

MiTⁱ® Developments

Mohawk Innovative
Technology, Inc.®



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High Temperature Non-Contact Seal Tested

A Mohawk Innovative Technology, Inc. (MiTi[®]) novel, non-contacting, Compliant Foil gas Seal (CFS) has been designed and successfully tested at temperatures to 600°C and surface velocities of up to 1200 ft/sec in a dynamic simulator representative of a small gas turbine engine hot section. Measured and analytical comparisons of leakage flow rates at varying differential pressures were made, showing that the CFS capability significantly exceeds the performance of both brush and labyrinth seals. The brush and CFS tests were performed with the rotor operating at speeds to 48,000 rpm. The labyrinth and CFS comparisons were made under non rotating conditions but, with each seal mounted in the rig. Besides the performance benefits, the CFS offers improved life and durability benefits when applied to most rotating machinery, as noted below.

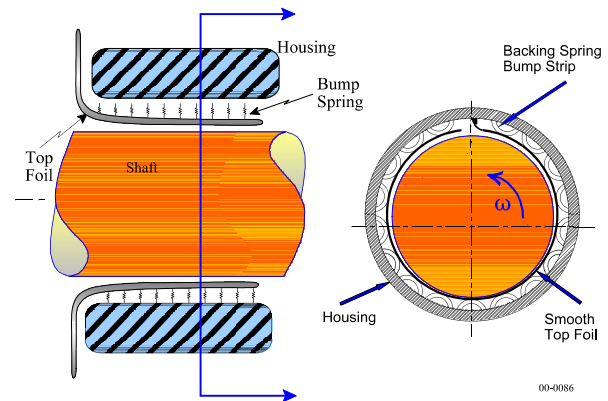


Figure 1. Schematic Diagram of a Compliant Foil Seal

Features and Benefits Offered by the CFS

FEATURES	BENEFITS
Small Operating Clearances	Low Leakage High Differential Pressure
Non-Contacting Operation	Consistent Performance Long life No wear debris
Compliant Structure	<ul style="list-style-type: none"> Hydrodynamic Action Reduces Leakage Stiffness and Damping Enhance Vibration Control Tolerant of Rotor excursions without high speed rubs Tolerant of misalignment & eccentric operation Well suited to integration with Foil Bearings

The Concept:

The CFS concept, as depicted schematically in Figure 1 and pictorially in Figure 2, is derived from MiTi[®]'s highly successful Compliant Foil gas Bearing (CFB) design. The CFS, like the CFB, is comprised of a smooth, compliant foil supported by a spring bump strip. The bump strips are designed and manufactured to provide spatially variable stiffness and damping support properties for the smooth, sealing foil surface. It is this spatially variable stiffness support that permits non-contacting CFS operation, even in

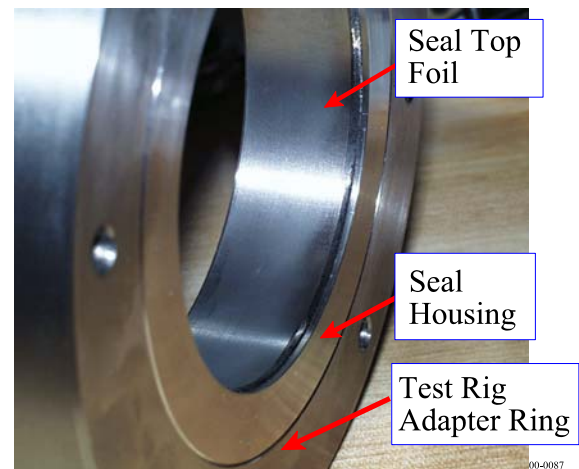


Figure 2. View of compliant foil seal.

the presence of large rotor excursions.

The performance of both the CFB and CFS is based on the hydrodynamically generated high pressure gas film built up as a very thin layer between the journal and the bearing or seal top surface (top foil) due to the shaft rotation. This thin gas film separates the seal surface from the rotating shaft sealing surface, resulting in non-contact, continuous operation. Strict accounting of all variables results in a seal with optimized performance attributes. While its primary purpose is the control of leakage, the similarity to a CFB results in its having a load bearing capacity as a secondary function. This capacity is predictable and can be incorporated in the overall bearing system design to provide

additional support stiffness and damping for improved rotor system dynamics.

Test Apparatus:

A high temperature, hybrid dynamic simulator design was built by MiTi[®] to demonstrate CFS operation. This test rig incorporated an air drive turbine and ball bearing support on the cold end. A CFB and a fully instrumented, pressurized, and heated test chamber is included on the hot end, as shown in Figure 3. The NASA developed PS304, solid lubricant film coating, was used for the CFB and CFS journals to prevent foil wear during startup and shutdown intervals when the hydrodynamic lift-off effects are minimal.

