURRENT RESEARCH PROJECTS

Fluid Film Bearings and Seals

Tilting Pad Journal Bearing Research - *Karl Wygant, Ron Flack, and Lloyd Barrett*

Work is continuing on the interpretation of several years' worth of data obtained from the fluid film bearing test rig. A series of test bearings with length-to-diameter ratios of 0.75, offset ratios of 0.5, and assembled radial bearing clearances of 2.90 mils, have been tested. All tests were carried out for speeds of 900 rpm, 1650 rpm, and 2250 rpm. The static loads applied to the test rig result in Sommerfeld number range of 0.1 to 2.0. Predictions using THPAD are being compared to measured eccentricities, film thickness, pressure profiles, and dynamic coefficients (reduced from dynamic forces and resulting vibration displacement).

A brief synopsis of the ongoing research areas in the testing of fluid film bearings follows.

The importance of pivot mechanism on bearing performance:

The emphasis of this research is to establish the influence of pivot mechanisms on tilting pad performance. From previously disclosed experimental measurements of ball and socket pivoted bearings, the hypothesis of pivot friction has been presented. Future tests are helping to validate and quantify this hypothesis. Specifically, research is centering on how pad static loading (directions and magnitudes) influence static and dynamic properties.

Influence of Preload and Sommerfeld Number:

A detailed comparison of analytic predictions to experimental measurements is being completed. This research demonstrates the functionality of tilting pad bearings in the negative preload regime. The importance of this work is twofold. First, the validity of analysis codes to predict bearing properties with negative preloads is being validated. Second, this research establishes the measured trends for a range of preloads and Sommerfeld numbers. This again is an important aspect in the validation of THPAD to experimentally derived data.

Significance of Pad Dynamics on Reduced Dynamic Coefficients:

This research establishes the influence of excitation frequency on tilting pad journal bearings. Sinusoidal forcing functions with frequencies ranging from 0.1X to 10X have been applied to a negative preload test bearing. Plots of stiffness and damping versus excitation frequency at constant Sommerfeld numbers show the importance of including pad dynamics in any analytic endeavor.

Repeatability and Uncertainty:

The rigid rotor fluid film test rig offers unparalleled detail on accuracy and repeatability. Comprehensive work is in progress that tracks both repeatability and the uncertainty of all measurements made in the past several years. This work is meaningful because it provides the confidence level to which analytic validation can be claimed. Also, insights into the non-linearity of bearing properties may be gleaned from this work.

Fluid Film Bearings - *Robert Prior, Ron Flack, and Lloyd Barrett*

The Fluid Film Bearing Test Rig is once again up and running after a short rest-bit between graduate students. Much of this past year has been spent with Rob getting familiar with the operation of the rig and its different systems. This includes the post processing of the data to calculate the dynamic bearing coefficients. All of the rig's instrumentation has been checked and recalibrated where required. Test bearing alignment procedures have been formulated to ensure the bearing is set-up such that the bearing pad is parallel to the shaft. Minor changes have been made in the procedures and reduction routines to improve efficiency. Baseline testing has begun to ensure proper operation of the test rig and data processing. This testing consists of measuring the dynamic coefficients of a bearing that was previously characterized by Karl Wygant and for which the coefficients are known.

In response to the memberships' requests that we modify the rig to attain greater speeds, we have undertaken a study to evaluate the possibilities and rough costs. We found that we can likely increase the operating speed of the test rig to about 4000 rpm without any major system upgrades. We are currently making the needed changes. Thus, future work shall include characterizing similar bearing sizes which have previously been tested, a length to diameter ratio of 0.75, offset ratio of 0.5 and assembled radial bearing clearances of 2.90 mil, but at higher journal speeds.

Labyrinth Gas Seal Code/Program Development - *Jinghui Chen, Paul Allaire, Ron Flack, Rainer Nordmann (Darmstadt University)*

A new gas labyrinth seal analysis code, LABY4, is under development to replace LABY3. Labyrinth seals are composed of seal teeth and chambers between the teeth. Conventional seal codes such as LABY3 often do not accurately predict the rotor dynamic coefficient stiffness and damping. A three volume approach has been developed for the seal analysis: volume 1 - the volume over the seal teeth, volume 2 - the volume over the seal chamber, and volume 3 - the seal chamber. Bulk flow equations are used in each volume with a zeroth order centered flow solution and a first order perturbation flow. The perturbation flow is used to evaluate the seal stiffness and damping properties. At this time, the zeroth order code has been written and is being verified. The 3-D fluid flow code TASKflow, by AEA, is being used to evaluate details of the flow and improve the computer code. The first order perturbation section of the code is under development.

