MiTi® Developments

Mohawk Innovative Technology, Inc.

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A Unique Powder Lubricated Journal Bearing Demonstrated to Operate up to 3 Million DN

The Powder-Lubricated, Quasi-Hydrodynamic Journal Bearing (PLQH) is a highly sophisticated and unique technology which has only very recently been developed and demonstrated to operate up to 3 million DN. It is based on 15 years of work conducted by Dr Hooshang Heshmat, who introduced the Quasi-Hydrodynamic Theory. This Theory states that powders can be caused to behave like liquid lubricants under appropriate geometries and pressures. When so applied, a hydrodynamic like pressure, this lubricates the bearing and creates a load capacity. This is a revolutionary concept that has only very recently been demonstrated and tests have documented exceptional performance capabilities.

The currently targeted application of this technology is as an Auxiliary Backup Bearing. It is ideally suited for a Backup Bearing for Magnetic Bearing supported systems, such as, ground and space based Flywheel Energy Storage Systems, Gas Turbine Engines, and Advanced Auxiliary and Integrated Power Unit Systems. Although magnetic bearings have many advantages, they require self-contained back-up or auxiliary bearings for protection during a failure or severe transient. Most conventional Auxiliary Backup Bearings are of the rolling element type. Rotors dropped onto these bearings are susceptible to violent backward whirl, which generates large centrifugal bearing loads that cause severe bearing wear radio deterioration.

The uniqueness of the Powder Lubricated Quasi-Hydrodynamic Journal Bearing (PLQH) lies in its application of dry triboparticulate powders to provide a long life, low power loss auxiliary bearing. The introduction of powders between the bearing pad and rotating shaft generates a quasi-hydrodynamic film that separates the shaft and bearing, minimizing wear and transferring a significant portion of heat away from the contact zone. The PLQH bearing design approach eliminates the (backward whirl, instability, and extremely short life) problems associated with conventional backup bearings, since no moving parts are involved.

A series of experiments conducted by MiTi® has demonstrated the basic feasibility of developing powder-lubricated quasi-hydrodynamic bearing for advanced rotating machinery. Based on the demonstrated operation of a powder -lubricated journal bearing at speeds to 3 Million DN, these may be the only bearings capable of meeting and completing the ever demanding tribological goals of a solid lubrication system for extreme environments. The two major technology components for this system are the powder pelletized lubricant delivery system and the compliantly mounted slider type journal bearing. Figure 1 shows the Molybdenum Disulfide (MoS_2) pellet and the Titanium Carbide (TiC) bearing pad.

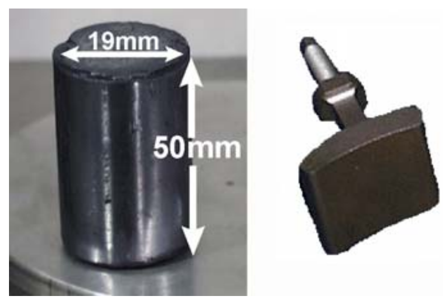

Figure 1 MoS2 Pellet and TiC Bearing Pad

The self-contained solid/powder lubricated hydrodynamic journal bearing consisted of five equally spaced bearing pads (Fig.2) with a bearing diameter of 100mm (3.939in.), projected pad area: 682 mm^2 (1.058in^2) with bearing diametrical clearances of 0.1 and 0.2mm (0.004 and 0.008in). The pads were pre-loaded at 60% from the leading edge and were attached to the bearing cartridge via sets of adjustable compliant pad mounts that were designed to provide radial, pitch and roll stiffness.

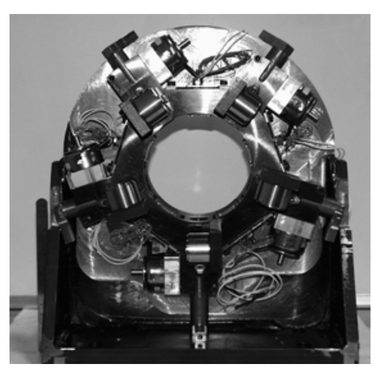

Figure 2 PLQH Bearing Assembly

The test bearing cartridge and compliant elements were made of nickel-base alloy, Inconel 718. The 100 mm test journal was made from M50, and the bearing pads were made from Titanium Carbide cermet. The test journal and pad surfaces were ground after proper heat treatment and then lapped to obtain a surface finish better than 0.1μm (4μin) rms. The MoS_2 powder pellets, made with a proprietary MiTi® binder, were placed in cylindrical sleeves attached to constant force springs. These were further controlled by an electromechanical system employing solenoids, as shown in Figure 3.

