MiTi Developments

Mohawk Innovative Technology, Inc.

Vol. 6

Spring 1999

Oil-Free Turbocharger Demonstration Paves Way to Gas Turbine Engine Applications

Mohawk Innovative Technology, Inc. (MiTi) successfully operated the oil-free, 150 Hp turbocharger shown in Figures 1 and 2 to 95,000 rpm (100% speed) with turbine inlet temperatures to 1200°F. This breakthrough development in turbochargers for diesel engines was made possible by MiTi's patented compliant surface foil air bearings. These self acting bearings support the rotor on a cushion of air while the rotor operates at very high speeds and temperatures. Operating with gas as the lubricant reduces the drag on the rotor for improved response, eliminates the introduction of polluting contaminants in the engine exhaust, and offers reductions in turbocharger bearing related maintenance costs. The team development effort combined Schwitzer off the shelf turbocharger components, a NASA developed high temperature solid lubricant coating and MiTi foil bearings and designed rotor.

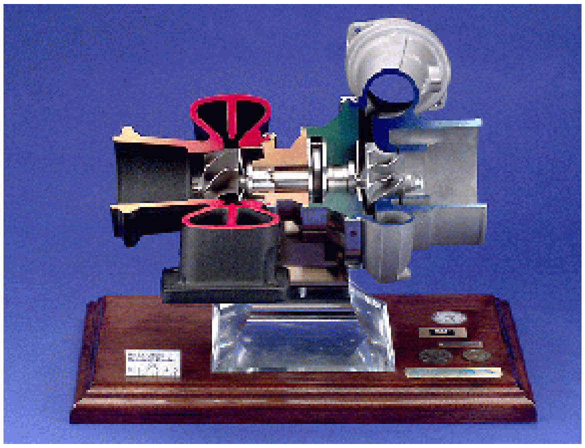

Figure 1 - Oil-Free Turbocharger Display

This successful test exceeded the first build goals of 80,000 rpm and 1200°F turbine inlet temperatures and is the first ever demonstration of an oil-free turbocharger. Based on the success of this demonstration, additional gas stand performance and over speed testing to 120,000 rpm at 1200°F will be completed, followed by testing on a 600 HP heavy duty diesel engine at Caterpillar.

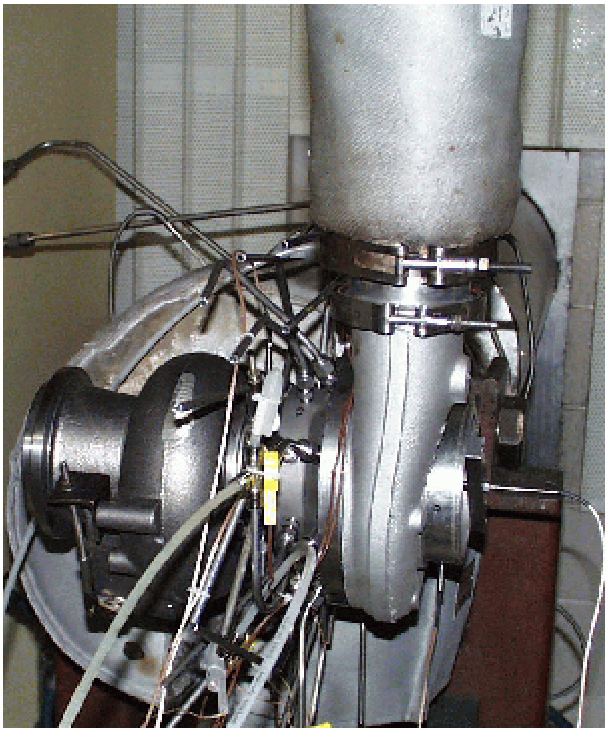

Figure 2. Oil-Free turbocharger installed in gas stand.

Foil bearings are especially attractive for systems where conventional bearings are unsuitable due to temperature, speed, working fluid or any combinations thereof. Since foil bearings are oil free, and can operate with the ambient air or working gas, they are also an environmentally friendly solution for systems where lubricant contamination would be problematic. Other high speed rotating machinery systems that can benefit from the compliant surface air bearings include small aircraft gas turbine engines, automotive gas turbine engines, micro-turbines for electric power generation, compressors, and cryogenic turboexpanders to name a few. Dr. Heshmat, President and Technical Director of Mohawk Innovative Technology, Inc. and leading authority in compliant surface air bearings has stated that this development is on target to support his earlier prediction that a gas turbine engine using compliant surface air bearings will fly before 2010.