Liquid Annular Seals/Helically Grooved Seals/Program Development - *Paul Allaire, Jinghui Chen, and David Brown (Heriot Watt University)*

It is desired by a number of ROMAC companies to continue to improve the annular liquid seal codes. The new seal code for plain and annular grooved seals, SEAL3, was recently developed and released. The new topics under development are inlet swirl and helically grooved seals. The equations of motion are under development. It is expected that a three volume approach, similar to that for gas labyrinth seals, will be employed

Optimization of Fixed Pad Fluid Film Bearings for Rigid Rotor Machines -*James Byrne, Paul Allaire, José A. Vázquez, Susan Carlson-Skalak*

A fixed pad fluid film bearing optimization computer code has been developed for the design of lower power loss, minimum film thickness and high rigid rotor stability has been completed. It is based upon the code THBRG with some enhanced convergence routines. Bearing length, diameter, preload, pad length and other factors in the bearing are adjusted to produce the optimum design. The optimization method is extended to a two bearing rigid rotor such as found in air conditioning compressors and other rigid or nearly rigid rotors. The code was to be released in 1999. This project is funded by Carrier Corp. of United Technologies, Inc.

Tilting Pad and Fixed Pad Bearing New Governing Equations and Computer Code - *Minhui He and Paul Allaire*

New, more accurate forms of Reynolds and energy equations with cross film viscosity variations have been formulated. These forms allow for the solution of the equations without having to solve a three dimensional finite element code. A two-dimensional finite element formulation has been developed for the future bearing code. Further, the formulations allow for treatment of the new industrial type leading edge and other lubrication methods as well as axial pressure gradients in the bearing pads. Test cases are currently being run to verify the accuracy of the new formulations and an initial code has been developed.

Fluids

Plexiglas Pump - *Daniel Baun and Ron Flack*

The Plexiglas pump apparatus has been modified and magnetic bearings/load cells have been installed which can directly measure the reaction loads at the bearing locations. Both average (static) and instantaneous (dynamic) force measurements can be made. All the bearings have been calibrated to establish their force versus air gap and coil current characteristics. In addition the uncertainties due to hysteresis and the frequency limitation of the bearings have been determined. The complete control and instrumentation system (calibrated differential proximity probes, high output power amplifiers, analogue PID controllers, and data acquisition system) have been installed and their functions verified.

A PC based interrupt driven adaptive open loop controller has been added to the apparatus. The open loop controller can simultaneously control subharmonic, harmonic and superharmonic vibrational frequencies. Practically this means that the synchronous and 4x rotor vibration due to mass unbalance and the blade pass frequency respectively can be attenuated while the rotor is whirled at 1/2x on a user selected orbital path. Control of the rotor vibration and orbit bath are critical for the study of fluid induced impeller/stator interaction forces because the rotor orbital paths between the reference force measurements and the actual hydraulic force measurements must be accurately duplicated.

Force measurement tests have been run for the single, symmetric double and concentric volute pump geometries using both 4 and 5 vaned impellers. Some of the direct force measurements where compared to the forces previously calculated using LV and pressure data. Reasonably good comparison was observed. In addition comparisons with other published force measurements and standard thrust models were made. An extensive study of the effect of impeller-to-casing relative position on hydraulic force and hydraulic efficiency was made for the 4 vaned impeller operating in the concentric volute. Three very interesting and significant finding from this study are: (1) A concentric volute pump can be made to have the same static force characteristic as a conventional log spiral volute pump. (2) A concentric volute pump can be made to have a comparable or even slightly higher efficiency than that of a conventional log spiral volute pump. (3) The optimal impeller-to-casing relative position to obtain (1) or (2) are the same. Some preliminary studies of the static impeller position stiffness for both the single volute and the concentric volute configurations with a 4 vaned impeller were made. Both casings exhibited negative direct stiffness and destabilizing cross-coupled stiffness characteristics. A testing program designed to measure casing/impeller hydrodynamic interaction coefficients (added mass, stiffness and damping) is currently underway. This program will include a comparison between impeller static position stiffness and dynamic impeller stiffness.

Paralleling the experimental work, a computational effort using the commercial CFD code, TASCflow, has been initiated. The goal of this effort is to model the Plexiglas pump and establish good correlation between the forces from the CFD and the direct forces from the apparatus. In addition velocity distributions in the impeller and casing as well as the pressure distribution around the impeller and the casing will by compared to experimental measurements form Miner and Flack 1988 (ROMAC Report #369) and de Ojeda and Flack 1992 (ROMAC Report#438) respectively. Initial comparisons between the CFD results and experimental results for pump performance, static forces, velocity distributions and pressure distributions are good. Using the experience and knowledge gained from modeling the incompressible flow in the Plexiglas pump analogous CFD studies will then be conducted for compressible flows.

