



Hybrid Foil Magnetic Bearing Tested

In a recent series of tests, Mohawk Innovative Technology, Inc. successfully operated its oil-free, hybrid bearing to over 30,000 rpm. This breakthrough development was accomplished under a US Army Small Business Innovation Research Phase II sponsored program and demonstrated for the first time ever, the operation of a hybrid foil and magnetic bearing at a size consistent with gas turbine engine and auxiliary power unit applications. Operation of the 100 mm diameter foil bearing at 30,000 rpm, which is equivalent to 3 Million DN (where D is diameter in mm and N is speed in rpm), exceeds conventional rolling element bearing DN capabilities by at least 50%.

Hybrid Bearing Description

The hybrid foil/magnetic bearing, as its name implies, combines two oil free bearing technologies to take advantage of the strengths of each. Foil bearings, such as shown in Figure 1, are very effective at high speeds, since load carrying ability increases rapidly with increased shaft surface velocity. At operating speeds, the compliant foil air bearing is also tolerant of transient and shock events. Correspondingly, magnetic bearings, such as shown in Figure 2, provide nearly constant load carrying ability over the operating speed range, but are susceptible to overload during transient events.

The tested hybrid bearing was designed by MiTi to have a load capacity approaching 1500 lb. Larger designs are also possible. The test rig being used to validate the bearing operation and load capacity is shown in Figure 3. This gas

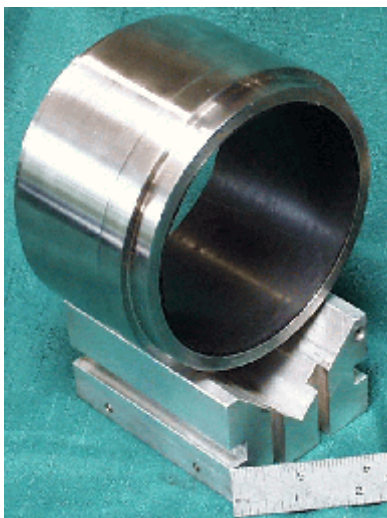


Fig. 1, 100mm foil bearing.

turbine simulator shaft weighs 140 lb, is 38.5 in long and places a static load of approximately 80 lb on the bearing.

Bearing Performance

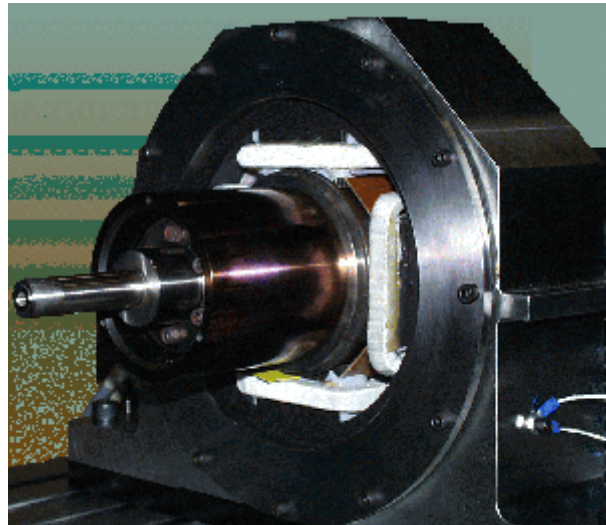


Fig. 2, 121 mm Magnetic Bearing

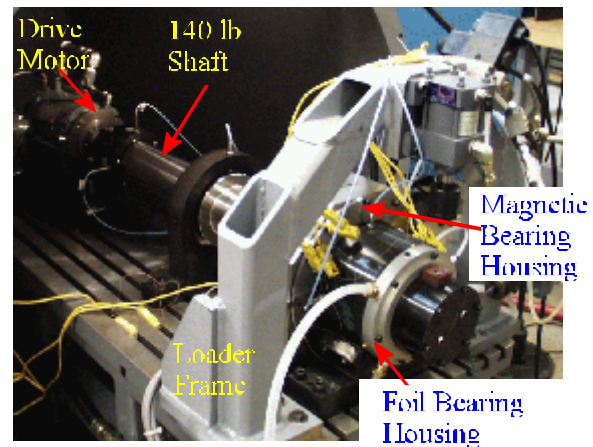


Fig. 3, 36,000 rpm hybrid bearing test rig.

