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
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. Electromagnetic 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.

- VISCOS DAMPERS REQUIRE HIGH VISCOITY FLUIDS (INCOMPATIBLE WITH TURBOPUMP FLUIDS).

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

- ELECTROMAGNETIC DAMPER EFFECTIVENESS IS GREATLY ENHANCED AT CRYOGENIC TEMPERATURES.

- ELECTROMAGNETIC DAMPERS ARE COMPATIBLE WITH TURBOPUMP FLUIDS.
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.
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.
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.
ELECTROMAGNETIC DAMPER SCHEMATIC

This figure shows a typical schematic of an electromagnetic damper. The principle elements of the damper are permanent magnets, copper coil, and magnetic iron. The coil (nonrotating) is rigidly attached to the bearing housing. Lateral 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.
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.
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 temperature there is a negligible difference between the tuned and untuned circuits. Also, the current is low.
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.
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.
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.
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 funda-
mental processes. Much of this conference addresses these first two problems
with development of numerical simulations of the most significant engine phe-
nomena. 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 sys-
tems. 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 fundamen-
tally 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 inter-
est 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 physi-
cal 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