Torque Converter - *Mark Gruber, Ron Flack, and George Gillies*

This is an independently sponsored industrial project that has been used to expand ROMAC's experimental flow visualization capabilities and understanding of the mixed flow in multi-element turbomachines. The internal flow field of different torque converter geometries are studied using laser velocimetry at different measurement planes throughout the pump, turbine and stator at three speed ratios corresponding to significantly different torque converter operating conditions. Both steady and periodic velocities are obtained. The effects of blade angles, passage shapes and operating conditions on the internal flow field and blade interactions are studied. From the experimental data, slip factors, mass flow rates, input/output torques, and incidence angles are determined. Results show highly unsteady element interface flows, large separation regions, and circulatory secondary flows in all elements. These inefficiencies can be minimized through valid geometry modifications supported by the experimental results. Collected experimental data is used to validate computational results obtained by a commercially available 3-D Navier-Stokes code.

Cyclone Cleaner - *Mark Fisher, Daniel Baun, and Ron Flack*

This project was sponsored independently by the Technical Association of the Pulp and Paper Industry (TAPPI) and Black Clawson Company and was completed over the past year. Cyclone cleaners are widely used in the paper industry to separate pulp sludge from water that is used as a transport fluid. The water and pulp sludge mixture enters the cyclone cleaner tangent to the inside radius. This causes the fluid mixture to follow the inside surface of the cleaner wall. The result is a swirling flow that produces high tangential velocities. The conical shape of the cleaner causes the inside surface to have a decreasing radius. This decreasing radius generates higher tangential velocities as the fluid moves downward toward the cleaner outlets. These tangential velocities produce centrifugal forces that cause the more massive pulp sludge to move to the outer surface of the cleaner, while the less massive water collects in the center. The separated pulp sludge and water exit the cleaner through two separate outlets at the bottom. Laser velocimetry was used to map the internal flow field in a cyclone cleaner at different inflow conditions. Three-dimensional velocity measurements were documented at several different axial planes. Several significant anomalies were identified including backflow and flow asymmetry. The data collected is serving as a benchmark to evaluate computational models of cyclone cleaners used to optimize and assess geometries.

KSB Pump - *Jens Kuss, Daniel Baun and Ron Flack*

Previous research was an investigation into the effects of discharge geometry and impeller/volute relative position on the hydraulic performance (efficiency, power & total head), and radial hydraulic forces in a centrifugal pump. In addition qualitative flow visualization using streak photography of the flow field in the region of the discharge was conducted. The streak photography results were correlated with the measured hydraulic performance parameters and radial thrust distributions. A number of volutes and discharge configurations were investigated and various impeller/volute relative positions were studied. Different specific speed pumps are currently being tested with the inclusion of surface oil flow visualization.

Experimental Compressor Program - *Eric Maslen, Lloyd Barrett, Ron Flack, and Tom Bernal*

As was revealed at the annual meeting this past summer, we ran into a contract snag on this project with one of the sponsors, McQuay International. After lengthy negotiations, McQuay has decided not to continue their participation, which leaves us without the motor housing, numerous electrical and instrumentation components, and the aero section as well as $25,000 in funding. We are currently in the process of determining whether ROMAC will continue this project and, if so, how it will pay for it.

In the mean time, all engineering drawings for the mechanical components have been completed and component testing has started. Two undergraduate students, Shalini Anand and Trung Hyunh, will complete undergraduate theses on support work for this project: Ms. Anand is working on the controls software and is adding a high speed serial link to the software to permit improved monitor and control; Mr. Hyunh will design some of the components for the test spindle.

Artificial Heart Pump Hydraulic Performance and CFD Modeling

- Houston Wood, Paul Allaire, Edgar Hilton, Anthony Curtas, Jim McDaniel, Nicholas Landrot and Honbo Fan

The artificial heart pump is a very small centrifugal pump designed to be implanted and pump blood in humans. The pump is approximately 4 inches in diameter and 1.6 inches long. The design flow rate of 6 to 10 liters per minute and head of 100 to 160 mm Hg was successfully obtained in both water and blood. Pumps in this small size are not commonly discussed in the pump literature and it is not known exactly how they should perform. Computational fluid dynamic (CFD) methods are being used to model the flow in the pump impeller and clearance passages (approximately 40 mils on each side) using the AEA TASKflow code. Washing flow through the clearance passages is required to keep the flow from stagnating and clotting. Analysis indicates that the impeller generates very strong flow but that the existing large clearances allow high backflow rates of as high as 60% of the impeller flow back through the clearance passages to the inlet. A much smaller clearance (15 mils on each side) would greatly reduce this leakage flow but still provide for the needed washing flow. New prototypes are under construction.