Figure 3 is a cross section of the oil-free turbocharger showing the location of thermocouples used during the gas stand testing. Results of the testing which was conducted at Schwitzer are shown in Figures 4 and 5. These figures show the temperatures at various locations inside the turbocharger bearing compartments for rotor speeds ranging from 50,000 to 95,000 rpm and with turbine inlet temperatures from 300°F to 1200°F. Externally supplied cooling air was used for these first tests in order to evaluate the impact of flow rates and inlet air temperatures. Subsequent testing will use compressor discharge air for bearing cooling. As seen in Figures 4 and 5 the maximum temperature rise over the cooling air occurred in the bearing closest to the turbine and remained below 300°F. Based on this data, finite element thermal analysis and high temperature simulator testing conducted at MiTi, the maximum bearing temperatures are not expected to exceed 1000°F in operational units. Vibration measurements also revealed very low rotor displacements as shown in Figure 6. Peak vibrations were approximately 1.25 mils at the outermost portion of the compressor at the maximum tested speed of 95,000 rpm.

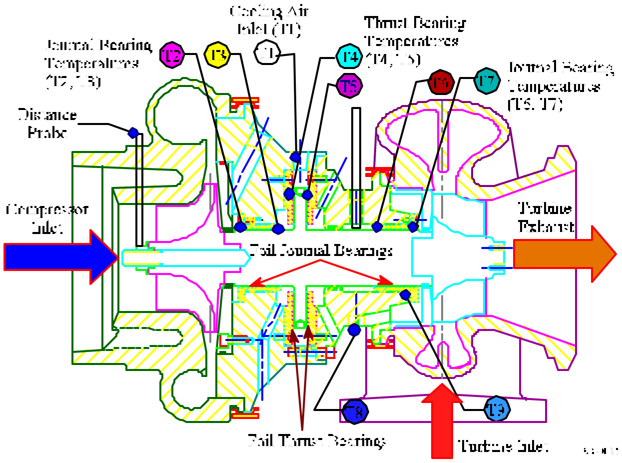

Figure 3. Cross section of oil-free turbocharger with installed thermocouple locations.

Simulator Guides Development

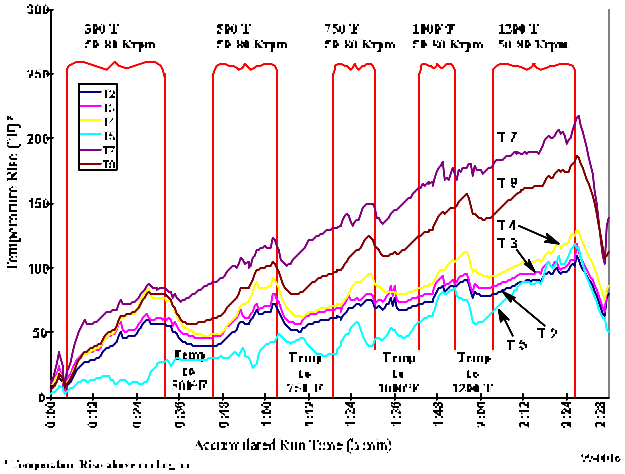

Figure 4 Bearing temperature rise above cooling air at speeds from 50,000 to 80,000 rpm.

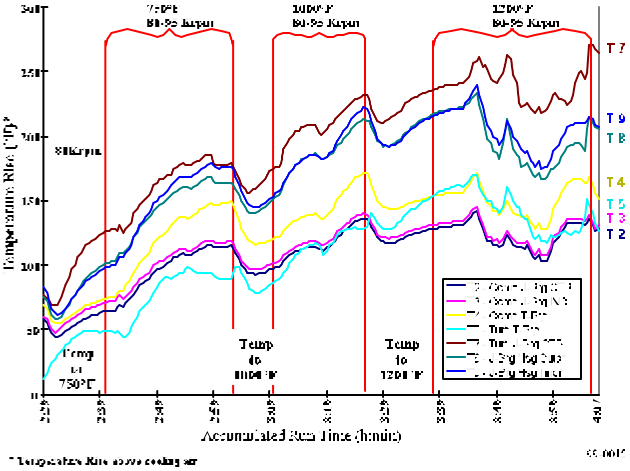

Figure 5. Turbocharger temperature rise as a function of turbine inlet temperature and speed.

