Volume 20 MiTi® Development Brief November 2004

150mm Foil Journal Bearing and Hybrid Foil Magnetic Bearing

Under the auspices of NASA's STTR program, Mohawk Innovative Technology, Inc. (MiTi®) scaled its patented 100 mm diameter bearing design up to 150 mm in diameter and applied its high temperature KOROLON coating to the foil surface. This bearing was then installed in a special bearing test rig and operated up to 27,000 rpm, resulting in an equivalent bearing DN value in excess of 4.0 million. Subsequent testing at high temperatures demonstrated the ability of the MiTi® foil bearing to operate at temperatures in excess of 1200 ºF, which is approximately 2.5 times greater than that of conventional bearings. These demonstrated capabilities showed that application to advanced aircraft gas turbine engines is possible and will allow for greatly reduce maintenance actions while also promoting very high efficiency.

There are a number of advantages to a Compliant Foil Bearing (CFB) operating at high speeds and an Active Magnetic Bearing (AMB) operating at zero and low speeds. Developing a Hybrid Foil Magnetic Bearing (HFMB), combining the CFB and AMB, takes advantage of the strengths of each, while compensating for each other's weaknesses. A HFMB such as this is capable of achieving high load capacity at all speeds and temperatures. The AMB provides excellent performance at low speeds where surface coating used in foil bearings have limited load capacity and the CFB provides excellent performance operating at high speed, where the AMB has transient shock and failure mode limitations. Unlike conventional magnetic bearing applications, the HFMB does not require a separate auxiliary/backup bearing for protection. In case of an AMB failure, a CFB plays the role of backup bearing so that the rotor can still run on the foil bearing alone and then come down to a safe stop. It exhibits the high load capacity characteristics of the CFB along with the high static stiffness and control versatility of the AMB. This hybrid system represents a significant technological advancement in terms of range of operation and reliability.

A test rig, based on a 50 Hp variable speed motor directly driving a test rotor with two instrumented bearings, a 150 mm magnetic bearing and a 150 mm foil bearing, is shown in Figure 1. The instrumented test HFMB, along with a cross sectional diagram, is given in Figure 2. The experimental goal was to perform an extensive series of tests in order to verify the performance of the largest 150 mm CFB for various operating conditions at room temperature to high temperatures, low lift-off and high speed. These tests emphasized CFB durability and transient capability by simulating different modes of switching the AMB "on" or "off". The rotor was levitated by the AMB at zero speed and started to run up. Upon reaching the CFB lift-off speed, load sharing between the CFB and the AMB was demonstrated in hybrid mode (See Figure 3).

Figure 1
Test Rig with a 150 mm Magnetic Bearing and a 150 mm Foil Bearing

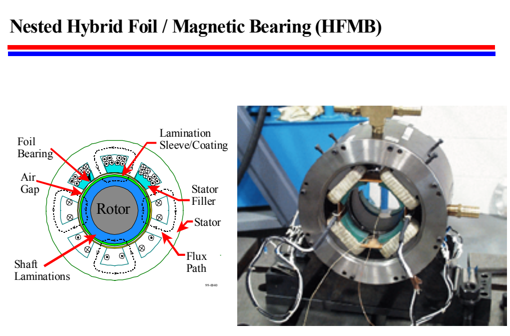

Figure 2
Instrumented HFMB Along with a Cross Sectional Diagram

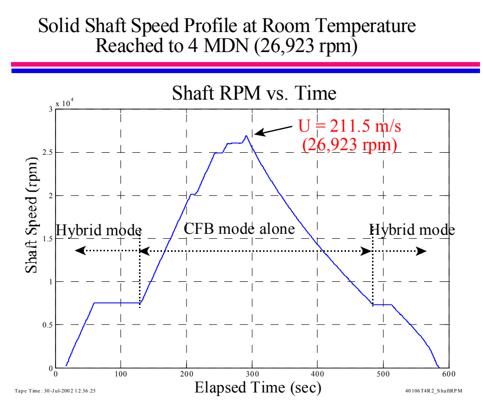

Figure 3
Hybrid Foil Magnetic and Compliant Foil Bearing as Stand Alone Performance as a Function of Speed; Speed Reaching 4 MDN