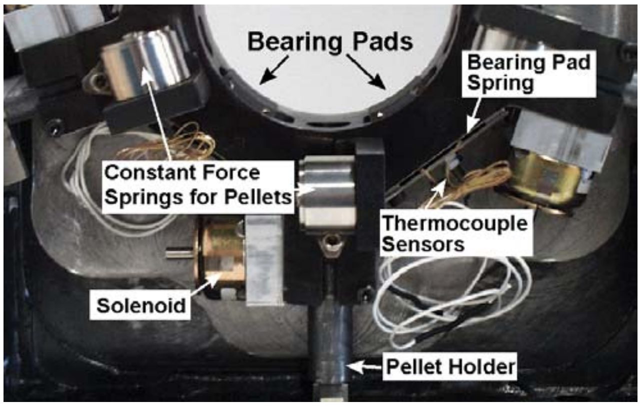

Figure 3 PLQH Bearing Components

A test rig was built with a rotor supported at one end with an Active Magnetic Bearing (AMB) and the PLQH bearing, and at the other end with a deep groove ball bearing. A schematic of the final test assembly is shown in Fig. 4. It incorporates an electric drive motor, shaft, magnetic bearing and the powder lubricated quasi-hydrodynamic bearing.

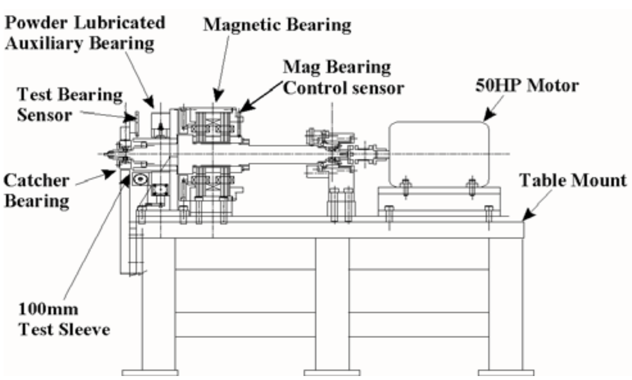

Figure 4 A Schematic of the Prototype PLQH Bearing

The rotor was 556mm (21.9in) long. The AMB had a 25.4mm (1in.) thick lamination stack, a 102mm (4 in) rotor OD and a typical 2 axis homopolar bearing with a total of 8 pole face configurations. The rotor weight at the AMB was 15.9kg (35lb). Figure 4 shows a photograph of the test rig hardware assembly mounted on a 25.4mm (1in)-thick steel base plate.

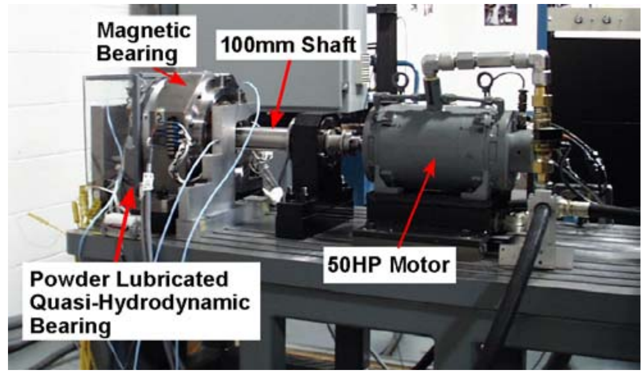

Figure 5 Actual Prototype PLQH Bearing Set-up

The working principle of the PLQH system was that as the shaft contacted the bearing pads due to AMB failure, an electrical signal caused the solenoids to deactivate. This released the powder pellets to the shaft and bearing pad interface, conversely, as the shaft was relevitated there was no longer an electrical signal and this reactivated the solenoids, causing the powder pellets to retract from the bearing pad interface.

A total of 10 thermocouples were used to continuously measure the temperature change of the pads during testing. The thermocouples were installed in the leading and trailing edges of the 5 axially centered pads. Two displacement sensors were located behind the magnetic bearing and these were used to control the shaft position. Two displacement sensors were also located near the PLQH bearing, and these were used to continuously monitor and measure the shaft motion. The signals from these sensors were output to both a dual channel oscilloscope, that measured the motion of the shaft during testing and a Dynamic Signal Analyzer (Fast Fourier Transformer (FFT)) to measure the frequency content.

The rotor was driven at the ball bearing end by a variable speed motor through a step-up pulley arrangement. The maximum rotor speed was more than 30,000rpm and the PLQH test model was tested to this high speed several times without failure.

