MiTi Developments

Mohawk Innovative Technology, Inc.

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Auxiliary Bearing Developed for 140 mm Shaft with 1000 Pound Load at 18,000 RPM!

To address the reliability needs of larger machines such as advanced aero and marine gas turbines, as well as industrial machinery supported by magnetic bearings, MiTi has recently delivered a prototype of the patented Zero Clearance Auxiliary Bearing (ZCAB) to a major gas trubine engine manufacturer. This auxiliary bearing is designed to operate at 18,000 RPM with a radial and axial loads of 1,000 pounds on a 140 mm diameter shaft. Its unique design allows it to capture and re-center a shaft if there is a failure of the magnetic bearing system. It also addresses short term overload through load sharing. As part of the final check-out, this bearing sustained 10 high speed engagements. Following testing, the contact surfaces showed some polishing (break-in), but no significant wear.

This bearing, shown in Fig. 1, has approximately 30 times the design load capacity of the previously reported ZCAB. It offers a new, high performance magnetic bearing back-up system which can address the needs of larger and/or higher speed machinery than conventional fixed clearance back-up bearings.

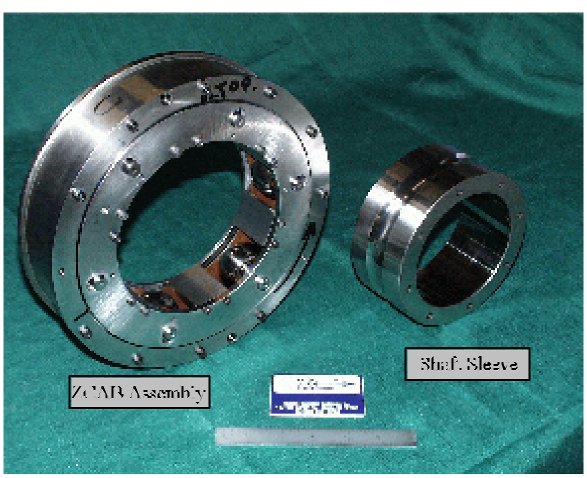

Figure 1 - 140 mm ZCAB Assembly

ZCAB Test Data

Prior to shipment of this bearing, a series of demonstration tests were performed to verify the performance of the hardware. These tests included actuations of the bearing at a variety of speeds, rotor-drop and coast-down events. During all of the tests, the ZCAB performed flawlessly, requiring no maintenance beyond lubricant replenishment. Figure 2 presents a typical plot of the shaft

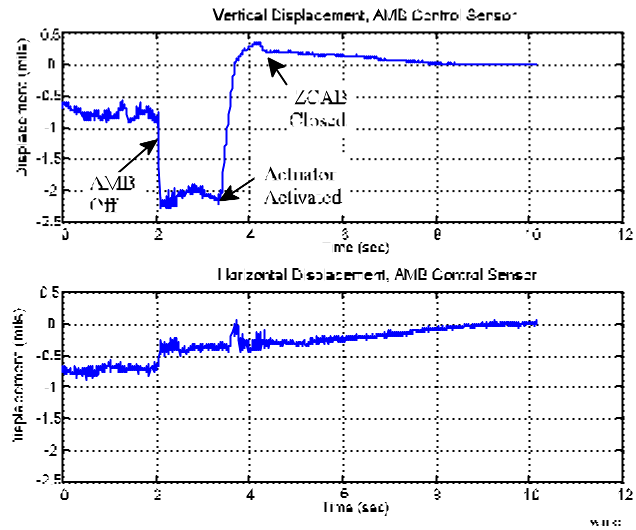

Figure 2 - 18,000 RPM Drop and ZCAB Engagement

motion during an 18,000 RPM simulated magnetic bearing failure, brief operation on the open ZCAB, motion during ZCAB actuation, and the start of the coastdown on the ZCAB. As can be noted from Fig. 2, the shaft orbital motion is small and well controlled throughout the transient. This is as expected for a reasonably well balanced shaft. Figure 3 presents the corresponding shaft synchronous orbit during run-up on the magnetic bearing and coast-down on the ZCAB. One interesting feature of this data is that the shaft orbit is actually smaller on the ZCAB than on the magnetic bearing. This is partially due to soft magnetic bearing characteristics from unrelated testing, but also from the excellent control over shaft motion provided by the ZCAB and its built-in damped mount arrangement.

