NEWSLETTER

November 1990

ROMAC INDUSTRIAL COMPANIES

Current list of companies as of November 1, 1990 (* denotes new member).

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

FACULTY/STAFF CHANGES

* <u>Waldemar G. Dahl</u>, Principal Scientist and Director of Technology Marketing for the Center for Magnetic Bearings

* <u>Susan A. Hayes</u>, Programmer/Analyst

* <u>F. Joseph Keith</u>, ROMAC Laboratory Experimental Engineer

* <u>Eric H. Maslen</u>, Assistant Professor of Mechanical & Aerospace Engineering (automatic controls and mag. bearings)

11th ANNUAL ROMAC INDUSTRIAL CONFERENCE

The 11th Annual ROMAC Meeting will be held June 24–28, 1991 at the Fairmont Hotel in San Francisco, CA. We will be sending out registration materials next Spring, and we look forward to seeing all of you again.

STUDENT SUPPORT

The ROMAC program currently has 32 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

Ph.D.
Carol Demas, w/Houston Wood
Myounggyu Noh, w/Paul Allaire
Sonja Smith, w/Houston Wood
Ping Zhong, w/Lloyd Barrett

Masters
William de Ojeda, w/Ron Flack
Steve Fedigan w/Ron Williams
Manuel Grau, w/Lloyd Barrett
Kevin Gruver, w/Ron Flack
Eric Klatt, w/Lloyd Barrett
Dan Maurer, w/Eric Maslen
David Meeker, w/David Lewis
Matthew Stewart, w/Eric Maslen
Subra Sundaram, w/Carl Knospe
Brad Williams, w/Ron Flack

CENTER FOR MAGNETIC BEARINGS

The Center for Magnetic Bearings, which was established by the University of Virginia School of Engineering and Applied Science and Virginia's Center for Innovative Technology (CIT) in July 1989, received \$396,000 from CIT for the period July 1990 – June 1991. The efforts by the Center for Magnetic Bearings during the past year have been well received by CIT, and the entire funding request we made to CIT for this current year was granted.

Mr. Wally Dahl, whom many of you met at the Annual Meeting last June, has joined the Center for Magnetic Bearings as our Director of Technology Marketing. This position is being funded by a special supplement by CIT to this year's budget. Wally is the former CEO of Falkenbridge International, one of the world's largest nickel mining companies, and is assisting us in working with industry to establish magnetic bearing research projects which will help further the acceptance and use of magnetic bearings by industry. His previous business experience is a welcome addition to planning efforts by the Center.

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 Sandy Maslen by U.S. mail or FAX to: 804–982–2037.

ROMAG '91 – March 13–15, 1991

You will be receiving in the next week or two a Preliminary Agenda outlining the program for this Conference and Exhibition. Please feel free to pass this brochure to your colleagues who may wish to attend. Thanks.

ROMAG '91
MAGNETIC BEARINGS AND DRY GAS SEALS INTERNATIONAL CONFERENCE & EXHIBITION
March 13–15, 1991 Washington, D.C. USA

Exhibits and technical information on magnetic bearings, magnetic supports, and dry gas seals. Current and future impact on pumps, centrifuges, turbines, compressors, and seals. State of the art technical presentations. Turbomachinery users discussion groups. Vibration and active support isolators will be a special topic of discussion.

Tutorial on magnetic bearing fundamentals. Exhibitors should make reservations now.

Contact: Prof. David Lewis,
Center for Magnetic Bearings,
Dept. of Mechanical and Aerospace Engineering,
Univ. of Virginia, Charlottesville, VA 22901, USA
TEL: (804) 924-3292
FAX: (804) 982-2037.

DATA ACQUISITION SYSTEM

A data acquisition and analysis system for general laboratory use is currently being developed. Assembled around a 20 MHz 386–based computer specifically designed to accommodate a large number of peripheral plug–in cards, this system will be capable of simultaneously sampling 12 analog signals at a continuous 50 kHz rate, or 48 signals at reduced rates. The system also includes counters, timers, D/A converters and an IEEE 488 interface to facilitate computer–controlled testing, waveform generation and data transfer from other laboratory equipment such as digital storage oscilloscopes and spectrum analyzers. System software includes both a commercial data analysis package (DADiSP) and specialized in–house code for controlling the various peripheral devices.