TEST PROCEDURES

The prototype bearing testing was accomplished in four distinct phases: short duration testing at low speeds ranging from 2000-5000 rpm, impact or rotor drop testing (transient shock simulating magnetic bearing failure) at 15,000 rpm, high speed testing at 30,000 rpm, and lubricant starvation testing, also at 30,000 rpm. For each of the tests, the following data was recorded: pad temperatures, shaft speed, bearing load, motor power loss and the rotor vibrational displacement during coast-down via an FFT waterfall plot. The data was recorded on two data acquisition systems, LabView and a digital tape recorder.

At the end of each test the bearing and journal surface were inspected for wear and film transfer. Surface roughness measurements were conducted on selected bearing pads and the shaft.

TEST RESULTS FROM EXPERIMENTAL RIG

Figure 6 shows the temperature increase of the bearing pads during the high speed test at 30,000 rpm on the fully lubricated PLQH bearing. The temperature increase for pad 3 was the highest, in the range of 155°F. Pads 2, 4 and 5 were similar, in the range of 115°F, and pad 1 was lowest, in the range of 90°F.

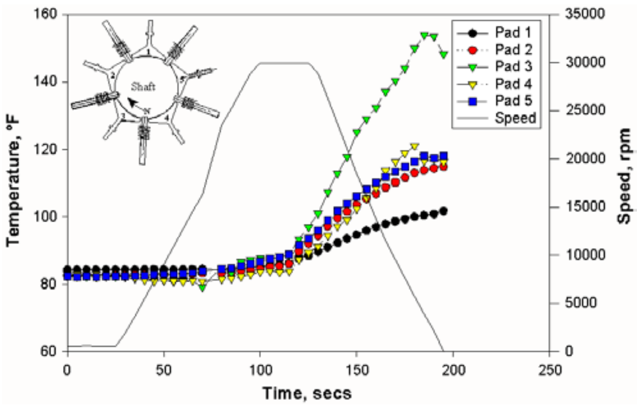

Figure 6 Temperature of PLQH Bearing Pads at 30,000rpm

The waterfall plot in Fig. 7 shows an initial smooth run-up on the magnetic bearing, and as the shaft was set-down to run on the PLQH bearing only a small amount of low frequency motion was observed.

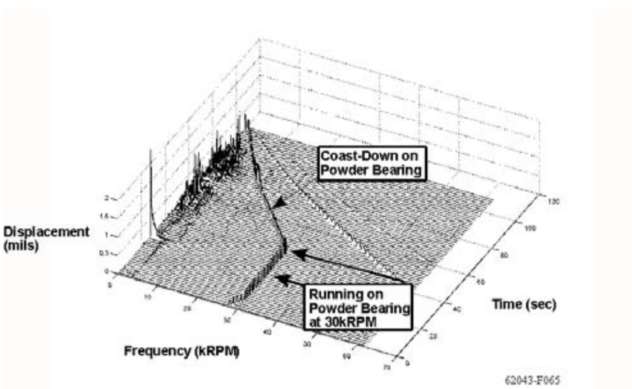

Figure 7 Waterfall Plot of PLQH Bearing Test at 30,000rpm

Figure 8 shows the temperature increases of the bearing pads under starvation conditions at 30,000rpm. The temperature increase for pads 3 and 4, which were the contacting pads on initial impact, was high in the range of 800-1000°F, whereas the temperature increase for pads 1, 2 and 5 was much lower, in the range of 200-500°F. The waterfall plot in Fig. 9 shows an initial smooth run-up on the Magnetic Bearing. Once the shaft was running on the PLQH bearing there was clearly some low frequency motion, associated with the 1st rigid body mode. Coastdown was done on the PLQH Bearing and there was a significant amount of low frequency motion.

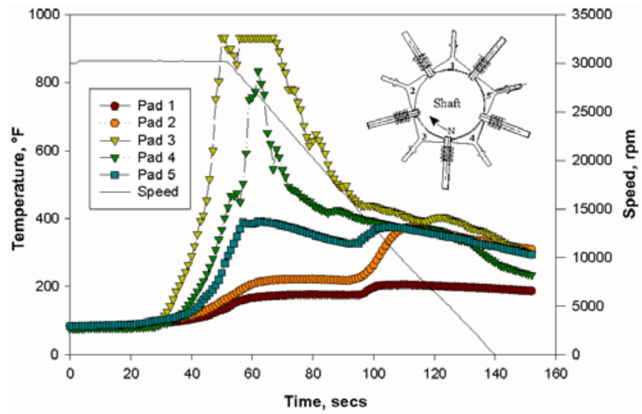

Figure 8 Temperature of PLQH Bearing Pads under Starvation Conditions at 30,000rpm

