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Novel Damping Concepts for Mechanical Backup Bearings and Passive Magnetically Suspended Rotors

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The following summarizes the research accomplished under the titled project. The period of research extended from August 2001 to August 2002. The team of researchers consisted of two Senior Research Associates: Mark Siebert and Carl Buccieri, one PhD student: Pete Kenney and one faculty member: Theo Keith, who was the P.I. Karen Balog was the Program Coordinator. The research was performed at both the NASA Glenn Research Center (GRC) in Cleveland, Ohio and at the University of Toledo. Accordingly, periodic group telephone meetings were held with the team members, the NASA technical coordinators and several other University of Toledo researchers working on-site at GRC.

Two passive magnetic bearing test rigs were designed and tested as a result of the work of this NRA. Additionally, two technical papers, based on this effort, were generated and are currently being reviewed. The papers are:

Paper No. 1

"Rotordynamics of a Radial Passive-Magnetic Bearing Axially Supported by Jewel Bearings"
by
Mark Siebert, the University of Toledo, Albert Kascak, U.S. Army Research Laboratory, GRC and Kirsten Duffy, the University of Toledo.

Paper No. 2

"Evaluation of a Rotor Supported by a Passive Radial Magnetic Bearings and an Active Axial Magnetic Bearing"
by
Mark Siebert and Ben Ebihara, the University of Toledo, Albert Kascak U.S. Army Research Laboratory, GRC, Gerald V. Brown, GRC and Kirsten Duffy, the University of Toledo

Summary of the Research Described in the Paper No. 1.

A rotor with two sets of radial passive magnetic bearings and an active axial magnetic bearing was designed and built. The active magnetic bearing was controlled by a PD analog controller. A number of P and D values were tried in levitating the rotor. Successful levitation was achieved and the natural frequencies were measured by means of a rap test. The damping was calculated by the 3 dB-down method. The rotor was modeled in a finite element rotordynamics code, and the undamped bounce and conical critical speeds were calculated. The finite element determined critical speeds were compared to the experimentally determined natural frequencies and the correlation was good. An analytic expression for force as a function of magnetic bearing gap was developed and compared to the experimentally measured force as a function of gap. The correlation was good.

Summary of the Research Described in the Paper No. 2.
A 100 percent passive magnetic bearing rotor was designed, constructed, and tested which includes rotor position probes to measure the location of the rotor and an electric motor. A C++ program was written to calculate the CFFT of the rotor position data and another program to determine the mode shapes. The natural frequency of the rotor was calculated by the FEM. Two sets of stator magnet housing materials were constructed: 304 stainless steel and OFHC copper. The rotor was spun to 14000 rpm with the OFHC copper stator housings and 9770 with the 304 stainless steel ones. The nonrotating damping factor of the rig was measured experimentally to be about 0.0045 for both sets of stator housing materials. The lengths of the synchronous mode shape vectors (X1, Y1) and (X2, Y2), calculated by using the CFFT results, were compared as a function of speed for the two cases of stator magnet housing materials. The OFHC copper stator magnet housings generally produced the lower mode shape vector lengths, meaning that there was a contribution of the OFHC copper relative to the 304 stainless steel concerning the rotating damping. The maximum Hertzian stress of the jewel bearing contact was calculated and compared to the Brinell stress limit of 440C stainless steel.

One of the problems with passive magnetic bearings is the low intrinsic damping since the damping is mainly the result of eddy-currents from the radial oscillations. The damping is low since the magnets used in passive magnetic bearings have low electrical conductivity. Additionally, the magnets are electrically isolated from each other magnet-to-magnet eddy current flow is blocked. In order to increase the eddy currents eddy-current dampers formed by continuous rings of copper were made.

The rings of OFHC (Oxygen-Free High Conductivity) copper were formed by soldering or electron-beam welding. The length of the rings is 20.3 mm (0.80 inch) which is the length of the magnet assembly in the passive magnetic bearing. The OD of the rings fits in the ID of the stator magnet assembly. The thickness of the copper rings varies from (1 mil) to (16 mils) in order to evaluate the effect of thickness on the damping. The rings that were 5 mils thick or less were formed by soldering the ends in a overlap joint. The rings that were greater than 5 mils thick were formed by electron-beam welding. The rings with a thickness of less than 5 mils could not be formed by electron-beam welding since the electron beam burnt through the thin copper.

The damping as a result of the copper rings in place has not yet been tested. Future testing will evaluate the nonrotating damping (by means of a rap test) and the rotating damping (as measured with a Digital Vector Filter) of the system with the rings in place.

Other Research Efforts:

In addition to the above, several other research pursuits were performed, which did not result, as of yet, in any technical publication.

The design and fabrication of a rig was performed for the testing of elastomers (O-rings specifically). This rig enabled load and deflection to be measured in order to obtain O-ring stiffness calculations. This research was used to verify the feasibility for the use of elastomers as a damping material for back-up bearings. The back-up bearings are used as a safety measure to support the rotor of a magnetic suspension bearing in the event of the loss of power to avoid a catastrophic failure. The research also investigated the possibility of elastomers as the material to dissipate transient forces in the event of a magnetic bearing failure and subsequent touch down event.

On-site research at the University of Toledo was initiated to obtain the dynamic stiffness and damping coefficients of O-rings that are installed individually or in series on a high-speed spindle. The work will be performed within the Tribology Laboratory at the University of Toledo and will make use of a high-speed magnetic bearing test rig. The spindle can rotate at speeds in excess of 75,000 RPM. This research has continued after the formal funding of the project expired. Currently, a ceramic sleeve is being secured and testing is expected to begin late this spring semester. Results will be reported in subsequent technical articles.