During this testing, the ZCAB was also used in its intended protective role at 12,000 RPM when a rub event caused large amplitude shaft motion. Figure 4 shows the shaft motion during this transient. Note that the ZCAB successfully reduced the amplitude of the motion, and a controlled orbit was obtained for the machine coast-down. This control of unstable shaft motion is one of the main advantages of the ZCAB over competing fixed clearance auxiliary bearing technology.

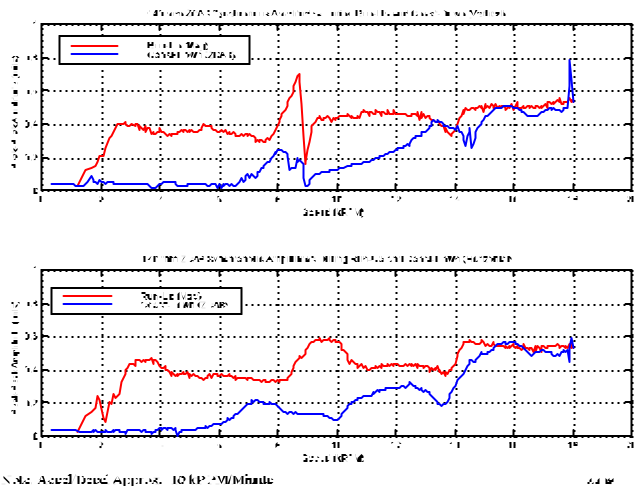

Figure 3 - Synchronous Motion for 18 kRPM Drop

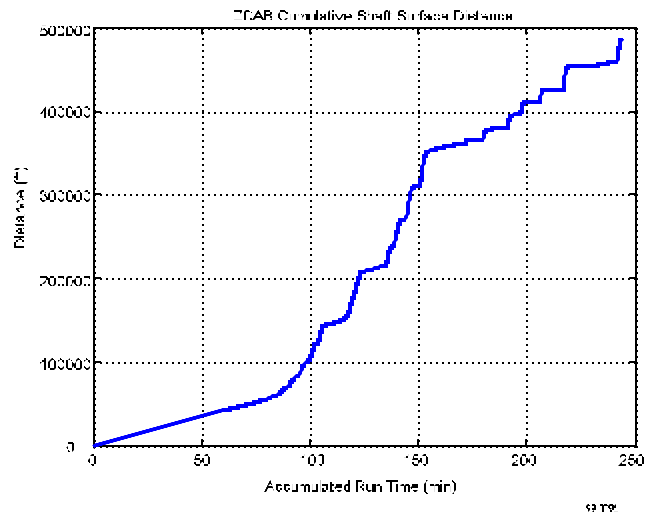

Figure 5 - ZCAB Accumulated Run Distance

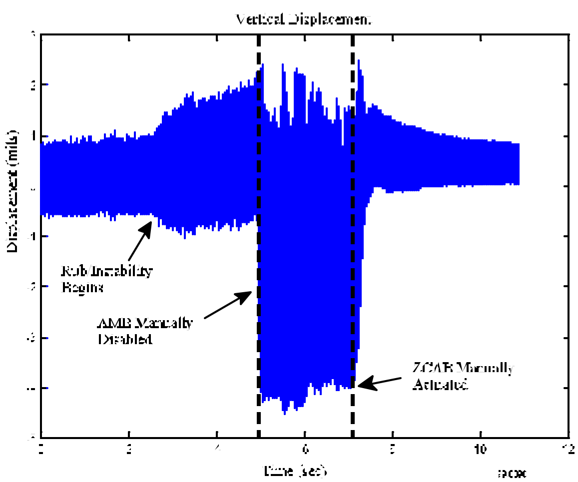

Figure 4 - Shaft Motion During Rub/Instability Actuation

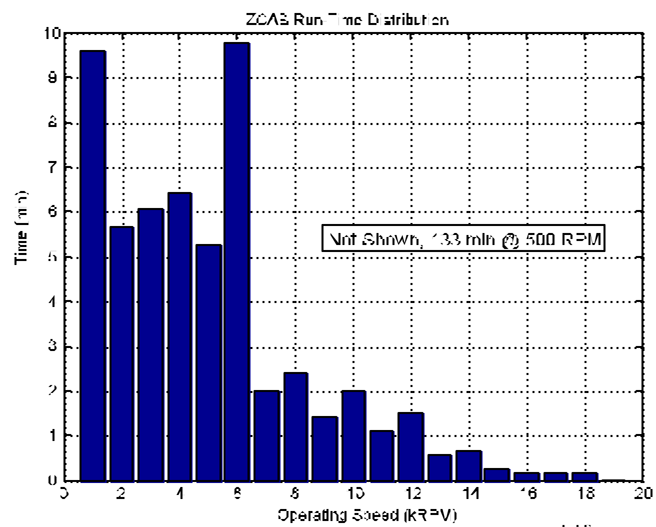

Figure 6 - ZCAB Run Time Distribution vs. Operating Speed

ZCAB Life

One of the other concerns addressed by the ZCAB is auxiliary bearing life. Current implementations of fixed clearance back-up bearings generally suffer from limited life. One of the features of the ZCAB is the potential for significant increases in life/number of drops without major refurbishment. This capability is especially valuable in aircraft applications, for example, which require a return to base capability, as well as mission critical machinery in industrial applications.

In the case of the 140 mm diameter ZCAB, the final check-out included 10 high speed engagements, many low speed actuations, and substantial run-time without component replacement. The only consumable used for this testing was lubricant. Figure 5 presents the accumulated run distance (for the shaft surface), and Figure 6 presents the distribution of run time versus speed. It should also be pointed out that this testing does not represent the life of the ZCAB. The customer accepted the prototype without refurbishment for further testing and evaluation!