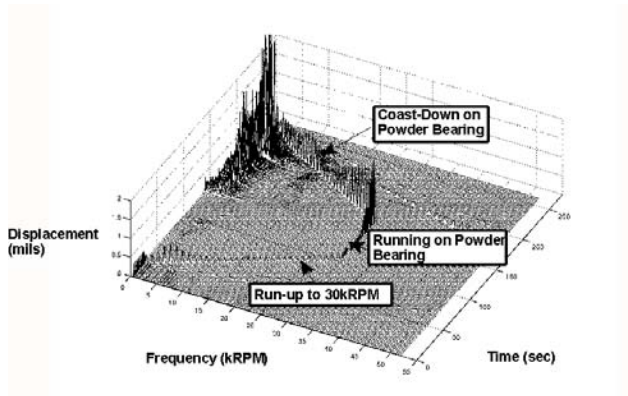

Figure 9 Waterfall Plot of PLQH Bearing Test under Starvation Conditions at 30,000rpm

Final evaluation was done on the bearing pads and pellets. Figure 10 shows the PLQH bearing pads and pellets after 6 hours of accumulated testing. From initial surface observations it appeared that there was no significant wear on any of the compliantly mounted slider pads, the MoS_2 powder had formed a protective surface film at the contact interface. The MoS_2 powder pellets were also intact and showed good structural integrity throughout the duration of the tests.

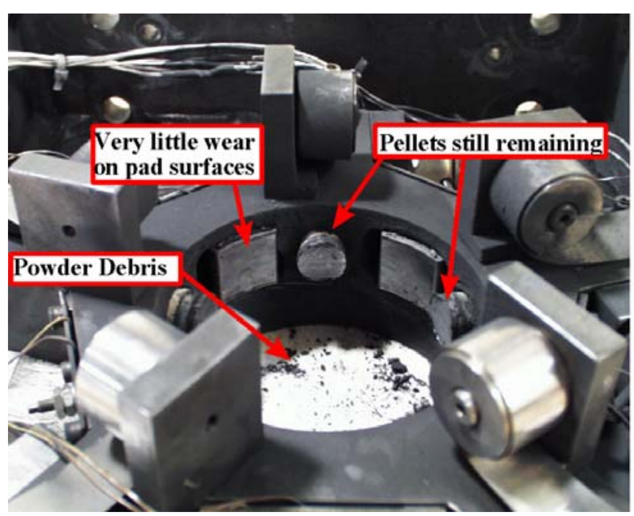

Figure 10 PLQH Bearing Pads and Pellets

RECORD BREAKING NEWS!
For the very first time a powder lubricated journal bearing has been demonstrated to operate at speeds equivalent to 3 million DN. Previous investigations involved a 5 pad journal bearing which was operated at 2 million DN.

This is a one of a kind bearing which has significant future implications on Auxiliary Bearing Technology. Powder lubricated journal bearings are particularly suitable for high temperature, high speed and extreme environments, that is, under conditions where liquid lubricants would simply not survive.

Following an accumulated test time of 6 hours under various loads and speeds, the test specimens were examined, and the bearing and shaft were observed to be in excellent condition. A thin protective layer of powder had adhered to the pad and shaft surfaces, resulting in wear protection to the bearing mating surfaces. Also, the acquired test data spanned the range of expected operating test conditions, including lubricant feed rate, bearing temperatures and operational dynamic performance. Thermal stability was achieved at all load and speed combinations

About MiTi®
Mohawk Innovative Technology, Inc., (MiTi®) is one of the world's leading developers and suppliers of high efficiency, oil-free compliant foil, magnetic, hybrid and auxiliary bearings for high-temperature, high speed and load applications. MiTi® is committed to providing innovative, cost-effective and timely rotor bearing system solutions for challenges in high-speed rotating machinery.

Besides foil bearings and seals, MiTi® previously developed another auxiliary or backup bearing for use with magnetic bearings. Examples of this product is shown in Figure 11 The Zero Clearance Auxiliary Bearing (ZCAB)

Figure 11 50&140mm diameter Zero Clearance Auxiliary Bearings

has small planetary ball bearing that are cam mounted to automatically close down and engage a rotor during magnetic bearing failures or over-loads. Suitable for oil-free and vacuum applications, it can be applied to flywheels, compressors, or other high DN applications.

MiTi® includes a stand-alone facility that includes engineering design offices, manufacturing facilities, and laboratory space for research and development, testing, and quality control. Welding, material heat treating, and lubricant coating facilities accommodate the manufacture of compliant foil gas bearings and seals, magnetic bearings, and auxiliary bearings. A hydraulic metal forming press and machining equipment are also available. For high-speed machinery development, MiTi® has both component dynamic balancing machines and portable balancing machines for-in place balancing of high speed rotors.

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