The rotor speed was measured with a standard fiber optic probe and a once per rev. counter. Radial x-y motions of the rotor were measured by standard eddy current displacement probes. During high temperature testing the probes at the hot end were shielded and cooled by air. The leakage test air was externally heated by two 3KW shell & tube heaters and introduced at the desired temperature. The seal module housing was separately heated by cartridge heaters circumferentially mounted in the housing case (See Figures 3 & 4) to maintain a uniform air temperature throughout. Six thermocouples were used to measure air temperature in and out and other critical operating components. A chart recorder documented all test temperatures. The absolute

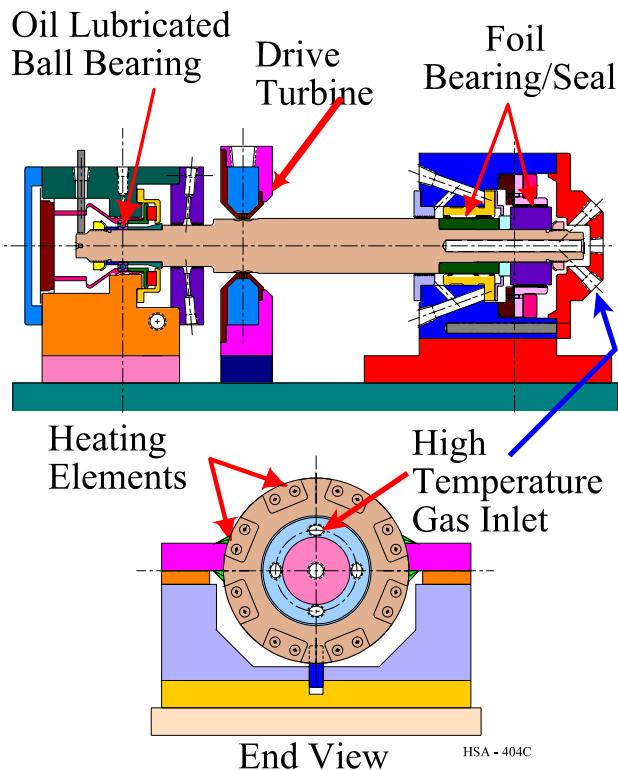


Figure 3. Schematic diagram of simulator

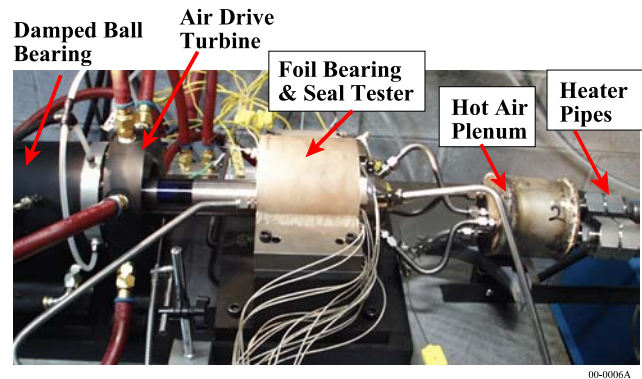


Figure 4. High-temperature foil bearing and seal tester.

pressure of the inlet/outlet air as well as the pressure drop across the CFS were measured and used to calculate seal leakage performance.

Results:

Test results document the superior performance of the CFS when compared to other types of seals. Additionally, the CFS showed no evidence of rubs or induced wear on the journal or seal surfaces, even when tested at speeds up to 1200 ft/sec and temperatures up to 600° C.

Three distinguishing characteristics were documented:

- significantly lower leakage flow rate compared to labyrinth and brush seals,
- outstanding capability to handle large shaft excursions without damaging wear, and
- demonstrated ability to support dynamic loads as a secondary function.

An example of measured leakage flow rates as a function of pressure drop across the seal for the CFS and brush seal is plotted in Figure 5. Both seals were specifically designed for this test rig, and the results are from separate tests conducted on each. The brush was constructed of Haynes 25 bristles positioned at a 40° angle. The non-dimensional results are based on the ratio of leakage flow of the CFS to the minimum leakage flow when the brush seal was installed. The limited differential of the brush seal was due to its large leakage flow rate that exceeded the ability of the test rig to create a larger ΔP . The brush seal was extensively tested up to a speed of 41,000 RPM and a total of 4 hours of operation. Severe wear tracks were found on the journal after the test.

The experimentally determined leakage flow rate for both the CFS and labyrinth seals is shown in Figure 6. Both seals were of comparable length, while the CFS was designed to operate at 0.02mm (0.0008 in.) clearance and the labyrinth at 0.127mm (0.006 in.). The labyrinth seal measurements were made with a non-rotating shaft. Again, the results showed

that the CFS consistently measured significantly lower loss flow rates. For both evaluations, one side was pressurized and the other side was at constant atmospheric pressure. In a separate test of the CFS it was determined that the leakage flow rate did not significantly change throughout the entire speed range for a constant 12 psi pressure drop across

