ELECTROMAGNETIC DAMPERS FOR CRYOGENIC APPLICATIONS

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ABSTRACT

Cryogenic turbomachinery of the type used to pump high-pressure liquid hydrogen at -423 °F and liquid oxygen at -297 °F to the main engines of the space shuttle are subjected to lateral rotor vibrations from unbalance forces and transient loads. Conventional dampers which utilize viscous fluids such as bearing lubricating oil cannot be used in turbopumps because the bearing compartments are filled with either liquid hydrogen or liquid oxygen. Liquid oxygen and liquid hydrogen have a viscosity comparable to air and, therefore, are not effective in viscous dampers.

Electromagnetic dampers are currently being explored at Lewis Research Center as a means of providing damping in cryogenic turbopumps because their damping effectiveness increases as temperature decreases and because they are compatible with the liquid hydrogen or liquid oxygen in the turbopumps. Therefore, these dampers make effective use of the cold environment inherent in cryogenic turbopumps.

OVERVIEW

ELECTROMAGNETIC DAMPER

Electromagnetic dampers are being explored at the Lewis Research Center as a means of damping rotor vibrations in cryogenic turbopumps. Use of this damper in turbopumps can extend bearing life and can lead to more reliable, less costly turbopumps.

- **DAMPING IS ACHIEVED BY GENERATING AN ELECTRICAL CURRENT AND DISSIPATING THE ENERGY AS HEAT.**

- **APPLICATION—SPACE SHUTTLE MAIN ENGINE TURBOPUMPS**

- **BENEFITS**
  - **CAN TOLERATE LESS ACCURATE ROTOR BALANCE**
  - **INCREASES BEARING LIFE**
  - **PROVIDES MORE LATITUDE IN ROTOR DESIGN**

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WHY USE ELECTROMAGNETIC DAMPERS IN TURBOPUMPS?

Choices of damping methods for cryogenic turbopumps are limited because of the cold temperatures and the very low viscosity of cryogenic fluids. Electro-magnetic dampers are very desirable for turbopump applications because they are compatible with cryogenic fluids and because their effectiveness is enhanced at the low cryogenic temperatures.
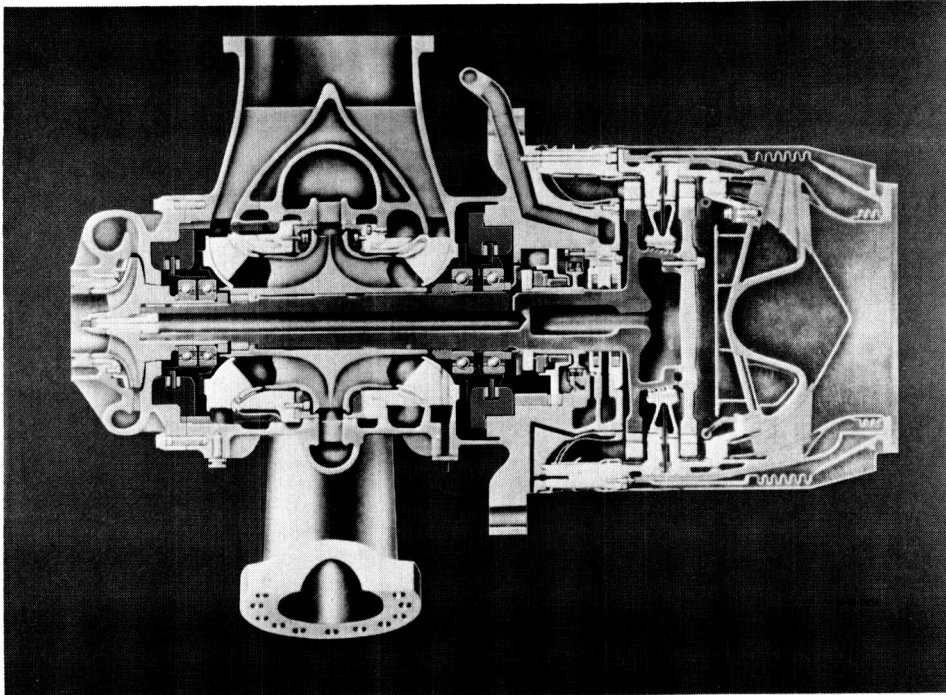
- **VISCOUS DAMPERS REQUIRE HIGH VISCOSITY FLUIDS (INCOMPATIBLE WITH TURBOPUMP FLUIDS).**