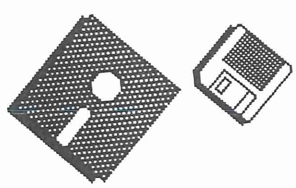
COMPUTER PROGRAMS

EZ – Susan Hayes

After compiling comments from the members at the last Annual Meeting and additional comments from people who have reviewed EZMENU, we have revived our efforts. We have tried a few other things in the past (including EZMENU – written in QuickBasic) but now in reviewing your needs, we have chosen C–worthy – an Interface Library. This program will make our software work similar to many of the software packages available today with input screens, menu systems, and mouse capabilities. We are taking into account the discussion and comments from the '89 ROMAC Users Group and the Annual Meeting this past June at Wintergreen.

Work is well underway and we hope to have a prototype version sometime in December. Since this is a program for the users we would still like the users heavily involved in the development and will send out beta versions once again for comments.

If you would like to be considered a beta test site, please contact Susan Hayes at 804–924–6234 or by e-mail at:
sah6j@virginia.edu (Internet)
or sah6j@virginia (BITNET).



TWIST2 – Some minor changes and error checking have been added to TWIST2.

1. Subroutine JACOBI, the algorithm that solves for eigenvalues, was put into double precision due to roundoff errors encountered on some machines.

2. Error checking to make sure parameter statements are correctly set to handle the input file.

3. It was found that during the transformation to modal coordinates, the rigid body mode was not included in the forced response section of TWIST2. We have now added the rigid body mode, and found that the forced response output values vary slightly. Note that the eigenvalues are still correct. If you are using TWIST2 for forced response, please let Susan know and she will send you an updated copy when it becomes available in the next month.

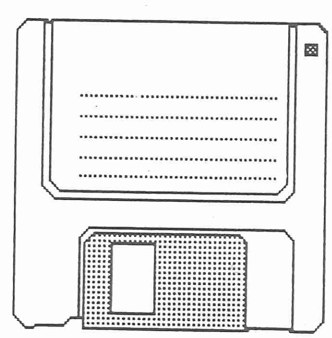
MAGDES – The program MAGDES, written by Joe Imlach, designs radial magnetic bearings. MAGDES runs on a PC and is written in TRUE BASIC. There are plans for a future version to be written in FORTRAN, but in the mean time if you would like a copy, the executable code will run on your PC.

AXMAG – AXMAG is a FORTRAN program that has been successfully used to design magnetic thrust bearings for a number of applications. It allows unformatted data entry, takes leakage and fringing effects into account, and can be run in both batch and interactive modes.

HYDROG1 – HYDROG1 is a program written by John Kocur for his dissertation entitled "Dynamic Analysis of Liquid Lubricated Hydrostatic Journal Bearings". This program is now available in a PC version. Please note that this program is calculation intensive and takes up to four hours for our test case.

ROMAC Metric Programmes – This program, as demonstrated by Vibrakon at the Annual Meeting, is available upon request and will be distributed to all members at the 11th Annual Meeting.

Another project that Susan Hayes and Deb Dhar are currently working on is the FRESP4 PC version. Because it is such a large code, we have only been able to have it running a very small model on the PC.



CURRENT LABORATORY RESEARCH PROJECTS

FLUID FLOWS

3–D Viscous Flow Simulations in Rotating Impeller Channels having Complex Geometries – Qingping Shi

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

(1). The computational grid is generated with a surface grid generation system proposed by Shi. It employs space–marching iteration to generate a 3–D grid with 2–D computer storage.

(2). The parabolized transport equations are used.

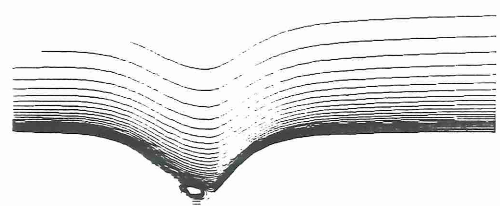
(3). A Coriolis–modified numerical procedure developed by Shi is applied. This scheme includes the influence of the Coriolis force on pressure corrections. Also a two–step pressure correction proposed by Rhie was modified to consider grid nonorthogonality and the contravariant velocity components are used instead of the scaled velocity components along curvilinear coordinate directions.

(4). Coriolis–modified $k - \epsilon$ turbulence models are used in the simulations.

The 2–D results were reported at the Wintergreen meeting and the 3–D version has recently begun to work. The geometry and the flow conditions of the radial discharge impeller tested by Eckardt are being used for the simulations. Rotation rates as high as 14,000 RPM have been successfully run.