Laser Measurements in Artificial Heart Pump - *Steven Day, James McDaniel and Paul Allaire*

The artificial heart described above will be employed in laser studies of the fluid flow passages. A planar imaging velocimeter (PIV) state-of-the-art laser system will be used to measure the fluid flow in the front clearance passage to evaluate the critical flow parameters. A full two dimensional sheet of light placed in the passage and carefully timed digital illumination allows for the measurement of all of the fluid velocity vectors to be measured at one time, fully capturing the flow properties.

Magnetic Bearings

Self-Sensing Magnetic Bearings

- Eric Maslen and Dominick Montie

We have nearly completed two funded projects in conjunction with Barron Associates, a Charlottesville firm specializing in neural networks and control. The objective of these projects was to extend existing self sensing methods to permit operation into magnetic saturation as well as to produce a hardware demonstration of a rigid high speed rotor in self-sensing magnetic bearings. We expect to have the rotor spinning by the end of this month.

As you may recall from the previous annual report, we have demonstrated through theory and simulation that the underlying strategy of our self-sensing method can permit self-sensing even in the event of partial actuator failure if the actuator is fault tolerant. (See earlier work on fault tolerant magnetic bearings.) We have submitted a proposal to NASA to continue our research to develop this concept for fault tolerant self-sensing, which we believe to be a very promising boost to this technology. In addition, we hope to shortly start work on self-sensing with tristate amplifiers, thereby eliminating a significant shortcoming to our previous work.

Equipment Donations

Keep ROMAC in Mind

If you have any surplus instrumentation lying around which you're about to discard or are not using, please consider a donation to our ROMAC labs. It may be quite useful in our experimental research in fluids, rotordynamics and magnetic bearings. Such usable and relatively recent equipment such as FFTs, oscilloscopes (DSO or analog), DVF-2 or DVF-3, PCs, and any type of transducers (position, pressure, acceleration, etc.) would be greatly welcomed and appreciated, especially since our equipment budget is always small. In return, you may get an immediate capital write-off on taxes from the gift donation.

Magnetic Bearing Loss Measurements - *Andy Braden, Paul Allaire, George Gillies, and Mary Kasarda (Virginia Tech)*

The high speed bearing loss test rig continues in operation. A series of bearings with equal pole face area, equal bias flux, and other comparable properties has been tested. The results so far have shown that the rotor power loss in magnetic bearings is approximately proportional to the bias flux density squared and inversely proportional to the air gap thickness. In contrast to previous theoretical expectations, the loss is independent of the number of poles in the bearing. At this time, a vacuum chamber has been fitted to the test rig to remove the losses due to air drag and concentrate on the magnetic losses in the rotor. It has been successfully pumped down to the system's anticipated operating pressure, and is ready for use. Future bearings to be tested include cobalt iron rotors, thin laminations (7 mil thickness) in the existing heteropolar/homopolar stators. A new homopolar stator has also been obtained from an industrial manufacturer of magnetic bearings. This project is funded by NASA Lewis Research Center.

Magnetic Bearing Finite Element Loss Computer Program - *Robert Rockwell, Paul Allaire, Catherine Lebiedzik, Mary Kasarda (Virginia Tech), Andy Provenza (NASA Lewis) and Jerry Brown (NASA Lewis)*

A 2-D finite element computer code was developed for magnetic bearing configurations. It included the effect of moving magnetic material in the rotor to evaluate the eddy currents generated in the rotor and the power losses. The calculated values gave good correlation to experimental measurements when an effective axial conductivity was used to model the lamination effects. Material saturation effects are currently being added to the code.

A 3-D finite element computer code is under development for computing iron losses in laminated magnetic bearings. It is capable of modeling both heteropolar and homopolar bearings. Eddy current losses in laminated rotors are modeled using an analytical solution for the magnetic vector potential in the rotor. This analytical solution will be coupled to the finite element solution in the rotor to allow for a full solution of the eddy currents in each lamination. This project is funded by NASA Lewis Research Center.