Preliminary testing completed to date has demonstrated successful operation of the magnetic bearing alone, the foil bearing alone and the combined hybrid bearing, each at speeds to 30,000 rpm. Once successful bearing operation was demonstrated, a series of simulated magnetic bearing failures were completed. This was followed by continuous operation of the foil bearing alone at a speed of 25,000 rpm for one hour. Confirmation that both elements of the hybrid foil/magnetic bearing were supporting rotor loads is

presented in Figure 4. This figure shows both rotor position and magnetic bearing control force while rotor speed was increased from 0 to 30,000 rpm. At the start of the rotor acceleration, the magnetic bearing supports almost the entire rotor load as noted by the magnetic control force. As speed is increased and hydrodynamic pressures are generated in the foil bearing, the rotor "lifts off" the top foil which in turn reduces the required magnetic forces to the point that the magnetic elements are only supporting approximately 15 pounds of the total static and dynamic shaft load at 30,000 rpm.

Continuous Operation

To demonstrate durability and reliability of the hybrid

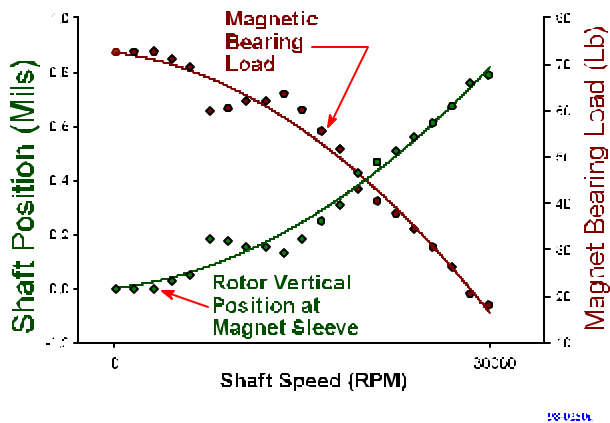


Fig. 4, Bearing control current and rotor position during rotor accel; (Bearing static load is 80 lb),

bearing even in the event of a electrical failure of the electromagnetic bearing elements, the foil bearing was operated continuously at 25,000 rpm for one hour. During this test, thermal stability of the foil bearing was achieved as show in Figure 5. Maximum temperature rise of the cooling air as it passed through the bearing was less than 60°F for the loaded or bottom portion of the bearing over the entire test run. The unloaded portion of the bearing (side) experienced less of a temperature rise as expected.

Transient Operation

In the event that some component of the electromagnetic bearing elements fails, electrical power is lost, or if transient loads exceed the load carrying capability of the electromagnets, the bearing system must continue to support the rotor. Tests were therefore conducted to demonstrate the ability of the foil bearing to support the rotor during transient events. A series of tests were successfully conducted at speeds up to 30,000 rpm where electromagnet failures and recoveries were simulated. Figure 6 shows results from 15,000 and 20,000 rpm tests. The lower speed 15,000 and 20,000 rpm tests are presented here since they represent the more severe condition for the foil bearing, (e.g. total bearing

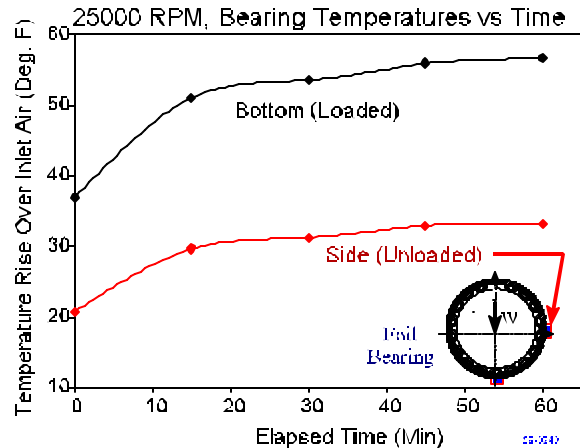


Fig. 5, Bearing temperature versus operating time at 25,000 rpm.

load capacity is lower at lower operating speeds).

With this hybrid bearing system, MiTi continues to advance the state of the art for oil-free bearings. The demonstrated hybrid bearing technology is being developed for gas turbine engines, auxiliary power units and other high speed rotating machinery.

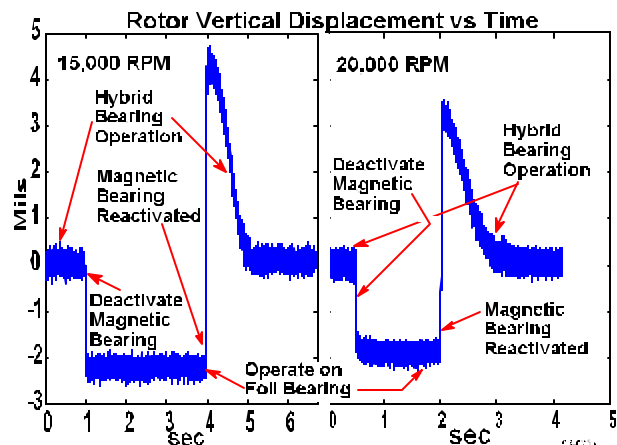


Fig. 6, Rotor response during simulated magnetic bearing failure and recovery

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