- **FLUIDS FOUND IN TURBOPUMPS HAVE VERY LOW VISCOSITY (COMPARABLE TO AIR).**

- **ELECTROMAGNETIC DAMPER EFFECTIVENESS IS GREATLY ENHANCED AT CRYOGENIC TEMPERATURES.**

- **ELECTROMAGNETIC DAMPERS ARE COMPATIBLE WITH TURBOPUMP FLUIDS.**

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HIGH-PRESSURE OXYGEN TURBOPUMP

Shown in the figure is a typical turbopump used in the space shuttle main engines to pump liquid hydrogen and liquid oxygen to the space shuttle main engines. These pumps have been plagued with rotor vibration problems and short bearing life. Electromagnetic dampers are being explored at Lewis Research Center to help solve these problems.
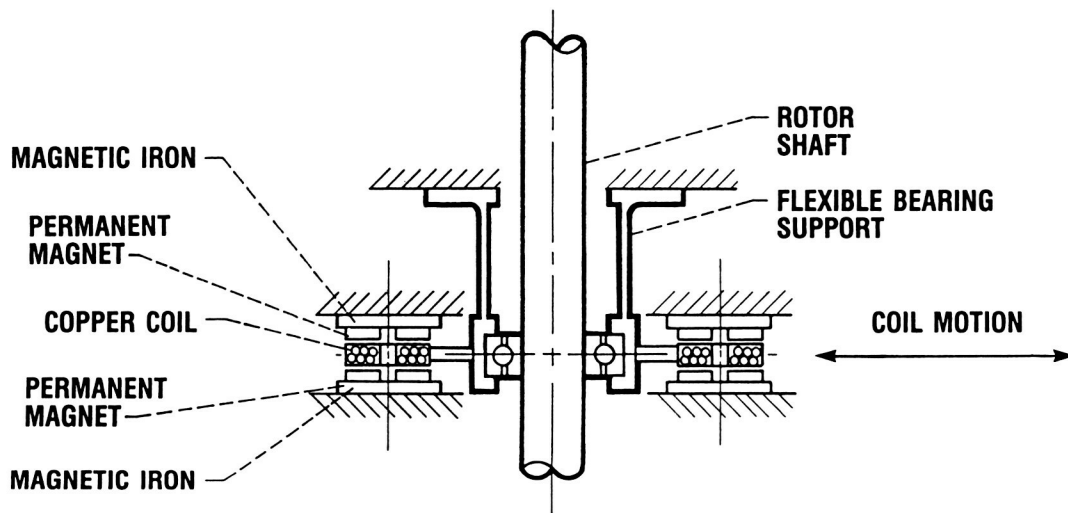
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ELECTROMAGNETIC DAMPER SCHEMATIC