Adaptive Magnetic Balancing of Flexible Rotors Using Singular Value Decomposition Methods - *Williams Foiles, Paul Allaire, Edgar Hilton, Jihao Luo, and Takis Tsiotras*

Adaptive magnetic balancing of high speed flexible rotors supported in magnetic bearings is under development. It uses the singular value decomposition, coupled with an influence coefficient method, to determine the optimum magnetic balancing method for flexible rotors. The Moore-Penrose generalized inverse is employed to solve the problem. The minimum number of balance planes, as well as minimum balance weights, can be used to effectively balance the rotor. The method will be implemented on the magnetic bearing controls test rig. This work is sponsored by NASA Goddard and American Flywheel Systems.

Linear Parameter Varying Controls for High Speed Flexible Rotors - *Jihao Luo, Edgar Hilton, Paul Allaire, Edgar Hilton, Takis Tsiotras (Georgia Tech), Zongli Lin and Hai Zhang*

High speed flexible rotors such as those used for high speed energy storage flywheels have properties which are not time independent. This is due to gyroscopic effects and other changes in the rotor such as centrifugal growth. A new linear parameter varying control method for use with such rotors has been developed. The method produces an overall reduction in vibration amplitude or other rotor parameters over a wide speed range. An algorithm has been developed for a test rig rotor in the controls test rig. At this time, rotor and bearing properties are being evaluated and uncertainties are being estimated. The controller will be experimentally implemented in the near future. This project is sponsored by NASA Goddard and American Flywheel Systems.

Real Time Control of High Speed Magnetic Bearing Systems - *Edgar Hilton, Paul Allaire, Marty Humphrey, and Naihong Wei*

Computer control of magnetic bearing systems requires high speed real time control. The computer system must have high through put rates that should be modular in nature. Newer and faster computers are continually coming online and other components such as A/D and D/A devices are improving as well. A methodology is being developed for implementation of high speed magnetic bearing real time controls using Unix based systems which can include new more advanced hardware as it comes along while only a minimum of software changes need to be made in the system. A system of this type is under development for the controls test rig for rotor operation up to approximately 20,000 rpm. Three suitable computers have been selected and purchased, as described below. This project is sponsored by NASA Goddard and American Flywheel Systems.

Feedback Linearization - *Michael Baloh, Gang Tao, Paul Allaire*

Magnetic bearings are nonlinear devices. A significant advance in modeling of these bearings to linearize them using feedback linearization theory has been developed. This allows berings to operate over a much wider range of clearances and flux values than previous methods. In addition, a new controller algorithm has been developed based upon a hyperbolic control law. It has the possibility of very low power operation for magnetic bearings as compared to conventional bias flux linearization methods.

Magnetic Bearing Controls Test Rig - *Edgar Hilton, Paul Allaire, Naihong Wei, Marty Humphrey, and Takis Tsiotras (Georgia Tech)*

A vertical magnetic bearing controls test rig is under development. It has three bearings: two are employed as magnetic bearings and the third is used as a force actuator. The rotor has been modeled and rap tested extensively for characterization. Also, the rotor has been levitated and characterization of the levitated magnetic bearing/rotor system is underway. A set of three high speed computers will be employed to implement the control system: 1) a system processor, 2) the lateral x,y magnetic bearing controllers, and 3) the axial magnetic bearing controller and the adaptive magnetic balancing system. This project is sponsored by NASA Goddard and American Flywheel Systems.

Artificial Heart Pump Prototype: Electromagnetic Bearings - *Michael Baloh, Paul Allaire, Edgar Hilton, Naihong Wei, Jeff Decker, and Roger Fittro (Aston University)*

The magnetic bearing supported artificial heart project has successfully operated the current prototype (CF3) in both water and blood under a wide variety of operating conditions. The pump is approximately 4 inches in diameter and 1.6 inches long. It is intended to be implanted in humans as a cardiac assist device. The pump hydraulic performance is described in some detail in another section.

There are magnetic bearings in the pump: 1) an inlet side thrust/ moment bearing divided into 8 segments and 2) a discharge side radial/thrust bearing, also divided into 8 segments. The bearings performed well in centering the impeller in the clearance passage in most cases; however, improvements are underway. The former CF3 bearings were constructed of a combination of materials which proved to have some problems so new bearings consisting of all silicon iron are under construction. Also, the load capacity of the very small bearing will be enhanced. The magnetic bearing coil currents were perturbed to identify the bearing and fluid characteristics of the operating pump under a number of operating conditions.

An advanced dedicated compact controller is currently being constructed for this pump using the new TI C60 chip and associated A/D, D/A boards. The new controller will be approximately the size of a textbook. Advanced robust controls work to improve pump performance under various fluid forces acting on the impeller is underway. This project is sponsored by Medquest Products, Inc. and is carried out jointly with the Artificial Heart Lab of the University of Utah.