A Numerical Simulation of Flow Separation in Centrifugal Diffusers – Gerry O'Leary

Experimental results in vaned centrifugal diffusers have shown that maximum pressure recovery occurs when the flow is just on the verge of separating from vane surfaces. To assist in designing for this max–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 new 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 in the literature. Development is continuing on methods to model adequately the wake region formed as the separation flow leaves the centrifugal diffuser guide vane. Future testing of turbulence models will, by nature of this overall approach, be restricted to the narrow boundary–layer flow region. Three–D modeling is still a current development objective.



Plexiglas Pump – Willy de Ojeda

Recently, 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 are being collected for both geometries. By comparison of the two sets of data, quantitative comparison of the static pressure forces will be possible. LV data will also be 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, a new graduate assistant.

Torque Converter–Kevin Gruver

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. 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, a new graduate student.

Cross–Coupling – Amish Thaker

Existing ROMAC computer program POT2D is being modified to enable calculation of cross coupling coefficients for centrifugal pumps. Steve Miner's code has been modified to allow whirling motion of the rotor shaft, and forces are currently being computed for both whirling and nonwhirling cases. Forces obtained for different whirling geometries will be used to calculate the cross coupling terms which will then be compared with measurements reported in the literature.

Secondary–Flow Modeling in a Centrifugal Pump – Avichal Mehra

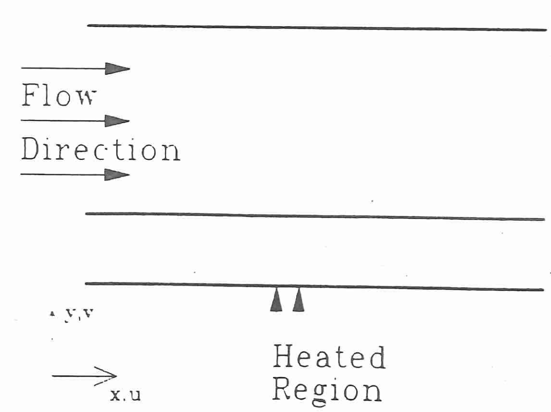
A finite–difference code is being developed to simulate accurately the flow in a blade channel of a centrifugal pump. The code quantifies the effect of secondary flows on forces and flow rates, thus enabling the designer to modify the geometry so as to achieve the required specifications. The emphasis is on a rapid solution algorithm and adaptability to a typical workstation or mainframe. Initial results are sought for a 15° log–spiral blade geometry. Mild boundary–layer separation can be treated reasonably well, and tip leakage will be included in a later version.

Diffuser Rig – John Ludden

The existing diffuser rig that was previously used for visualization and LV measurements is being modified by John Ludden, an undergraduate assistant. He will be replacing the circular arc curved blades in this constant head facility with triangular or wedge blades. His responsibility will be to modify the rig to accommodate different blade geometries and different numbers of blades and to make preliminary flow visualization studies with dye injection. The results will be used for comparison to predictions.

Convective Cooling – Rob Carlisle

We are proceeding with the modeling of internal coolant flows. The model involves marching of the finite difference representation of the two–dimensional reduced Navier–Stokes equations down a coolant passage. The model includes consideration of the effects of variable thermophysical properties of hydrogen, axial conduction in the passage walls, and the coupling of the energy & momentum equations in the flow.



FLUID FILM BEARINGS AND SEALS

Bearing Test Rig – Brian Pettinato

Brian Pettinato is currently readying the test rig for more bearing tests. He is retracing the steps of previous work and duplicating previous tests. When these preliminary studies are completed, he will be testing three lobe bearings with different preload and offset factors. 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.

Seals – Brad Williams

Brad Williams, a new MS student, is presently making some preliminary studies with LABY2, the labyrinth seal program. Over the past few weeks, a few indications that the program did not always converge have been brought to our attention. Brad is investigating why these problems are occurring and also comparing predictions of stiffness and damping coefficients from LABY2 to new data available in the literature since the program was written. The preliminary studies will indicate if dedicating a full time MS study is warranted or if the problems can be solved in a shorter period of time.

Misalignment and Other Film Thickness Effects in Fluid Film Bearings

Manuel Grau, a graduate student studying for a MS degree, is performing research in hydrodynamic bearing analysis. He is currently examining the effect of journal misalignment on bearing characteristics and ways that misalignment can be included in the rapid bearing calculation schemes used in TEMBRG and THBRG. He will also be making modifications to THBRG and possibly THPAD to incorporate user defined "non–standard" film thicknesses. He is also assisting Brian Pettinato in comparisons of our bearing program predictions to data from the bearing test rig.