ZCAB Concept

In essence, the ZCAB consists of a radial array of rollers positioned around the shaft as shown in Fig. 7. Under normal operation, there is a clearance space between the rollers and shaft as with a conventional rolling element back-up bearing. However, in the case of a magnetic bearing failure, the shaft drops onto several rollers which then move inward to eliminate the clearance space until all of the rollers contact the shaft. The ZCAB closure also serves to re-center the shaft for continued operation or magnetic bearing re-engagement. Following a re-engagement of the magnetic bearing, the ZCAB can then be re-opened to a non-contact configuration. During ZCAB operation, damping and compliance are provided through the ZCAB mount.

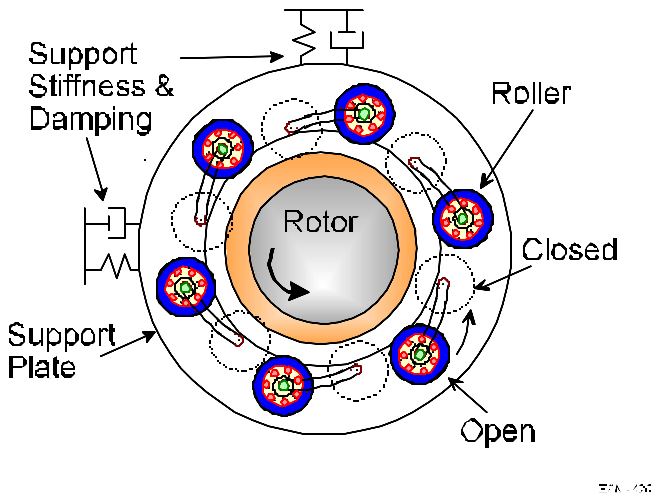

Figure 7 - ZCAB Concept

The elimination of the clearance space, lower component inertias, as well as the discrete roller contact will tend to eliminate the instabilities associated with a conventional clearance type rolling element back-up bearing. The design of this bearing also addresses many of the other concerns, such as ball skidding, cage instability, high rotation speed, etc. associated with a conventional rolling element back-up bearing. In the case of momentary magnetic bearing overload, the ZCAB can provide load sharing in either the open position, or a short term closure. ZCAB closure rate can be varied to suit the operational requirements, with a practical lower bound on the order of tens of milliseconds.

