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TURBOJET ENGINE DEMONSTRATION WITH A HIGH TEMPERATURE AIR FOIL BEARING

Hooshang Heshmat
Mohawk Innovative Technology, Inc.
1037 Watervliet-Shaker Road
Albany, New York 12205 USA

James F. Walton, II
Mohawk Innovative Technology, Inc.
1037 Watervliet-Shaker Road
Albany, New York 12205 USA

Michael J. Tomaszewski
Mohawk Innovative Technology, Inc.
1037 Watervliet-Shaker Road
Albany, New York 12205 USA

ABSTRACT

Recent tests demonstrated successful operation of a turbojet engine with a compliant foil air bearing using a new high-temperature solid lubricant coating. The hot section rolling element bearing and corresponding lubrication system were replaced with a compliant foil air bearing using a composite solid lubricant coating capable of operating at temperatures well above 650ºC (1200ºF). Detailed engine integration studies, bearing component rig testing and hot engine simulator tests were completed prior to the successful engine test. The rig and simulator tests verified high temperature capabilities of the bearing and its surface coating, the bearing journal design, bearing dynamic performance, and rotor-bearing system dynamic stability, prior to engine integration and test. Based on these preliminary efforts, the engine and bearing were assembled and tests were conducted that included over 70 start stop cycles (including hot restarts), seven simulated mission cycles and more than 14 hours of run time. The foil bearing and engine operated flawlessly throughout the test. Vibrations were very low and all temperatures and pressures were as expected. The post-test inspection revealed that the bearing, journal and coating were all in excellent condition. Keywords: compliant foil bearing, high temperature coating, solid film lubricant, gas turbine engine, and turbojet engine.

INTRODUCTION

Gas turbine engines having high specific thrust, high fuel efficiency, and are both durable and maintenance free are needed for a wide range of applications such as aerial targets, drones, Uninhabited Air and Air Combat Vehicles (UAV/UCAV). For example, highly efficient engines can increase UAV range and loiter time for greater data gathering. When used in drones or target systems, the quality of pilot training can benefit from improved performance and range to increase practice time and the realism of engagements. In turbojet powered munitions, increased performance can be translated into greater standoff, greater loiter time and/or reduced time to target.

The design of new engines or modification of existing engines to reduce size and weight, while also reducing fuel consumption and increasing thrust, can have a significant impact on overall system capability. Eliminating the bearing lubrication system can translate directly into increased fuel load. Operation at higher shaft speeds and turbine inlet temperatures can increase engine performance, but bearings that can operate at high temperatures without liquid lubrication are needed.

To address the engine system development issues, MiTi® has developed and demonstrated the supporting oil-free bearing technologies having improved load capacity and damping[1-7]. High-temperature, low friction coefficient coatings have also been developed for compliant foil bearings. These recent developments indicate that compliant foil air bearing (CFB) technology has the capability to be uses as main rotor support for a wide array of gas turbine engines, even engines up to and exceeding 5,000 pounds of thrust. This bearing technology foundation, successfully demonstrated in turboexpanders and turbochargers, has been instrumental in the successful turbojet engine test with a foil bearing placed directly behind the turbine[8-10].

BEARING SYSTEM DESIGN AND ANALYSIS

The overriding goal of the bearing design process was to yield a bearing that had dynamic stiffness and damping properties that would enable the engine rotor to operate stably at bearing temperatures to 650°C. Iterative bearing design and rotor-bearing system dynamic analyses were completed prior to hardware fabrication. The static load and operating speed range were used to size the bearing and establish the preliminary bearing dynamic coefficients for use in rotordynamic analyses. Based on the nominal static load of approximately 17.8 Newtons, a 50 mm diameter by 25 mm long bearing was selected for the initial design. A coupled elasto-hydrodynamic computer code was used to determine the speed dependent bearing dynamic coefficients that accounted for both speed and temperature effects. The predicted direct and cross-coupled stiffness coefficients shown in Figure 1 were then used in the rotor-bearing dynamic analysis to ensure rotor system stability throughout all engine operating conditions.

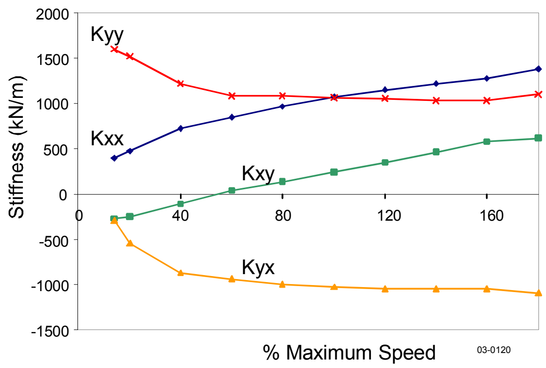

Figure 1. Foil bearing stiffness coefficients.

In parallel with the bearing design, high temperature coating testing was also accomplished. As seen in Figure 2, friction coefficients remain quite low until temperatures exceed 525°C when tested against a hard chrome coated shaft surface.

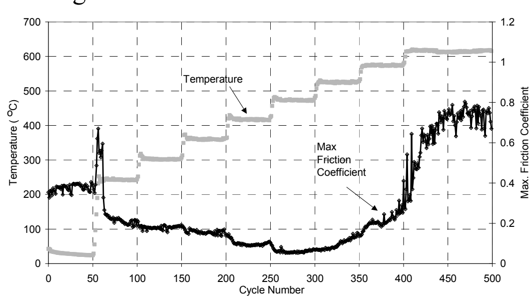

Figure 2. Shutdown friction coefficient for a test pad with a composite Korolon™ coating.

Following sub-component testing a full bearing was assembled and tested to 650°C and 110% full speed in an engine dynamic simulator rig. Posttest condition of the bearing was excellent as seen in Figure 3.

The bearing was then installed in the engine and tested. A total of 70 engine start stops, including, hot restarts, were completed to verify bearing integrity and life. Other tests included a total of seven simulated mission cycles and 14 hours of operation.

Based on this very successful demonstration, the feasibility of developing a truly oil-free gas turbine engine for flight has been established. Based on the engine configuration tested, it is estimated that engine weight reductions as high as 30% and cost reductions of up to 20% may be possible by eliminating the entire bearing lubrication system and using foil bearings.

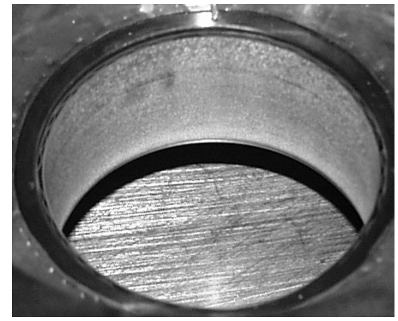

Figure 3. Foil bearing after test in dynamic simulator rig.

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