

WTC2005-63299

DRAFT -- TESTING AND COMPARATIVE EVALUATION OF SPACE SHUTTLE MAIN ENGINE FLOWMETER BEARINGS

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ABSTRACT

This paper provides a summary of testing of Space Shuttle Main Engine (SSME) flowmeter bearings and cage material. These tests were conducted over a several month period in 2004 at the Marshall Space Flight Center (MSFC). The test program's primary objective was to compare the performance of bearings using the existing cage material and bearings using a proposed replacement cage material.

In order to meet the test objectives for this program, a flowmeter test rig was designed and fabricated to measure both breakaway and running torque for a flowmeter assembly. Other test parameters, such as motor current and shaft speed, were also recorded and provide a means of comparing bearing performance. The flowmeter and bearings were tested in liquid hydrogen to simulate the flowmeter's operating environment as closely as possible.

Based on the results from this testing, the bearings with the existing cage material are equivalent to the bearings with the proposed replacement cage material. No major differences exist between the old and new cage materials. Therefore, the new cage material is a suitable replacement for the existing cage material.

INTRODUCTION

In order to meet the test objectives for this program, a flowmeter test rig was designed and fabricated to measure both breakaway and running torque for a flowmeter assembly. The flowmeter test rig assembly is shown in figure 1. Other test parameters, such as motor current and shaft speed, were also recorded and provide a means of comparing bearing performance. The flowmeter and bearings were tested in liquid hydrogen to simulate the flowmeter's operating environment as closely as possible. In addition to the cryogenic flowmeter tests, dry pocket tests were conducted on the different cage materials.

The bearings under investigation are part of the SSME fuel flowmeter that is installed as an integral part of the Low Pressure Fuel Duct. Its function is to measure the amount of hydrogen flowing through the fuel side of the engine and report

that data to the engine controller. This allows the engine controller to adjust to the correct mixture ratio for a given engine power setting.

This test program was initiated when Rocketdyne, the manufacturer of the SSME engine, was tasked to build several new replacement Low Pressure Fuel Ducts. When Rocketdyne attempted to procure new bearing cage material, it was discovered that the original bearing cage vendor was no longer in business and that the existing cage material could no longer be economically produced. Therefore, a new vendor had to be found, and a replacement material specified and re-certified. MSFC was asked to help with this task.

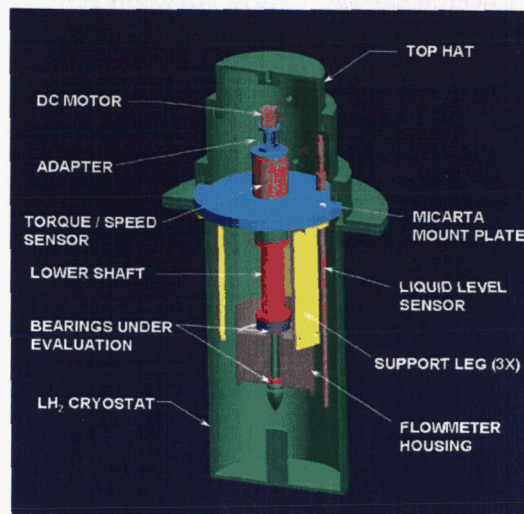


Figure 1. SSME Fuel Flowmeter Test Rig.

TESTING APPROACH

In order to fully evaluate both the existing and new cage material, three types of tests were conducted:

Flowmeter breakaway tests in LH₂. Objective: to measure the torque, motor current, and voltage required to first spin the flowmeter. These tests were run with the flowmeter submerged

in LH_2 as a linearly increasing voltage was applied to a DC drive motor. Once the flowmeter started to spin, the test was stopped. A total of 30 tests were run for each bearing set

Flowmeter running tests in LH_2 . Objective: to measure the torque, motor current, and voltage required to accelerate the flowmeter to the desired speed. The ramp rate in flowmeter speed approximated the ramp rate experienced in a typical SSME start transient. These tests were run with the flowmeter submerged in LH_2 as a voltage was applied to a drive motor. The voltage caused the flowmeter to ramp to approximately 3400 rpm in 3.5 seconds. The flowmeter was held at speed for 3 seconds before power was cut to the motor. The flowmeter was allowed to coast to a stop. A total of 30 tests were run for each bearing set. Figure 2 shows the flowmeter being installed into the hydrogen cryostat.

Cage pocket tests at ambient temperature. Objective: to measure the breakaway torque, motor current, and voltage for individual bearing cages. These were bench top tests conducted at ambient temperature. Since the cages are split into two halves, tests were made on half of the split cage pocket.