Development of this turbocharger followed the procedures MiTi engineers established in previous successful system applications, such as air cycle machines and turboexpanders. The fundamental approach employed by MiTi begins with a preliminary design tradeoff study and assessment of changes needed to accommodate the compliant foil air bearings. Following the tradeoff study a detailed design and analysis of the selected rotor-bearing system configuration is completed, including rotordynamic, bearing and thermal analyses. Using the results of the system analysis, MiTi then designs and fabricates a dynamic simulator, to verify system dynamic performance and thermal management issues in a controlled environment.

The simulator shown in Figure 7 was fabricated and successfully used to demonstrate the dynamic performance of the rotor and bearing system at speeds to 121,500 rpm, at

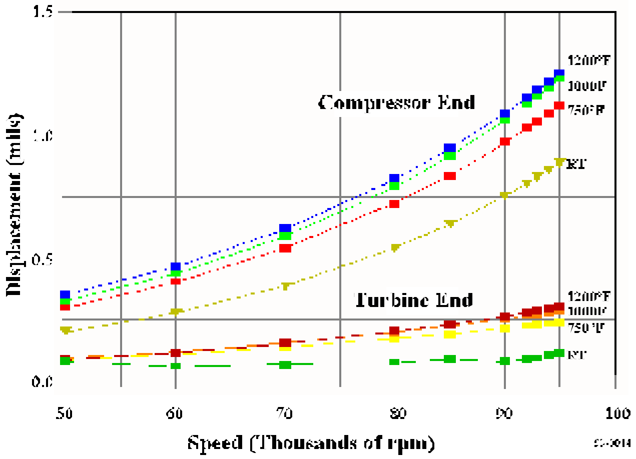

Figure 6. Plot of turbocharger rotor displacements as a function of speed and turbine inlet temperature.

various rotor roll orientations, under transient shock conditions and even at elevated temperatures. Figure 8 is a waterfall plot of rotor vibrations at the compressor end of the rotor during an over speed test to 120,000 rpm. Peak compressor rotor vibrations during the high speed test were less than approximately 1 mil. This over speed test was used to validate the structural integrity of the shaft which experiences a maximum tip speed in excess of 1900 feet/sec at the periphery of the thrust runner disk. The over speed test also verified the high speed performance of the bearings.

Following the high speed testing, the simulator was installed on a hinged platform so that a simulated roll type maneuver or condition could be conducted with the rotor operating at a variety of speeds. Roll tests were conducted at speeds to 95,000 rpm and up to 90 degrees roll angle without incident. Once the roll testing was complete, transient shock testing was conducted. In these tests the rotor system was brought up to a selected speed ranging from 60 to 90,000 rpm. The simulator housing was then elevated by a roll maneuver to a specified height and the simulator dropped. As seen in Figures 9 and 10, rotor motions for both the 70,000 and 90,000 rpm operating speeds even under shock levels of 19 g, are not excessive. Rotor motions were limited to a peak to peak amplitude of less than 7 mils. Further these transient vibrations were quickly damped out with rotor orbits remaining at levels less than 1 mil peak to peak. The post test inspection of the rotor and bearings revealed no evidence of shaft to bearing contact.

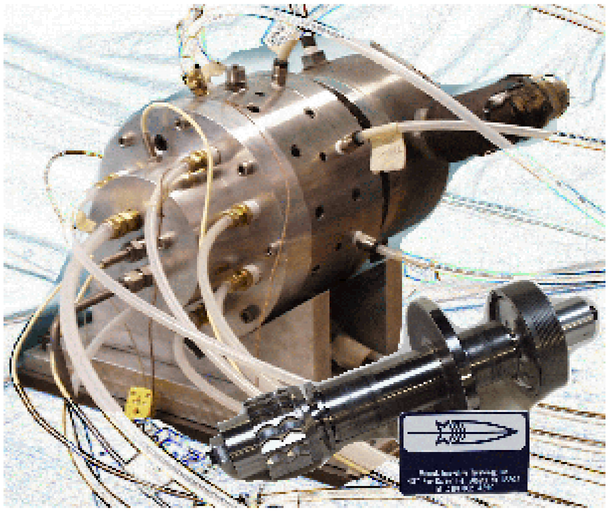

Figure 7. Simulator test rig and rotor used to verify system dynamics before prototype system tests.