This figure shows a schematic of an electromagnetic damper. This type of damper converts energy from an unwanted mechanical vibration to an electrical current and dissipates the energy as heat. It is particularly well suited to the cold environment found in turbopumps because their damping effectiveness increases at low temperatures.
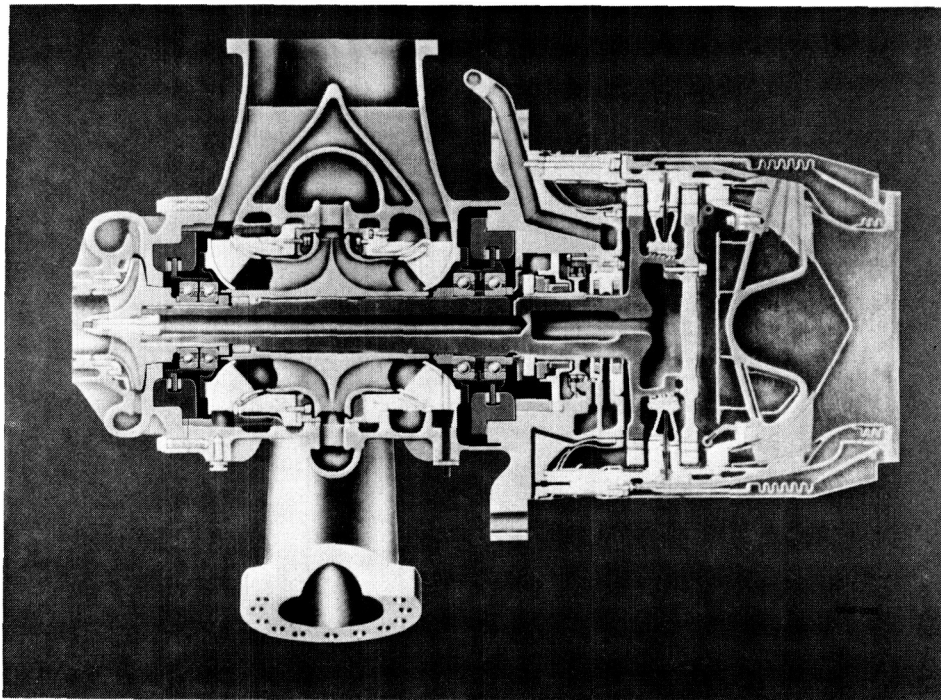

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POSTER PRESENTATION
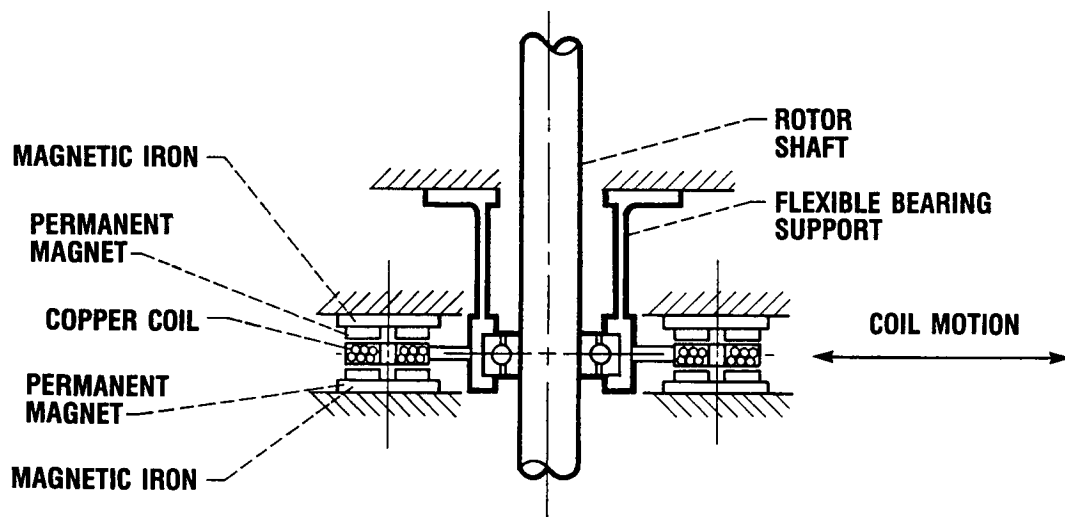
HIGH-PRESSURE OXYGEN TURBOPUMP

This picture shows a high-pressure liquid oxygen turbopump of the type used in the space shuttle main engines. These pumps have rigidly mounted bearings which are submerged in liquid oxygen; hence conventional viscous dampers using lubricating oils cannot be used for damping purposes. Electromagnetic dampers are being explored as a means of providing damping in these pumps. Use of electromagnetic dampers in these pumps could provide greater flexibility in the design of turbopump rotors and also could permit less precision in balancing the rotor.