Electromagnetic/Permanent Magnetic Bearings Design for Artificial Heart Pump - *Jeff Decker, Paul Allaire, Michael Baloh and Brad Pantuck*

A new electromagnetic/permanent (EM/ PM) magnet design has been developed for the artificial heart pump prototype number 4 (CF4). The bearings have a ring configuration which is very compact and efficient. A major objective in this design is to minimize the bearing power consumption due to coil losses. The bearings have a permanent magnet bias flux generation but are controlled with electromagnetic coils. The bearing rings are divided into eight poles each, one for the inlet side of the pump and one for the outlet side of the pump, constructed in such a way as to largely uncouple the ring quadrants from one another. Saturation links are employed to minimize the lift off forces needed to start up the pump. Some simple circuits with similar design have been constructed and are undergoing testing.

One strong candidate for the control approach is that of sliding mode controls. This method provides robust control for nonlinear magnetic bearings using high speed switching amplifiers. It is also suited to self sensing as seen by the successful implementation (listed above). A development effort on sliding mode controls for the rigid heart pump rotor is underway. This project is sponsored by Medquest Products, Inc. and is carried out jointly with the Artificial Heart Lab of the University of Utah.

Physiologic Control of the Artificial Heart Pump - *Yi Wu, Paul Allaire, Milton Adams, Gang Tao and Michael Baloh*

It is necessary to adjust the speed of the artificial heart motor to match the physiologic needs of the human body. Typical activities are 1) sleeping or resting, 2) sitting or other moderate activity, and 3) stair climbing or other highly active needs. The adjustment of the motor speed to these activity levels should be carried out automatically, without patient intervention. A model of the human circulatory system, the artificial heart and a physiologic controller has been developed and is being improved. It has been found that the controller developed so far can effectively control motor speed under certain conditions.

Major Funding Obtained

The Virginia Artificial Heart Center (Faculty Members - Paul Allaire, Houston Wood, James McDaniel, Gang Tao and Milton Adams) received a grant from the National Institute of Health for $2,500,000 to develop the next generation of artificial heart over the next four years. The new heart will be smaller and more power efficient than the previous model. It will be implanted in animals and humans for testing.

Sliding Mode Controls for Rotors in Magnetic Bearings - *Jun-Ho Lee, Xuerui Zhang, Michael Baloh, Paul Allaire and Gang Tao*

Sliding mode control algorithms were developed for an integral sliding mode control of a balance beam. A detailed study was carried out to evaluate the stability limits of the beam-magnetic bearing system with step disturbances. This work is currently being extended to include an artificial heart pump rotor with five degrees of freedom. Both simulations and experimental results were obtained.

Self Sensing Magnetic Bearings Using Using Observer Based Optimal Regulator Theory - *Wei Jiang, Jun-Ho Lee, Michael Baloh, Gang Tao and Paul Allaire*

Controller synthesis methods are being developed to obtain magnetic bearing control with self sensing. Discrete time control is used to stabilize a plant using an observer based optimal regulator. The magnetic bearing currents and voltage signals are measured an the signals are used to evaluate the air gap thickness in the magnetic bearing. The resulting state space control is being implemented on a simple single-input single output balance beam test rig at this time. The method will be extended to multiple-input multiple-output systems in the future.

Rotor Dynamics

Testing of a Flexible Rotor on Flexible Bearing Supports

José A. Vázquez, Lloyd Barrett and Ron Flack

In the flexible rotor rig, a flexible shaft is supported by two identical fluid film bearings. The bearings are mounted on flexible supports on top of a heated oil-filled reservoir. The entire apparatus is clamped to a 900 kg concrete block. This block is isolated from the laboratory floor by rubber pads and additional concrete blocks. The support design is based on a beam type construction with stiffening plates connected at the ends. It is constructed of aluminum with drain holes to accommodate the oil drained from the bearing housing. The stiffness of these supports can be modified in the horizontal direction while the stiffness in the vertical direction remains almost constant. The dynamic behavior of the supports was characterized using frequency response functions (FRF's). The FRF's were obtained using electromechanical shakers and performing a frequency sweep over the range of interest. Transfer functions were obtained from these FRF's using the parameter estimation program TF_IDENT. These transfer functions are then used as the description of the supports in analysis programs such as FORSTAB, ROTSTB and FRESP2.