These tests were run by placing a bearing cage in a cage pocket test fixture. A linearly increasing voltage was then applied to a drive motor. The breakaway torque, current, and voltage were measured until the shaft first started to spin. Five breakaway tests were run in each pocket. Since a cage has seven pockets, a total of 35 tests were run per half cage.

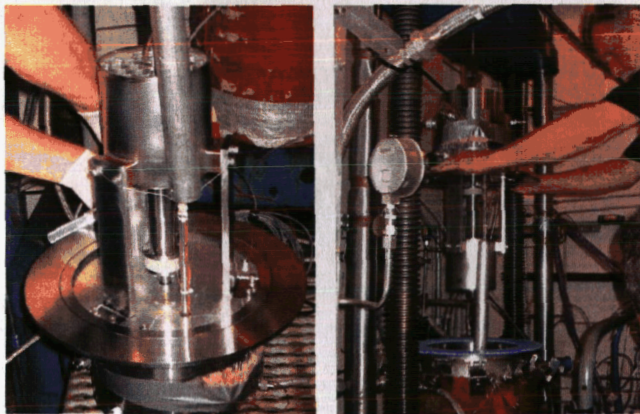


Figure 2. Installation of Flowmeter Test Rig

RESULTS

The running test results for one bearing set with the new cage material are shown in Figure 3. The figure shows both shaft speed and current for 20 tests. These results are typical for the other bearing sets. Both the average speed and standard deviation were calculated for these 20 tests and compared with the other bearing sets.

The averaged shaft speeds for all four bearing sets are shown in Figure 4. As can be seen, the bearing set with existing cage material (labeled OLD-STLE) falls within the bounds of the bearings with new cage material.

During a running test, a constant voltage profile was applied to the drive motor. The flowmeter was allowed to freely accelerate to a steady state speed dictated by system inertia, viscous drag, and friction. Since the inertial loads and viscous drag were held constant, only friction could vary. Therefore, any differences in torque and speed could be

attributed to differences in friction. A bearing set with greater friction would therefore accelerate and spin slower than a bearing set with less friction. From a comparative standpoint, the average steady-state speed of the old-style bearing set (3420 RPM) fell nearly mid-way between lowest and highest average speed of the new-style bearing sets (3330 RPM and 3480 RPM respectively). This gives a very strong indication that the bearing friction for the old-style bearings also fell between the new-style bearings.

In the cage pocket tests, the breakaway current and torque were greatest for the old-style cage material, however, the breakaway values were only marginally higher.

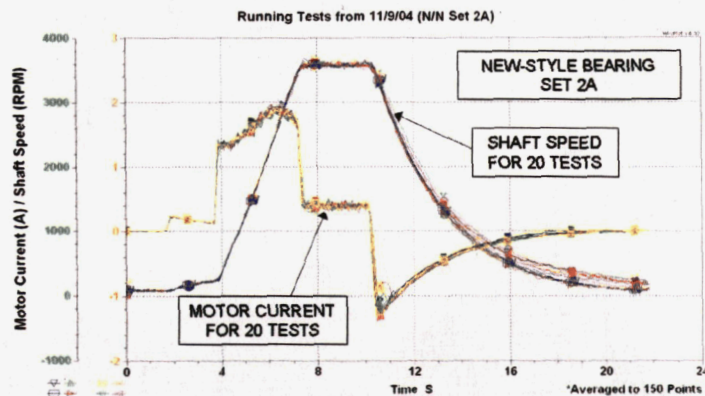


Figure 3. Results of Running Test, Bearing Set 2A

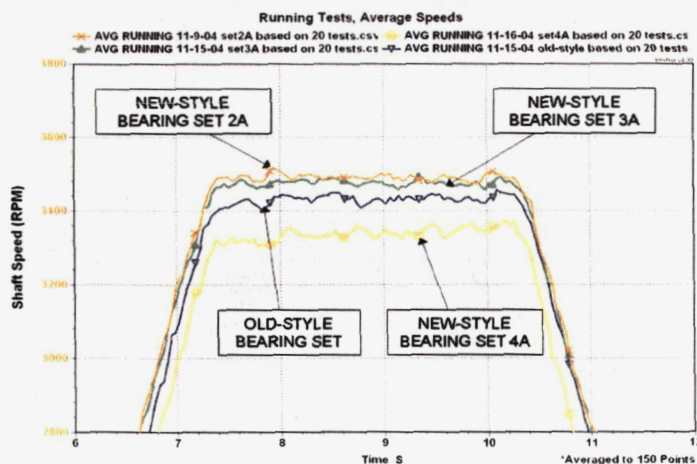


Figure 4. Ave Running Speed for Each Bearing Set Tested

CONCLUSIONS

Based on the results from this testing, the bearings with the existing cage material are equivalent to the bearings with the proposed replacement cage material. All three types of tests produced results that lead to the same conclusion: no major differences exist between the old and new cage material. Therefore, the new cage material is a suitable replacement for the existing cage material.