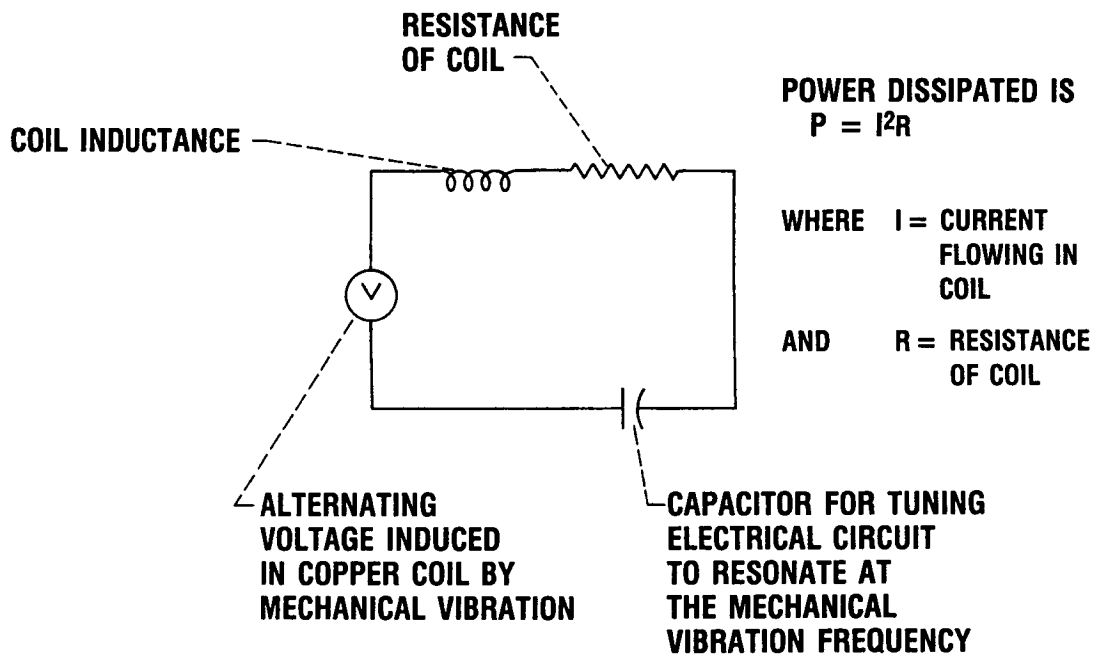CD-88-31904

ELECTROMAGNETIC DAMPER SCHEMATIC

This figure shows a typical schematic of an electromagnetic damper. The prin-
ciple elements of the damper are permanent magnets, copper coil, and magnetic
iron. The coil (nonrotating) is rigidly attached to the bearing housing. Lat-
eral vibration of the bearing housing produces a coil motion, as shown in the
figure. This motion causes the coil conductors to cut the flux lines of the
permanent magnets, thereby generating a current in the coil. The current
flowing in the coil causes the coil to heat up. This heat is dissipated in
the liquid oxygen, thereby providing damping for the vibrating bearing housing.