The rig has been tested with tilting pad bearings and three lobe bearings for 15 support configurations. The measured unbalance response and stability thresholds were used for the experimental verification of the program FORSTAB. Comparisons between predicted and measured unbalance response and instability thresholds were presented at the last annual meeting. The predicted and measured location of the first and second critical speeds agreed within 3.4 % for all support configurations. The predictions of the instability thresholds agree with the experimental data within a confidence bound of 0.01 in the logarithmic decrement. ROMAC report 431 shows the comparison between the predictions using FORSTAB and the experimental data.

Rotor Critical Response Estimation / Model Reconciliation- *Eric Maslen, José A. Vázquez, Tom Bernal, Hyeoung-Joon Ahn*

The first stage of this work was completed last winter by Chris Sortore and reported through his dissertation.

As you may recall from the presentations at the annual meeting, the outcome of this work is two analyses. The first is aimed at determining the best way to estimate rotor responses using available test data, and at the same time, assessing the accuracy of the resulting estimates, including the effects of model uncertainty and unmeasurable disturbances. This analysis can be used in a number of ways. One is to assess experimental methods (accelerometer placement) to determine how well internal motions can be estimated. The other is that the estimator can be used on line for improved condition monitoring and alarming or, in machines with active bearings, for active control of critical clearances.

The second analysis is aimed at improving the fidelity of engineering models by adjusting the model in an intuitively sensible manner to make it match test data. With this tool, you can take the baseline rotor/bearing model that you would use for a machine survey, identify model elements that you think are the most uncertain, and combine this with any experimental data you have for the machine. The analysis tool will automatically adjust the uncertain model elements to make the adjusted model match the experimental data.

We have begun planning for the continuation to this work. Our immediate objective is to develop an

experimental strategy to use the existing large flexible rotor test rig (2.5 m rotor) to corroborate and demonstrate the methods developed in Chris's thesis. We will be helped substantially in this process by the three month visit of a KOSEF fellow, Mr. Ahn. Mr. Ahn is a PhD candidate in the laboratory of D. C. Han at Seoul National University in Korea, with a specialization in sensing, magnetic bearings, and flexible rotordynamics.
Another objective of this continuation work is to find a good way to match these tools to the type of data and models that our industrial partners most commonly use. To this end, we would like to find several industrial members who would be willing to share some data and models with us. The outcome of this effort will be formal software tools with data formats amenable to industrial models and industrial data. If you are interested in participating in this program, please contact Jose Vazquez.

Rotating Machinery Stability Test Rig

C. Hunter Cloud, Lloyd E. Barrett and Eric H. Maslen

With the stability of machinery being a major concern, this project is focusing on addressing two issues: (1) what test techniques are suitable for accurately measuring the stability of a rotor/bearing system, and (2) how do tilt pad bearing characteristics (preload, etc.) and common phenomena such as unbalance influence the actual stability levels and thresholds versus modeling predictions.
To investigate these issues, a test rig is currently being designed which incorporates a 6 foot shaft mounted on 2.75" diameter journal bearings. Magnetic actuators will supply excitation forces in the form of cross-coupled stiffness and non-synchronous forcing. Several tilt pad bearing designs will be tested.
Final design of the rig is expected to be completed in January with construction beginning this coming summer.

Rotor Stability Analysis Including Tilting Pad Thrust Bearings *-Pablo Rodríquez and Lloyd Barrett*

Pablo is continuing his work on including tilting pad thrust bearing models intoFORSTAB. At this stage, he has completed the background research and has developed the dynamic reduction method that will be used to implement the models in FORSTAB.
He is currently programming these models in FORSTAB, and once the routines are properly tested, he will focus on quantifying the effect that tilting pad thrust bearings have on the lateral stability and forced response of rotor systems.
This project has ramifications for including future models into FORSTAB such as disk flexibility. The basic structure of FORSTAB and the tilting pad thrust bearing formulations used here have been chosen to allow for this type of future development.

Singular Value Decomposition Methods for Balancing and Forced Response Analysis of Rotors - *William Foiles, Paul Allaire, and Edgar J. Gunter*

A new method of balancing flexible rotors has been developed. It uses singular value decomposition, coupled with an influence coefficient method, to determine the optimum balancing method for flexible rotors. The Moore-Penrose generalized inverse is employed to solve the problem. The minimum number of balance planes, as well as minimum balance weights, can be used to effectively balance a rotor in the field. The method can also be used to evaluate the worst case unbalance response in the rotor. The method has been applied to some industrial rotor balancing cases and will be verified by application to flexible laboratory rotors. An extensive literature survey on balancing has been assembled and will be published in the Shock and Vibration Digest. A computer code to be employed in industrial balancing is under development.