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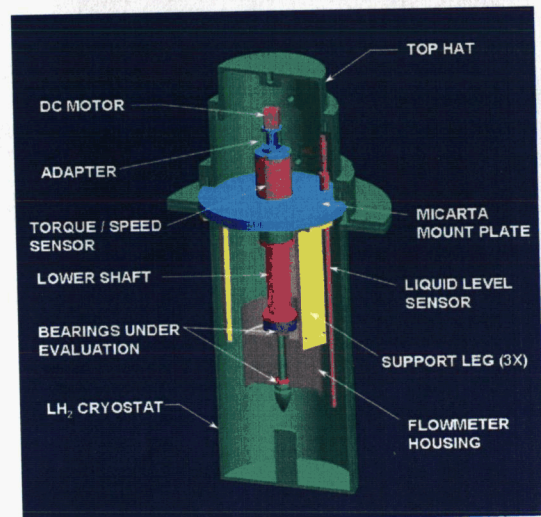


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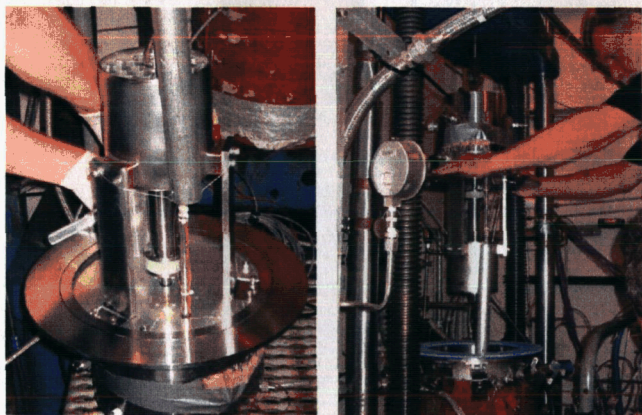


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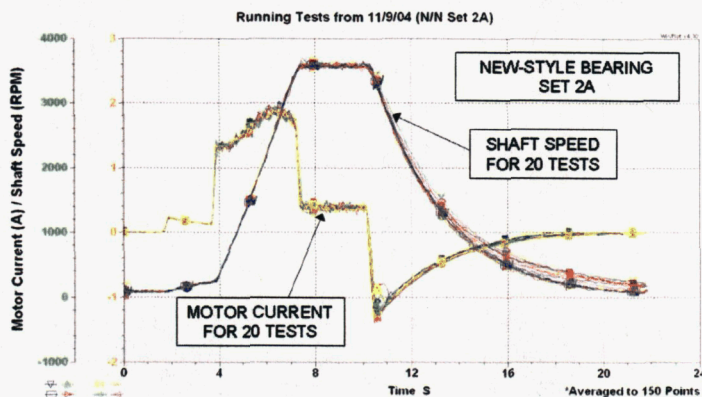


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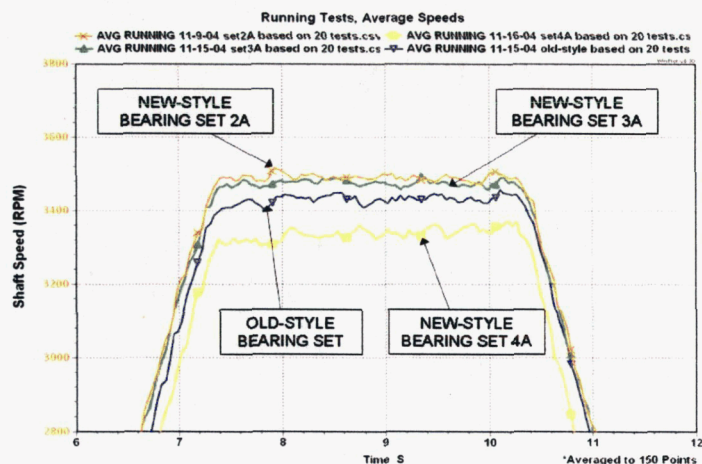


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