MiTi Developments

Mohawk Innovative Technology, Inc.

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Foil Bearing Used as Back-Up for Magnetic Bearing

In a recent series of development tests, Mohawk Innovative Technology, Inc. successfully demonstrated the use of a state-of-the-art foil bearing as a back-up bearing for a magnetic bearing system. In these tests, the response of an oil-free, hybrid foil/magnetic bearing system to thirteen different magnetic bearing failure and recovery modes was evaluated at realistic operating speeds. This data also being used to guide development of an expert system for magnetic bearing simulation and predictive diagnostics.

This breakthrough development was accomplished as part of a US Army Small Business Innovation Research Phase II sponsored program which demonstrated, for the first time ever, the operation of a hybrid foil and magnetic bearing system at a size and load capacity consistent with gas turbine engine and auxiliary power unit applications.

Hybrid Foil/Magnetic Bearing

Fig. 1, Foil Bearing

The hybrid foil/magnetic bearing combines two oil free bearing technologies to take advantage of the strengths of each. Foil bearings, such as shown in Fig. 1, have good load carrying ability and transient shock response at high shaft speeds. Magnetic bearings, such as shown in Fig. 2, provide nearly constant load carrying ability over the operating speed range, but are susceptible to overload during transient events, and have potentially catastrophic failure modes.

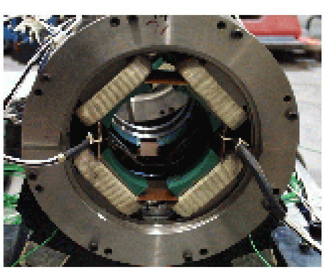

Fig. 2, Magnetic Bearing

Unlike more conventional magnetic bearing applications, the hybrid foil/magnetic bearing does not require a separate back-up bearing. In this bearing, the foil bearing component provides the transient/failure protection, as well as significantly increasing the load capacity for a given bearing system size and weight. For example, the bearing system designed by MiTi for these tests has been tested with an applied load of over 1200 pounds combined with a dynamic load of approximately 100 pounds. This bearing system is shown in Fig. 3.

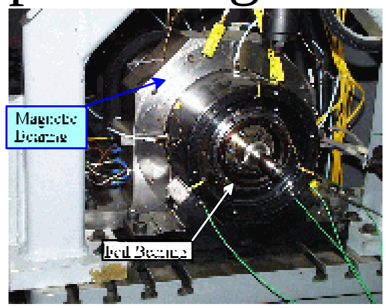

Fig. 3, Test Rig Bearing System

The test rig used to for these tests is based on a gas turbine simulator shaft, which weighs 140 lb, is 38.5 in long and places a static load of approximately 80 lb on the test bearing. A hydraulic loading system allows higher loads to also be applied. The magnetic bearing is a homopolar design with eddy-current position sensors. This rig is designed for a maximum operating speed of 36,000 RPM.

Failure Mode Testing

To demonstrate the ability of the foil bearing component of the hybrid bearing to act as a backup bearing for the magnetic bearing, the system response to potential magnetic bearing failures and failure recoveries was investigated. For this investigation, thirteen different simulated failures were investigated at speeds of 15,000 RPM and 25,000 RPM. The failure modes selected for this investigation were:

1) Vertical Sensor Failure
2) Horizontal Sensor Failure
3) Both Sensors Failure
4) Loss of Vertical Displacement Signal
5) Loss of Horizontal Displacement Signal
6) Loss of Both Displacement Signals
7) Loss of Left Horizontal Amplifier Output
8) Loss of Both Horizontal Amplifier Outputs
9) Loss of Top Vertical Amplifier Output
10) Loss of Both Vertical Amplifier Outputs
11) Loss of Bias Current
12) Loss of All Control Amplifier Outputs
13) Loss of All Amplifier Outputs and Bias Current

To simulate a worst case scenario, the bearing load was supported almost entirely by the magnetic bearing prior to the failure event. In addition, lightly-damped magnetic bearing characteristics were selected for use during this testing. Based on previous experience, MiTi engineers examined both the initial failure transient, as well as the system recovery In many cases, the recovery transient was actually more severe than the failure transient under these operating conditions.