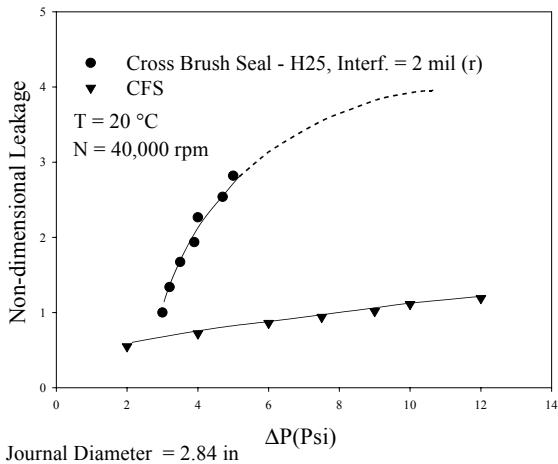


Figure 5. Comparison of CFS vs Brush Seal experimentally determined leakage flow

the seal. This is explained by the effect of increased hydrodynamic pressure within the CFS causing a reduced cross-flow effect that negates the higher ΔP at the boundaries. This experimental result is shown in Figure 7. In subsequent testing, the CFS was demonstrated at 1000°F (538°C) at speeds to 48,000 rpm (equivalent surface speed of 1189 FPS). The very low losses, as evidenced by the small flow factors during both runup and coast down, gives

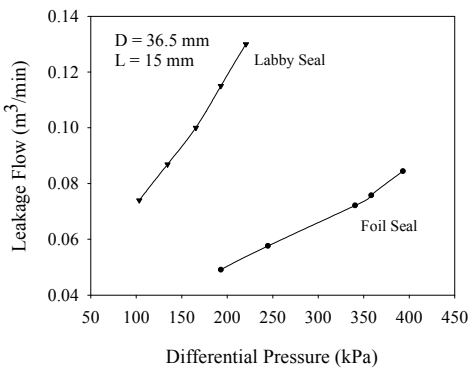


Figure 6. Comparison of CFS and Labyrinth Seal experimentally determined leakage.

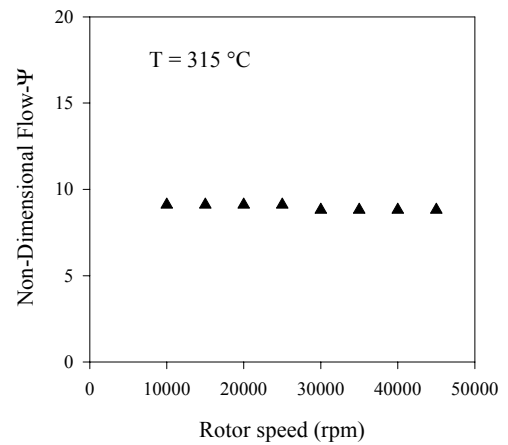


Figure 7. CFS experimentally determined leakage flow as a function of rotor speed.

evidence of the low losses attainable with the CFS, even over a wide speed and temperature operating range as shown in Figure 8.

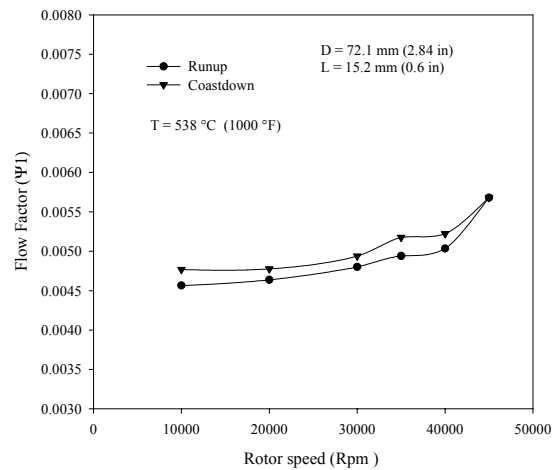


Figure 8. CFS flow factor as a function of speed

Conclusions/Summary

Demands for ever more efficient and reliable engines continue to drive the introduction of enabling technologies. The reduced secondary losses and lower maintenance costs offered by the CFS, when combined with MiTi's recently introduced CFB's, now enable the design of totally oil-free gas turbine engines and other high speed rotating machinery of higher power density, efficiency, and reliability. This technology is now developed and available for commercial applications.

Sponsors:

This work was sponsored by NASA and Mohawk Innovative Technology, Inc. The emphasis on achieving ever higher power density, extended life turbo machinery has placed a high priority on the development of enabling technology regarding seals. The brush and labyrinth seals currently employed in gas turbine engines have limited structural compliance and therefore continuously incur increasingly damaging wear from shaft excursions throughout the operating life of the engine. This progressive deterioration of seal effectiveness and the resulting turbine performance erosion has spurred the search for viable alternatives.

About MiTi®

MiTi is a technology company committed to developing advanced rotating machinery using our oil-free bearing and seal technologies. MiTi has developed a line of compliant foil bearings ranging in size from 15 mm to 100 mm in diameter. These oil-free compliant surface hydrodynamic gas bearing bearings have been operated at speeds in excess of 200,000 rpm, temperatures to 1200°F, loads approaching 1000 lbs, and life in excess of 100,000 start stop cycles (equivalent to more than 10 years life).

Besides foil bearings and seals, MiTi has developed two auxiliary or backup bearings for use with magnetic bearings. An example of one of these products is shown in Figure 10



Figure 9. Turboexpander components and foil bearings.

For Additional Information, contact:

High Speed ZCAB



Figure 10. 50 & 140 mm diameter Zero Clearance Auxiliary Bearings



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