We appreciate the help from those industrial users who have sent example bearings and suggestions for bearing geometries to consider.

EXPERT SYSTEMS

This work is to produce software that can aid in diagnosing rotating machinery problems. A user friendly editor has been written to expedite the addition of rules. One facet of the program is to better classify spectral information. One approach being pursued by Jim Morelli, a current Master's student, is through neural network analysis and may be useful in optimizing control algorithms and especially for the case of multiple–input multiple–output systems with some "cost" function that may be complicated.

ROTOR DYNAMICS

Bearing Optimization for Flexible Rotor Stability

Deb Dhar, one of our laboratory engineers and a Ph.D. candidate, is working 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.

As a laboratory engineer, Deb has been actively working with Susan Hayes and industrial members in using and modifying some of the ROMAC rotor dynamic and bearing programs.

Reduced Order Models for Improved Rotor Dynamic Analysis

Sriram Srinivasan, 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 supplements earlier efforts by Jim Bielk and Leon Hassenpflug in this area, and we anticipate being able to incorporate both reduced order models and previously developed rapid solution techniques to further reduce analysis time. 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.

Including Complete Tilting Pad Bearing Models in Rotor Stability Analyses

Ted Brockett, an MS student, is nearing completion of his work on including complete tilting pad bearing representations into the ROTSTB stability program. He is employing a dynamic condensation technique similar to that used by Jim Bielk in FSTB3, 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 into ROTSTB and to including magnetic bearing and controls models into our rotor dynamic programs.

Incorporating Rotor Casing Models into Rotor Stability Analyses

Karl Wygant, also working toward an MS degree, 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–collocated magnetic bearing sensors into a ROTSTB type analysis method. His efforts are laying the groundwork for including experimentally obtained dynamic information into more of our rotor dynamic analysis programs.

Bearing Optimization for Force and Vibration Transmission Reduction

Sungwon Lee, another Ph.D. student, is continuing his work in optimizing bearings to minimize force and vibration transmission to supporting structures. He is particularly interested in the application to shipboard mounted machinery. He is using frequency response function techniques similar to those used in the FRESP programs developed by Chip Queitzsch several years ago. His work is also a useful adjunct to magnetic bearing efforts in vibration isolation work currently underway or planned, in the laboratory.

MAGNETIC BEARINGS

Digital Control of Magnetic Bearings – Ron Williams, John D'Addio, Joe Keith, and Steve Fedigan

The effort to develop digital control for magnetic bearings has continued this year with an increased emphasis on practical control implementations. The new work within ROMAC has moved away from independent axis PID control and toward more powerful and flexible algorithms. A control computer that will serve as powerful laboratory controller testbed is currently under construction.

The new controller is based upon a floating point digital signal processing computer. This computer is approximately two orders of magnitude more powerful than the typical personal computer when compared in terms of floating point operations per second. This machine has been designed to provide control for five coordinated magnetic bearing axes. Multiple input multiple output control algorithm support is anticipated with this machine, and this control will be accomplished with sampling rates of up to 50,000 samples per second per axis. This should be sufficient to permit control of the fastest rotors currently anticipated by ROMAC.

The integration of this new controller with power switching amplifier modules will provide a flexible environment in which the control algorithm designers can develop and test their new algorithms. The entire controller system has been designed in a modular fashion so that future adjustments, modifications, and extensions will be manageable. Also, since hardware and software have both been designed and implemented by ROMAC faculty and staff, we retain the greatest possible flexibility in support of our projects.

Magnetic Actuator Design – Paul Allaire, Patrick Depret–Guillaume

Recent research in magnetic actuator design has yielded new design strategies resulting in more nearly optimal structures which achieve significantly better force to weight ratios than for our previous designs. We have acquired a 2–D finite element analysis package for magnetic structures and have begun using this tool to further optimize our actuator designs and to calibrate the analytic design equations we use at the preliminary design stage.

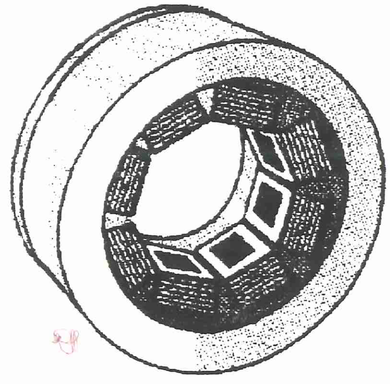
The design of a set of high temperature magnetic bearings is in progress with an initial target operating temperature of 800°F. These are fairly large bearings with a radial capacity of 500 lb and a thrust capacity of 6000 lb.