MAGNETIC IRON

PERMANENT
MAGNET

COPPER COIL

PERMANENT
MAGNET

MAGNETIC IRON

ROTOR
SHAFT

FLEXIBLE BEARING
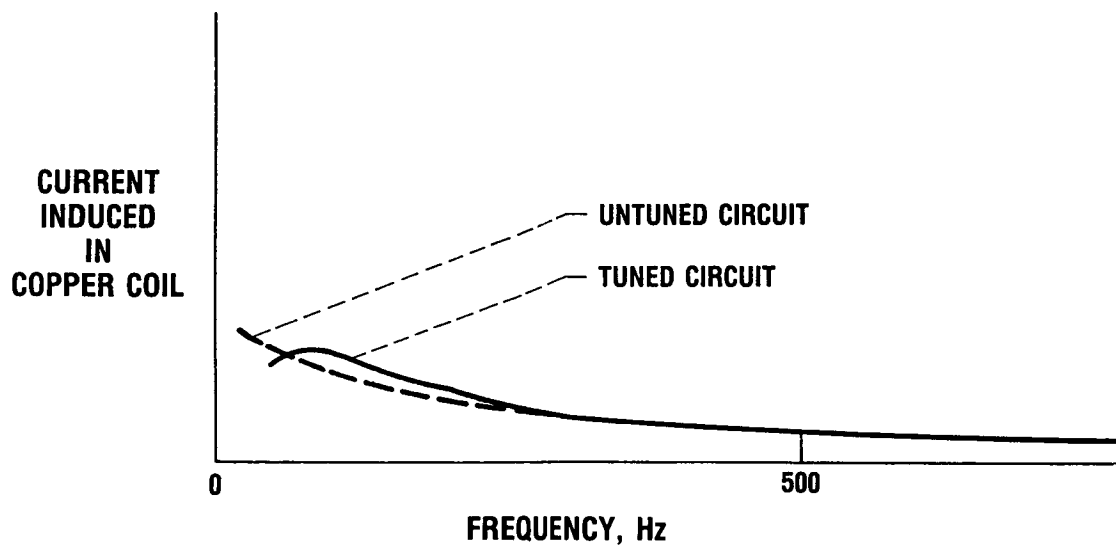SUPPORT

COIL MOTION

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In order to maximize the current generated in the coil, a capacitor is placed in series with the coil. This forms a series circuit with resistance, capacitance, and inductances, as shown in the figure. The resistance is the coil resistance, and the inductance is the coil inductance. This circuit can be tuned such that the current flowing in the coil is maximized at the frequency of the vibrating shaft. The tuning is accomplished by selecting the capacitance such that the electronic circuit has a resonant frequency equal to the mechanical shaft vibration. Tuning the electronic circuit to the mechanical vibration frequency thus maximizes the effectiveness of the damper.

RESISTANCE OF COIL

COIL INDUCTANCE

POWER DISSIPATED IS
$$P = I^2R$$

WHERE I = CURRENT FLOWING IN COIL

AND   R = RESISTANCE OF COIL

ALTERNATING VOLTAGE INDUCED IN COPPER COIL BY MECHANICAL VIBRATION

CAPACITOR FOR TUNING ELECTRICAL CIRCUIT TO RESONATE AT THE MECHANICAL VIBRATION FREQUENCY

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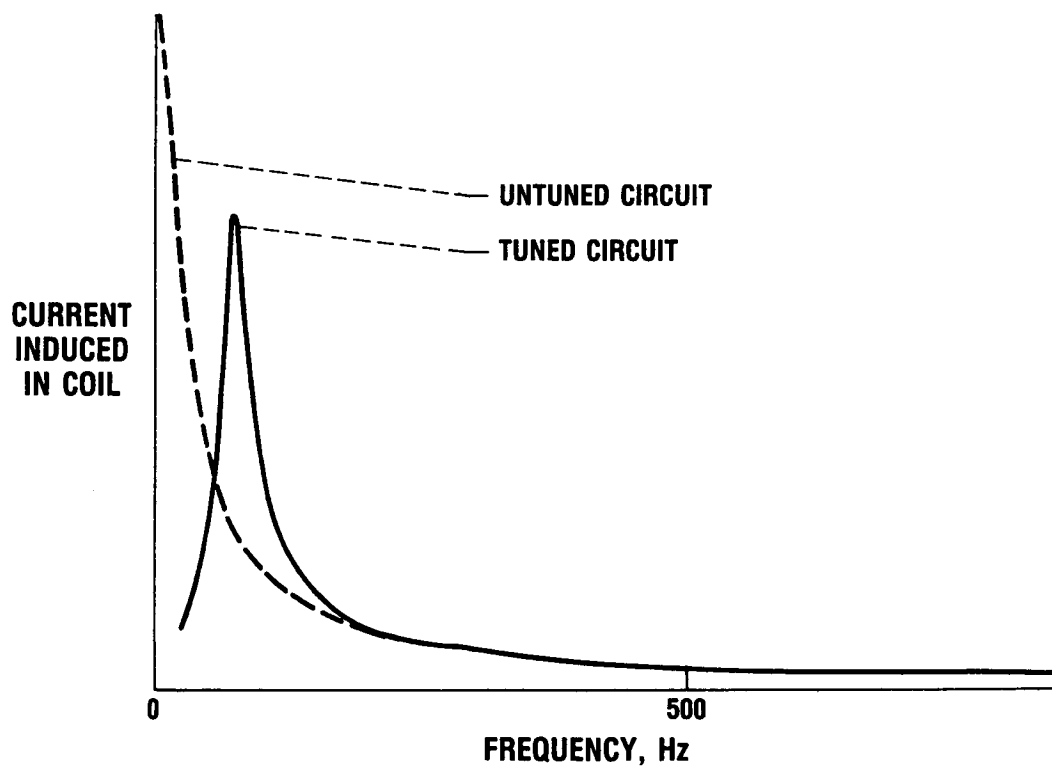CURRENT INDUCED IN COIL VERSUS FREQUENCY - ROOM TEMPERATURE