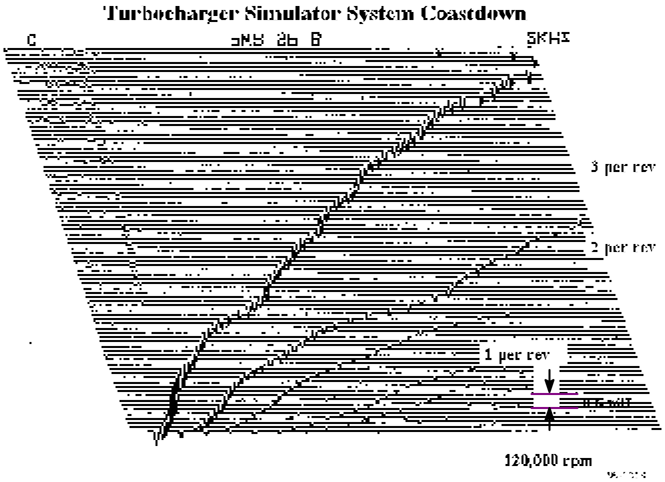

Figure 8. Waterfall plot showing peak vibrations during coast down from 120,000 rpm

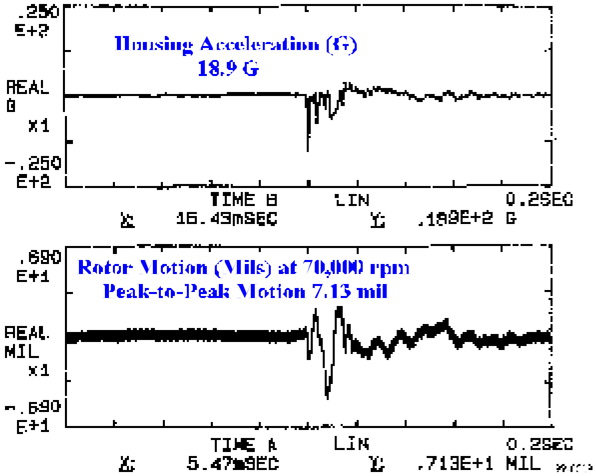

Figure 9. Impact shock level and rotor motions for simulator while operating at 70,000 rpm.

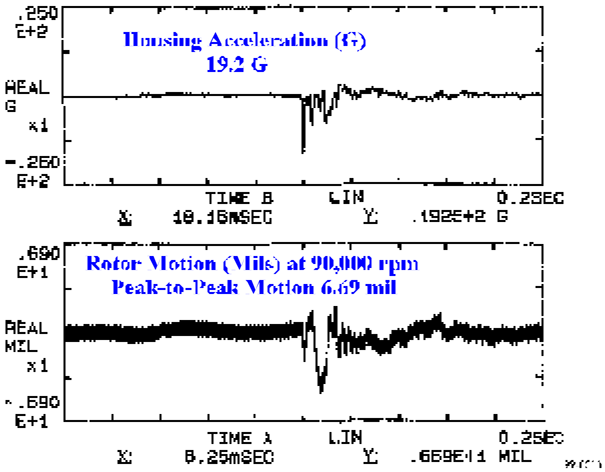

Figure 10. Impact shock levels and rotor motions for simulator while operating at 90,000 rpm.

This demonstrated shock tolerance is typical of MiTi's foil bearings, making them suitable for both vehicle and aerospace applications.

Technology Developments Support Expanded Applications

In a parallel development reported earlier, MiTi has also demonstrated operation of a 100 mm diameter compliant surface bearing under loads to approximately 1000 pounds and speeds to 30,000 rpm. This larger bearing is sized to meet a wide range of potential applications such as gas turbine engines for general aviation and helicopter engines as well as larger industrial compressors.

