Final Technical Report

for

Demonstration, Testing and Qualification of a High Temperature, High Speed Magnetic Thrust Bearing

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Demonstration, Testing and Qualification of a High Temperature, High Speed Magnetic Thrust Bearing

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The gas turbine industry has a continued interest in improving engine performance and reducing net operating and maintenance costs. These goals are being realized because of advancements in aeroelasticity, materials, and computational tools such as CFD and engine simulations. These advancements aid in increasing engine thrust-to-weight ratios, specific fuel consumption, pressure ratios, and overall reliability through higher speed, higher temperature, and more efficient engine operation.

Currently, rolling element bearing and squeeze film dampers are used to support rotors in gas turbine engines. Present ball bearing configurations are limited in speed (<2 million DN) and temperature (<500°F) and require both cooling air and an elaborate lubrication system. Also, ball bearings require extensive preventative maintenance in order to assure their safe operation. Since these bearings are at their operational limits, new technologies must be found in order to take advantage of other advances.

Magnetic bearings are well suited to operate at extreme temperatures and higher rotational speeds and are a promising solution to the problems that conventional rolling element bearings present. Magnetic bearing technology is being developed worldwide and is considered an enabling technology for new engine designs. Using magnetic bearings, turbine and compressor spools can be radically redesigned to be significantly larger and stiffer with better damping and higher rotational speeds. These advances, a direct result of magnetic bearing technology, will allow significant increases in engine power and efficiency. Also, magnetic bearings allow for real-time, in-situ health monitoring of the system, lower maintenance costs and down time.

The high temperature magnetic bearing facility at NASA GRC has previously been used to develop magnetic bearing technologies and components. Since its beginnings, the facility has been used to measure linearized force coefficients (position, current stiffness, and damping) versus speed, bias current, excitation frequency, and eccentricity. The facility was also used to demonstrate stable rotor levitation and fault tolerance of a radial magnetic bearing at extreme temperature (1,000°F) and at speeds to 15,000 RPM. At the same time, the rig was used to develop special high temperature wire and modular coil development. The last configuration of the rig completed testing of a totally new, modular, extreme temperature (1,000°F), high load (1,000 lb) radial magnetic bearing. This configuration was used to demonstrate high speed operation (30,000 RPM) and a novel, hydrostatic backup bearing system. A new, fault tolerant control algorithm, compatible with the modular bearing design, was developed and demonstrated to extreme temperature and high speed (25,000 RPM). Also, a high temperature conical facility has been designed in detail and is awaiting fabrication.

The high temperature magnetic bearing facility was modified to accept a high temperature magnetic thrust bearing (HTMTB) that was designed and fabricated at Texas A&M University under a separate grant. A major portion of the upgrade consisted of developing a LabVIEW based data acquisition (DAQ) system. The DAQ system was completed and monitors torque, speed, bearing currents, loads, and temperatures. The system can be adjusted and data is saved to spreadsheet files for later interpretation. The DAQ system was successfully demonstrated during shakedown testing.

Instrumenting the HTMTB was another area that was addressed. The system was shipped with some sensors installed; however, only one load cell was installed in the thrust direction. Additional load cells were specified and ordered; however, they were not installed because by the time they arrived, the grant was concluded. Other instrumentation was specified, ordered, and installed, including temperature sensors and readouts, speed sensors, and position sensors. They systems were all integrated with the DAQ.

During buildup and shakedown testing, many problems with the system were identified. When trying to operate at elevated temperatures, the support bearings would overheat. A major problem was alignment of the rotor in the stator elements and adjusting the gap and stops. Because the rotor/stator have a parabolic design, alignment and correct gap are vital to avoid rubbing and contact between the parts. As the system heats up, there were issues with the parts moving relative to each other and thus change or eliminating the required gap. Alignment had to be redone at high temperatures and no tools were provided for this scenario. Special long, metal feeler gauges were specified and ordered and modifications of other provided alignment tools were specified and implemented. These tools allowed for some alignment at high temperatures, but most of the alignment issues were a result of the rig design.

The facility was operated at room temperature first to determine coil current as a function of bearing gap. A clamp-on current meter was used and the facility operated to 18,000 RPM. Current from 0 to 18 amps was applied and load measured. This was repeated for several air gaps. These tests showed a significant variation in load capacity, depending on how large the gap was between the rotor and stator. Other issues were encountered with how the bearing was preloaded using the designed system. It was discovered that load and gap changed as a function of preload, even though the preload was only suppose to be for the support bearings. There were also questions of the repeatability of loading because it appeared the gap would change after the first loading. Tests were done measure repeatability and hysteresis of the bearing at room temperature without rotating the shaft. Some results of these tests are summarized in the Appendix. Additional tests were done at higher temperature and rotating, but because of design issues with the facility, were stopped.

After the design issues and instrumentation issues were identified, steps were taken to remedy the situation. Instrumentation was ordered. Additional cooling was added to the facility to help maintain the support bearing temperature below their operation limit. Several major design changes were required for the system to become fully functional, therefore it never reached full speed or temperature. Recommendations were made, however funding has been canceled for this program and no changes were made. The final action of this program was to document the changes and recommendations, decommission the facility, pack it, and return it to Texas A&M University to await modification. The program is suspended until funding is restored.