This figure shows the current generated versus frequency for typical tuned and untuned circuits at room temperature. This illustrates that at room tempera- ture there is a negligible difference between the tuned and untuned circuits. Also, the current is low.

CURRENT INDUCED IN COPPER COIL

— UNTUNED CIRCUIT

— TUNED CIRCUIT

0   500

FREQUENCY, Hz

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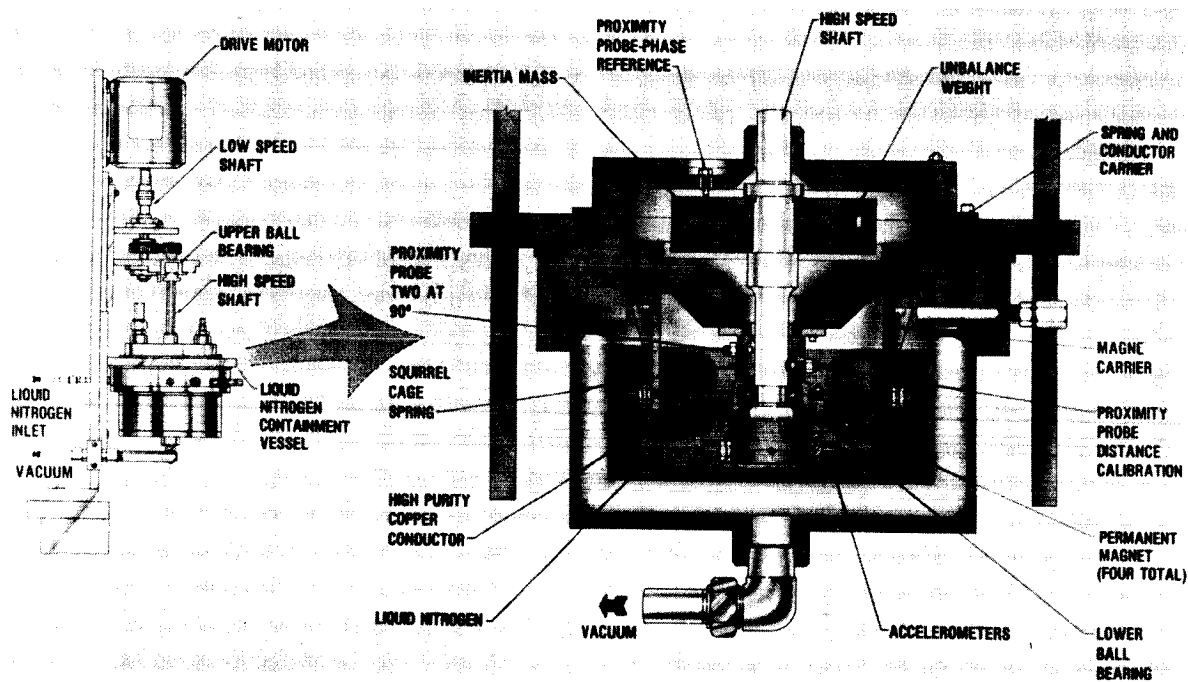## CURRENT INDUCED IN COIL VERSUS FREQUENCY − LIQUID NITROGEN LOW TEMPERATURE

This figure shows the current generated versus frequency for tuned and untuned circuits at liquid nitrogen temperature (-321 °F). At the tuned frequency, the current output is much higher for the tuned circuit than for the untuned circuit. This illustrates the effectiveness of the damper at cryogenic temperatures.