The ZCAB is thus ideal for aerospace and industrial applications of magnetic bearings. It is capable of both high load, short term load requirements such as surge, two-phase flow upsets, and shut-down due to magnetic bearing failure, as well as longer term operation in critical machinery following magnetic bearing failure. The ZCAB has also demonstrated the capability for low maintenance survivability of drop transients. Additionally, it is possible to build a ZCAB such that the rollers and bearings, which are the primary wear items, are field replaceable without requiring shaft/ZCAB removal from the machine.

ZCAB DESIGN/ANALYSIS

As should be evident from the figures, the ZCAB is a complex system which requires considerable attention to structural, rotor dynamic, tribological, and thermal management issues for successful application. As such, MiTi has assembled a multi-disciplinary team and design philosophy to address these issues and ensure the successful application of the ZCAB to a variety of machinery.

The design approach begins with preliminary component sizing based on customer load and speed requirements. For this step, MiTi has developed several proprietary design tools. Following initial component sizing, a more detailed dynamic analysis is performed using a linked combination of custom MiTi analysis tools and upgrades to the commercial rotor dynamic code DyRoBeS. This step includes linear rotor dynamic response and stability analysis, as well as transient response evaluation of critical displacements and forces for the ZCAB supported rotor. This

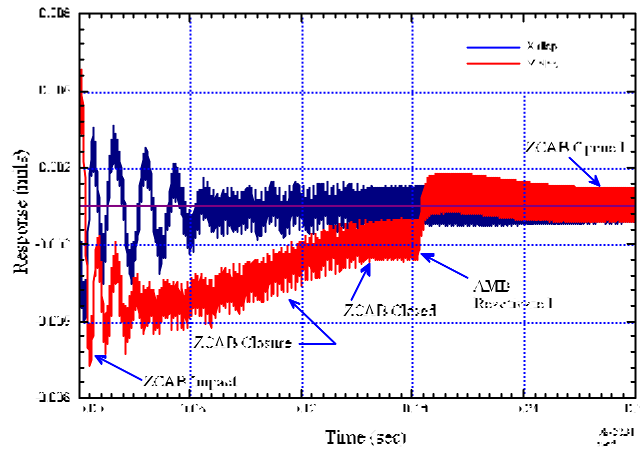

Figure 8 - ZCAB Displacement Transient

capability is crucial for designing the proper damped mounting system to ensure control of the rotor and acceptable roller bearing loading. Figure 8 shows a typical transient displacement response.

In parallel with the dynamic evaluation, other team members address the tribological issues of material choices, lubricant selection and surface form. Depending on the requirements, for example, a choice could be made for weight over life, or sacrificial wear of the rollers to minimize shaft damage. Many tradeoffs can be made in the tribo-material area depending on the final application goals.

The final portion of the ZCAB design is thermal management. The ZCAB system must not only have appropriate dynamic behavior, and acceptable material wear characteristics, but heat generated by the bearings and contact surfaces must also be controlled. The multi-disciplinary design approach MiTi takes to ZCAB design addresses these issues as well.

These design procedures are supported by experimental testing ranging from the fundamental tribosystem level such as shown in Fig. 9, to subcomponent tests, such as shown in Fig., 10 to full scale ZCAB dynamic testing as shown in Fig 11.