Analysis and Solution of High Vibration in an Industrial Steam Turbine - *Paul Allaire, Adhemar Castilho (Petrobras), Augusto Gomes (Petrobras), John Nicholas (Rotating Machinery Technology), William Foiles (General Electric), Minhui He, and Jim Byrne (United Technologies)*

A critical path steam turbine used in refinery applications has had a recent history of high vibration problems of a synchronous nature. A very detailed analysis of the rotor, steam turbine casing, and support structure has indicated several problems: 1) operation of the machine near the second critical speed, 2) non-optimized fluid film bearings, 3) an outdated coupling design and 4) an overly flexible support structure. A redesign of the problem components has been carried out and will be implemented. The resulting vibrations have been reduced from approximately 5 mils in the operating range to 0.5 mils.

Rotor Critical Response Estimation -

Eric Maslen and Chris Sortore

Chris Sortore will defend his PhD Dissertation in Rotor Critical Response Estimation in November or December. This work has been very successful in that it has developed methods and tools for determining the predictive accuracy of a combination of rotor response modeling and experimental calibration. Originally intended as a method of obtaining rotor response at critical clearance locations for use in online adaptive balancing (as developed by Carl Knospe), this work has produced an organized approach for reconciling theoretical models to experimental measurements and for assessing the ability of the theoretical model to determine rotor response at locations which cannot be directly measured.

RECENT LABORATORY EQUIPMENT ACQUISITIONS

ROMAC participates in the Commonwealth of Virginia's Equipment Trust Fund (ETF) Program, wherein the University is granted matching funds by the State, towards the purchase of new laboratory equipment for use in its teaching and research missions. This is one particular method in which ROMAC funding gets leveraged relative to our laboratory needs. The fund match from the state is typically one-for-one, thus making it possible, in essence, to purchase new equipment at the equivalent of "half-price" to ROMAC. This year, we have requested that the ETF program sponsor the purchase of two heavy-duty power supplies (60 Vdc, 35 A) for use in the Plexiglas pump rig, and two new Pentium II computer systems for general use by the students in the ROMAC Computer Lab. The very significant amount of computational work done by our students makes it absolutely imperative that we keep our Computer Lab as up-to-date as possible so that code development and related tasks can move forward rapidly and reliably.

Requests for ETF recommendations are solicited early each Summer, and the School of Engineering's total request is considered by the state in the following Fall. A list of approved equipment is subsequently provided to each of the Department Chairs, and purchase requisitions are then placed near the end of the calendar year. Although this is a long lead-time process, the significant financial benefit to ROMAC and its member companies makes it all very worthwhile. Individual items of capital equipment are also purchased directly on an individual basis by ROMAC during the academic year, on an "as needed" basis.

Another mechanism for equipment acquisition is the donation of research hardware to our laboratories. This September we benefited directly from this possibility when SKF Industrial Division's local field engineer, Mr. David Rogers, gave a CMPS90 Bearing Monitoring System to the University. This system, designed and marketed by SKF, includes a CMVL10 Picolog Machine Condition Logger, the Picolog PRISM2 software, accelerometers, cables and accessories. The apparatus is used to acquire vibrational data and analyze it to reveal trends that might indicate impending machine problems or potential bearing failures far enough in advance of such an event to avoid unscheduled downtime for maintenance. Long-term loans and gifts of equipment are very important to ROMAC Laboratories, and we encourage our members to consider this possibility when evaluating their own inventories of test and measurement hardware and software, which might contain surplus items that could be of use to us. Please contact George T. Gillies at (804) 924-6235 for further information.

FOR MORE INFORMATION

We want to hear from you!

Write to ROMAC at the return address given on the next page or contact the Office Manager by telephone at (804) 924-3292 or by fax at (804) 982-2246. We receive Internet electronic mail at:

romac@virginia.edu

Visit our homepage at:
http://www.virginia.edu/romac

Your inquiries, comments, and suggestions will be appreciated. Updates to keep our Industrial Contact List current are always welcome!

ROMAC Short Course
May 23-25, 2000
Rotordynamics

This course will be held at the University of Virginia with no registration fee for ROMAC members. The course will cover the analysis and interpretation of critical speed, forced response, and stability analyses of rotor-bearing systems including bearing support and casing effects and bearing design. The course will be held in one of the electronic classrooms with a computer for each student and will include hands on instruction on the use of ROMAC computer programs. A detailed agenda and hotel information will be sent to ROMAC members in Jaunuary. If you have any further questions, please contact Crystal Besecker at (804) 924-3292 or cds5y@virginia.edu.

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