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ELECTROMAGNETIC DAMPER TEST APPARATUS – LIQUID NITROGEN

This figure shows a rig which is used for conducting electromagnetic damper experiments in simulated cryogenic turbopump conditions. The electromagnetic damper is submerged in liquid nitrogen at –321 °F. Vibration of the lower bearing housing is induced by unbalancing the rotor disk. Damper performance is evaluated by measuring lateral shaft displacements (shaft orbits) and processing these data in a computer to get synchronous rotor response and damping ratio.

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SUMMARY

Research on electromagnetic damping for cryogenic applications is being explored at Lewis Research Center. The program is oriented towards providing new damping methods for cryogenic turbopump rotors of the type used in the space shuttle main engines. Research to date has shown that this type of damper must be electronically tuned to the frequency of the mechanical vibration in order to be effective as a damper. This is accomplished by forming a series "resistive, inductive, capacitive circuit" and selecting the capacitance such that the circuit is tuned to the frequency of the mechanical vibration. Research testing of the tuned cryogenic electromagnetic damper is planned for the near future.

PARALLEL COMPUTING

SESSION OVERVIEW

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Structural Dynamics Branch
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Our knowledge of the physical processes that interplay within the complex dynamic environs of modern turbomachinery exceeds our ability to compute their overall effect. We can analyze aspects of most of the important processes effects, but we cannot readily compute their overall impact on system response.

We cannot design an engine mathematically today - we need experimental versions to "adjust" our mathematical models. There are several reasons for this. First of all, we do not always understand the physical interactions between processes such as those between thermal effects on basic material properties, the coupled aero-structural response of blades made from such materials, and the coupling of such blade vibrations with net rotor-shaft system response. Understanding of physical process interactions like these requires further study. Secondly, we are unable to adequately numerically simulate many fundamental processes. Much of this conference addresses these first two problems with development of numerical simulations of the most significant engine phenomena. The third and final problem is one of even being able to compute those processes which we understand and which we can reasonably simulate. The computing problem can rapidly exceed the capacity of today's computers. These complex problems become so large that they will only be solved by breaking them into parts which can be simultaneously solved in parallel computer systems. This session deals with some initial work to develop needed parallel computing methods for structures.

Generally, there are three areas of interest. First, there may be fundamentally new approaches for solving traditional problems which "map" well onto parallel computers - with great increases in computing speed and efficiency. The talks on multigrid analysis and parallel eigenvalue extraction are in this first category. Secondly, tools are needed to help formulate and construct parallel computing programs which, by their very nature, can be exceedingly complex and difficult to manage. The presentation on adapting high-level language programs using data flow and the poster session for doing graphical computations in parallel are in this second category. The third area of interest involves making use of our current huge investment in existing single-processor mathematical methods and models (such as finite-element models) and our need to adapt these models to the parallel processing. The presentation of iterative finite-element solvers is in this category.

These are only the first steps toward the eventual coupling of complex physical system models which will enable "mathematical" engine system design as well as the detailed study of various interactions within engine systems.

PARALLEL COMPUTING

SESSION OVERVIEW
- L.J. KIRALY, CHIEF, STRUCTURAL DYNAMICS BRANCH, NASA

MULTIGRID FOR STRUCTURES ANALYSIS
- A.F. KASCAK, U.S. ARMY AVSCOM/STRUCTURAL DYNAMICS BRANCH, NASA

PARALLEL COMPUTER METHODS FOR EIGENVALUE EXTRACTION
- F. AKL, OHIO UNIVERSITY, ATHENS, OH

ADAPTING HIGH-LEVEL LANGUAGE PROGRAMS FOR PARALLEL PROCESSING USING DATA FLOW
- H.M. STANDLEY, UNIVERSITY OF TOLEDO, TOLEDO, OH

ITERATIVE FINITE-ELEMENT SOLVER ON TRANSPUTER NETWORKS
- A. DANIAL AND J. WATSON, SPARTA, INC., HUNTSVILLE, AL

MULTIPROCESSOR GRAPHICS COMPUTATION AND DISPLAY USING TRANSPUTERS (POSTER)
- G.K. ELLIS, STRUCTURAL DYNAMICS BRANCH, ICOMP

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