Electric Motor Rig – Matthew Stewart

Work is well under way on a portable demonstrator magnetic bearing rig with an integrated midspan electric motor. The midspan motor provides a substantial instability mechanism, making the dynamics of this rig quite interesting. We hope to have this rig running at the ROMAC conference next June.

Sensor Design – Daniel Maurer

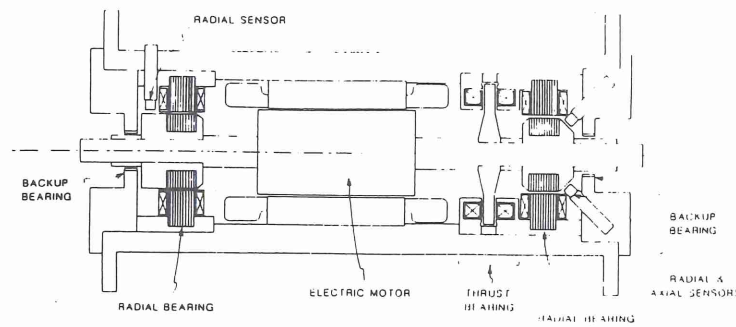
In response to a growing need for position sensors with configurations and operating characteristics not commercially available, a program has been initiated to develop our own sensors. Objectives include full quadrant differential sensors for reduced noise, low frequency inductive sensors which can "see" through canning, and a direct digital probe for efficient interfacing to our digital controller.



Controller Design – Eric Maslen

A study of controller synthesis for rotor suspensions has been completed. This work examined the use of observer based state feedback with load models to derive dynamic controllers for rotor stabilization and response optimization. The mathematical formulation for the general n–rotor, m–sensor, p–actuator problem was developed and examined for some realistic rotors. Common effects such as sensor–actuator noncollocation and sensor/amplifier bandwidth limitations are readily accommodated in this formulation. Although the results of this study are not yet ready for direct hardware implementation, it does lay the essential framework for a practical synthesis procedure and clearly indicates the achievable performance as well as some of the real pitfalls.

COMPRESSOR / BEARING LAYOUT



Open Loop Control for Vibration Reduction – Carl Knospe, Bob Humphris, and Subra Sundaram

Magnetic bearings permit much greater control of rotor dynamics than conventional bearings and may be used to reduce synchronous and harmonic response. Open loop control is achieved through the injection of synchronous signals into the magnetic bearing coils on top of the feedback control used to achieve stable suspension, stiffness, and damping. The bearing properties, system stability, and transient response are not affected. The open loop control produces a rotating magnetic field on the shaft which acts to counter the rotor's vibration.

Open loop control has recently been demonstrated on a simple magnetic bearing rotor rig. When the rotating magnetic fields were properly adjusted, a two hundred fold reduction in midspan orbit at the first critical speed was achieved. The magnetic fields were also adjusted to minimize the vibration transmitted to the foundation. A two hundred fold reduction in the synchronous transmitted vibration was also achieved. We are about to begin a detailed testing program to supplement these results.

When the new digital controller becomes available in 1991, it will be programmed to perform the open loop control. The proper rotating magnetic fields will be found automatically through estimation algorithms. The open loop control strategy will then be adaptive, following any changes in the unbalance, rotor dynamics, or running speed.

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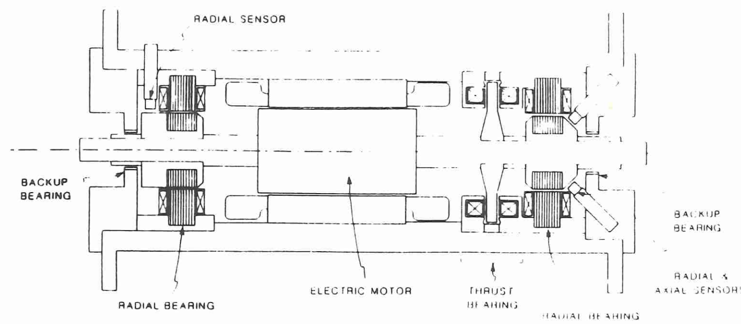

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