Appendix

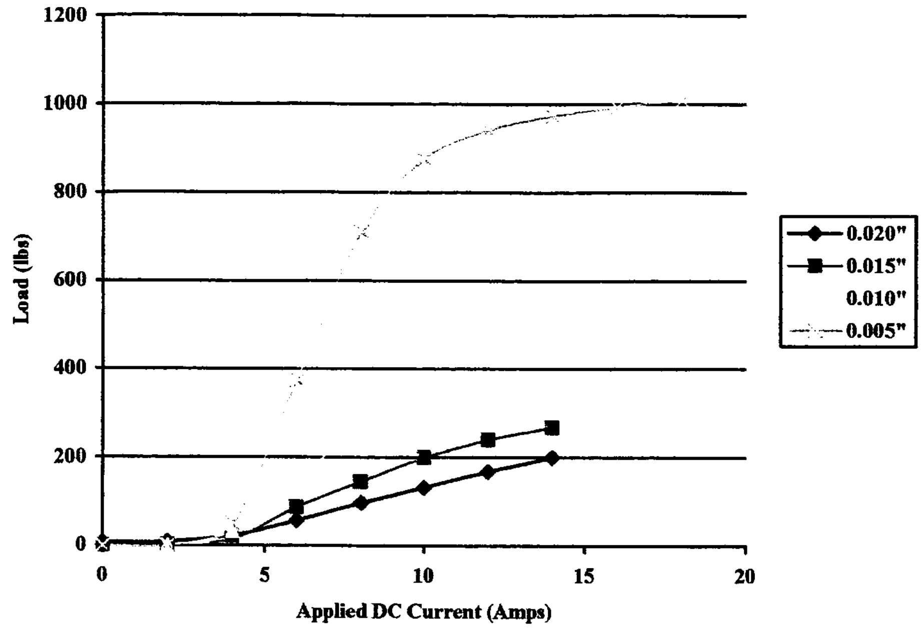

Figure 1 – Load as a function of air gap for room temperature, non rotating conditions

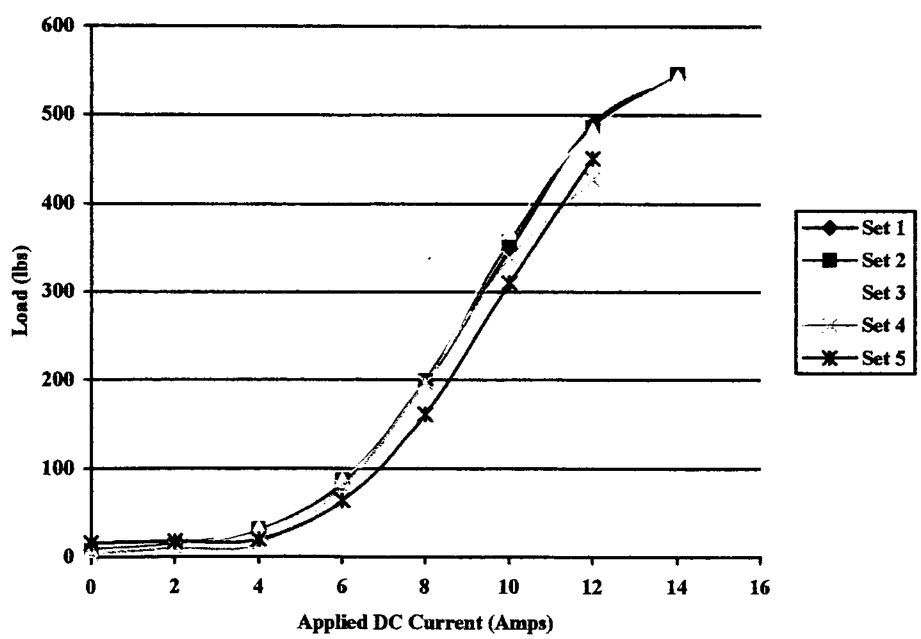

Figure 2 – Repeatability of measured load as a function of applied current at room temperature and non-rotating

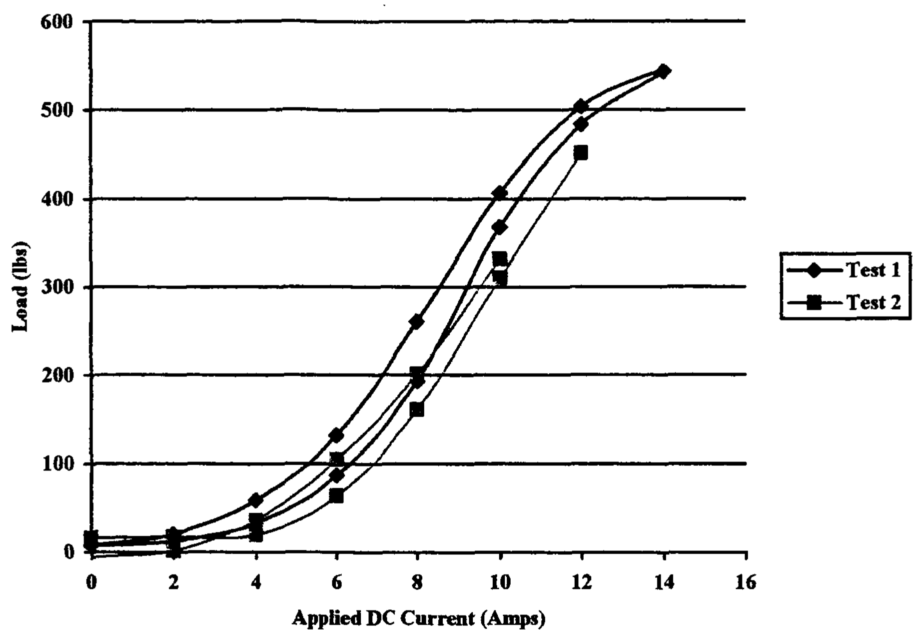

Figure 3 – Load cell hysteresis at room temperature and non-rotating