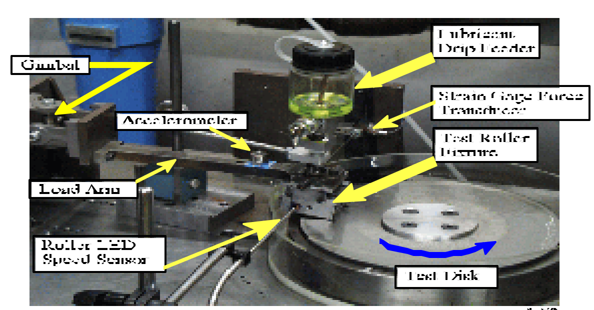

Figure 9 - Roller on Disk Testing

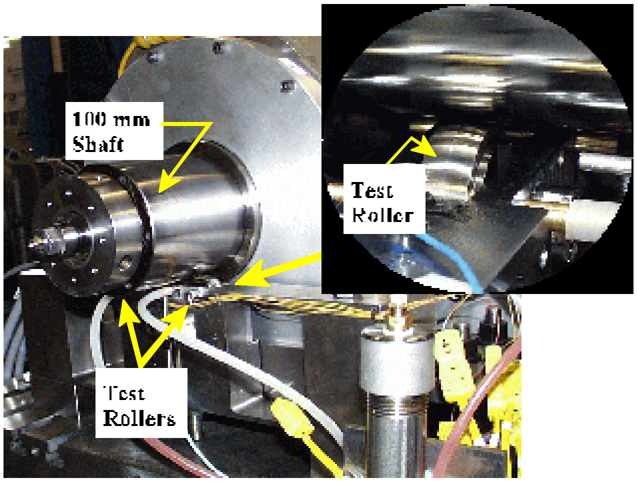

Figure 10 - Two Roller Subcomponent Test

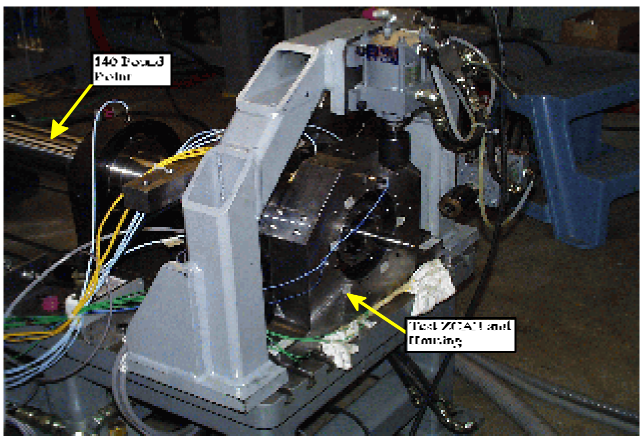

Figure 11 - 140 mm ZCAB Test Setup

ZCAB DEVELOPMENT

With these very successful demonstrations of the ZCAB concept, along with MiTi's hybrid foil/magnetic bearing technology, and the extreme temperature possibilities of powder lubricated bearings, MiTi has given magnetic bearing designers more reliable, higher performance alternatives to fixed clearance rolling element or solid bushing back-up bearing designs. These technologies remove one of the major obstacles to wider application of active magnetic bearings for rotating machinery. Be it high load, high speed or high temperature, MiTi leads the way in developing new back-up bearing system technology to give designers a variety of high performance bearing systems to meet today's and tomorrow's needs. As part of its commitment to tomorrow, MiTi has also recently moved into a larger facility with over 8000 square feet of laboratory, development and manufacturing space, including two hardened test cells for high speed machinery research. Figures 12, 13 and 14 show pictures of the new facility.

Figure 12 -Hardened Test Cells

Figure 13 - Test Rig Area for Larger Test Rigs

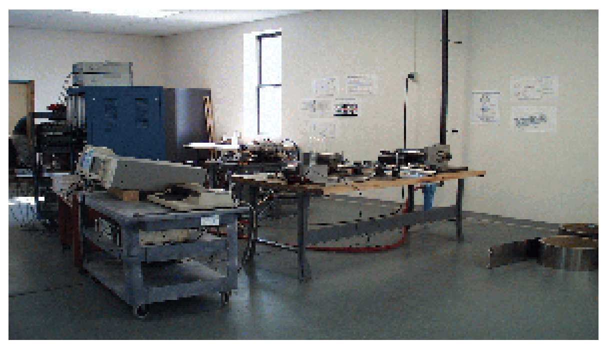

Figure 14 - Test Rig Area For Smaller Test Rigs

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