Besides scaling tests of the compliant surface foil bearing to assess the load carrying capacity of larger bearings, MiTi and NASA have collaborated to develop a bearing and lubricant system for operating temperatures of up to 1200°F. The NASA developed PS-304 solid film lubricant coating, has been tailored to work with the MiTi compliant surface foil bearings. Testing of the MiTi bearing and NASA lubricant has focused on the critical life limiting factor of compliant surface gas bearings, namely start-up and shut-down. During start up and shut down, when speeds are low and generally less than a few thousand rpm, there is insufficient hydrodynamic film to support the shaft. At these low speed conditions the shaft and the bearing surfaces come into contact and wear may occur. Without the proper combination of bearing design, bearing materials and lubricant coating, over time this wear can reduce bearing capacity until the bearing can no longer support the rotor loads even at high speeds. To ensure that the bearing and lubricant coating system has the desired life, start-stop cyclic testing was accomplished under both room temperature and at temperatures to 1200°F and at different static load conditions. Results of these tests are shown in Figures 12 and 13.

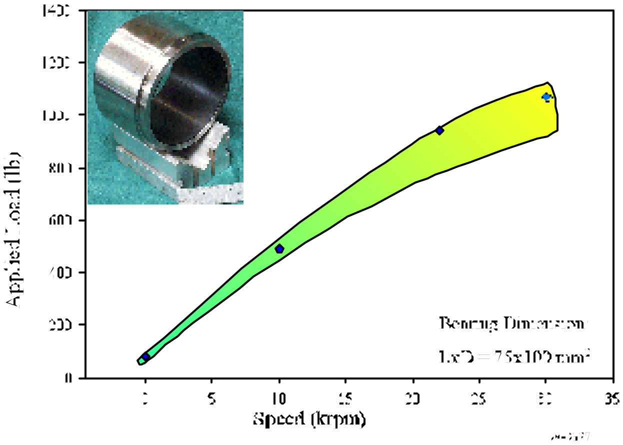

Figure 11 - Measured Performance of 100 mm diameter Foil Bearing.

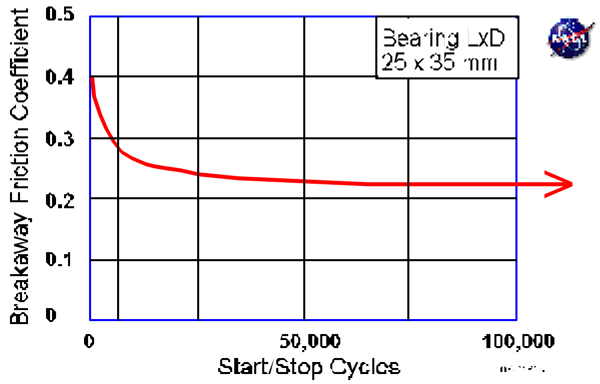

Figure 12. Minimal change in starting torque even after 100,000 start-stop cycles at 1200°F.

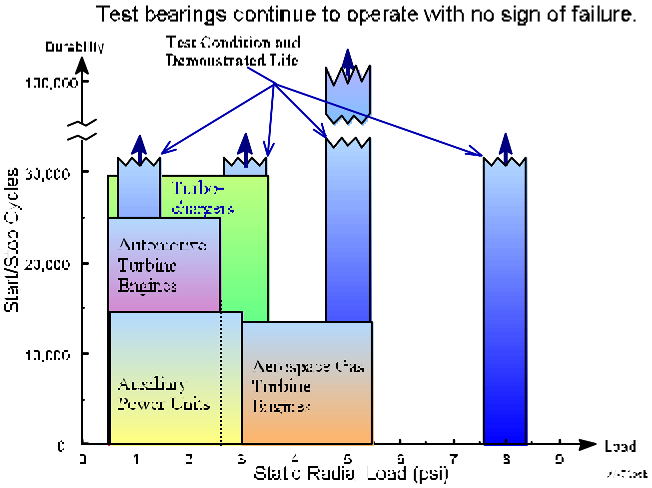

Figure 13. Demonstrated bearing life as a function of static load compared to life requirements for applications.

Machine Ready!

With the successful demonstration of the prototype turbocharger MiTi is now developing commercialization plans for the bearings, the oil-free turbocharger, and is investigating alternative applications such as gas turbine engines, auxiliary power units and compressors.

For Additional Information, contact
Mohawk Innovative Technology, Inc.
1037 Watervliet-Shaker Rd.
Albany, New York 12205
Telephone: (518) 862-4290 Ž FAX (518) 862-4293
e-mail: MiTi@albany.net
Visit our web site: http://www.miti.cc