Figure 4 presents a typical shaft vertical response at the foil bearing displacement sensors for a failure which simulates sensor or cable damage which results on a loss of electrical continuity between the sensor and the sensor signal conditioning unit (-24 VDC control system inp ut). Horizontal

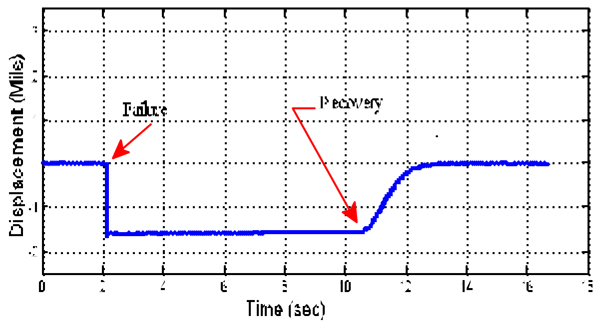

Fig. 4, Vertical Sensor Open Failure at 25,000 RPM

shaft motion for this test was negligible.

Figure 5 present a typical shaft vertical response at the foil bearing displacement sensors for any system failure which results in a loss of the vertical displacement

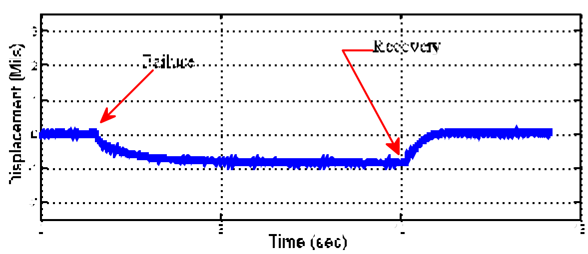

Fig. 5, Loss of Vertical Displacement Signal at 15,000 RPM

measurement (0 VDC control system input). Again, horizontal shaft motion was negligible for this test.

Figure 6 present a typical shaft vertical responses at the foil bearing displacement sensors for a system failure which

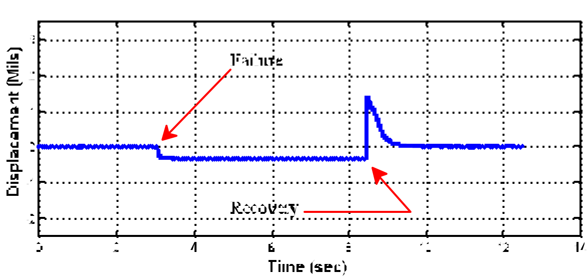

Fig. 6, Loss of all Control Amplifier Outputs at 25,000 RPM

results in no control amplifier currents. Horizontal shaft motion for this test was negligible.

Figures 7 and 8 present typical shaft vertical responses at the foil bearing displacement sensors for a system failure which results in a loss of both control amplifier currents and bias current. The response shown in

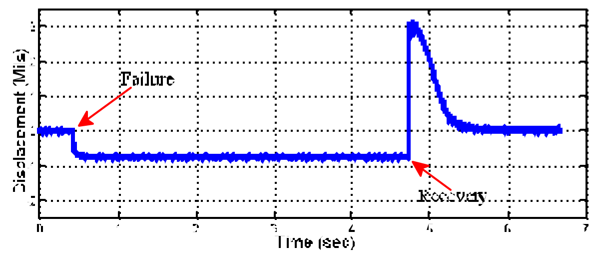

Fig. 7, Loss of all Amplifier Outputs and Bias Current at 15,000 RPM

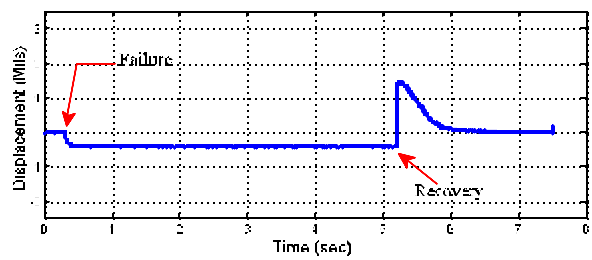

Fig. 8, Loss of all Amplifier Outputs and Bias Current at 25,000 RPM

Fig. 7 was obtained at 15,000 RPM, the response shown in Fig. 8 was obtained at 25,000 RPM. Horizontal shaft motion for these tests was negligible.

Success!

In all 26 test cases, the transient during both failure and recovery was well controlled by the foil bearing. In addition, a foil bearing alone coast-down from full speed under shaft load was demonstrated in later testing. These tests demonstrate that the foil bearing component of a foil/magnetic hybrid bearing is an effective back-up bearing for the magnetic bearing, allowing both continued operation following a failure, as well as damage-free equipment shut-down.

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