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During the HFMB mode, the operation at increasing speeds was evaluated. At 7,600 rpm the AMB was turned off to let the rotor drop down on the CFB to evaluate the operation in the CFB mode alone and examine the AMB failure situation. That means the CFB is capable of being a reliable auxiliary/backup bearing for the magnetic bearing system if the AMB failed or became overloaded. The rotor speed was increased to 15,000 rpm and the bearing housing temperature was also increased. The temperature rise of the foil bearing is shown in Figure 4. The temperature of the CFB and its housing was increased, as shown in Figure 5, to 1200°F within half an hour by means of 33 cartridge heaters. Figure 6 depicts an HFMB and an AMB at speeds to 30,000 and loads exceeding 130 psi (applied load divided by the bearing projected area) as can be seen from the composite plots of Figure 6. The AMB load capacity increases by more than 300%, yet the overall bearing volume and weight increases insignificantly when AMB is hybridized with the CFB.

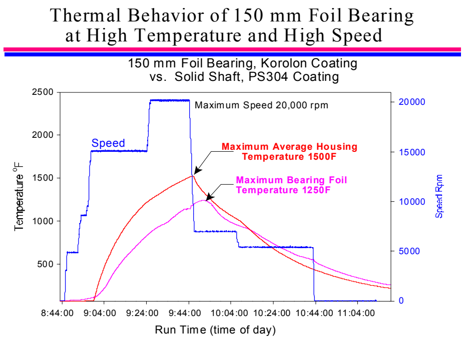

Figure 4
Thermal Behavior of a 150 mm Foil Bearing as a Function of Ambient Temperature and Rotor Speed

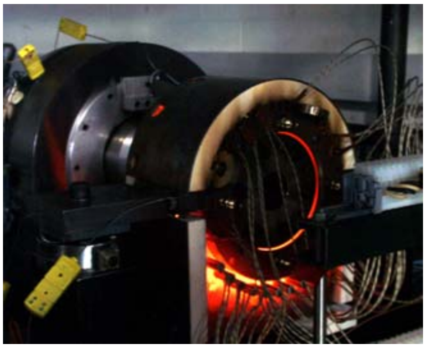

Figure 5
HFMB Running at High Temperature

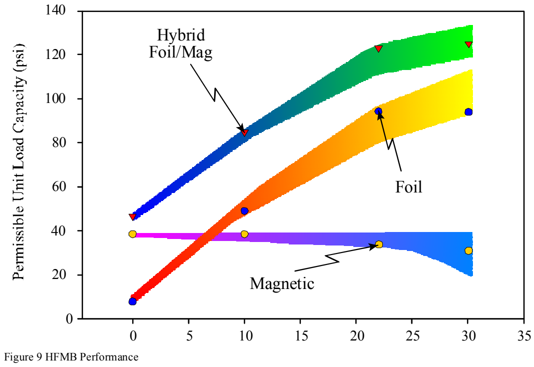

Figure 6
Experimental HFMB Performance

Accomplishments:

●Designed and fabricated a 150mm compliant foil journal bearing (CFB) then tested at room temperature to high temperature (1200°F) and high speed (27000 rpm). This is believed to be the largest compliant foil journal bearing ever built and tested.

●Achieved 26923 rpm: i.e. 4+MDN or surface velocity of 211.5 m/s.

●Owed to advancement in CFB design – the variable compliant structure design used in this 150mm CFB – operation in the hydrodynamic region was extended to a record low surface velocity of 5 m/s with 400 N load, thereby minimizing low speed surface coatings interaction, thereby enhancing CFB durability for extended lift-off/touch-down conditions.

●A novel high temperature/speed test rig capable of operating up to a speed of 30000 rpm and a temperature capability up to 1500ºF was built to test this 150 mm CFB & AMB.

●It was demonstrated that the CBF is a reliable auxiliary/backup bearing as well as a load sharing device for an AMB system. Through transient tests, the 150 mm failure was simulated. The CFB was repeatedly subjected to such AMB failure conditions.

●MiTi® KOROLON high temperature coating was used on the bearing top foil surfaces. This coating exhibited excellent anti-wear characteristics. The KOROLON demonstrated greater compatibility with NASA's PS304 coating that was applied to the counter face (rotor surface) as well as other coatings such as thin chromium coatings and others.

Through NASA's STTR program we were able to conduct this research and are especially thankful for Dr. Christopher Della Corte's collaboration and our technical program manager, Dr. Mark Valco of the U.S. Army Research Lab, for their continued support of our efforts.

For more information visit our web site at http://www.miti.cc and refer to Dr. Heshmat's publications, listed on his biography page.