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Control Drum Bearings**

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TECHNICAL DATA RECORD		PAGE 1 OF 48	<i>W. Kurzeka</i>																				
AUTHOR DEPT & GROUP NO P. H. Horton 737-751		DATE June 27, 1968 - 1. 27. 68																					
TITLE Thermal Cycle Testing of the Advanced ZrH Reactor Control Drum Bearings		GO NO 7759																					
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SUBACCOUNT TITLE Advanced ZrH Reactor Bearing Development		AUTHORIZED CLASSIFIER SIGNATURE DATE <i>W. Kurzeka</i> 6-27-68																					
DISTRIBUTION Bldg.		STATEMENT OF PROBLEM Study the performance of the Advanced ZrH Reactor Bearing (Al_2O_3 on TalOW vs P5 carbon-graphite) during thermal cycling to 1500° under a vacuum of 10^{-8} torr or better. Determine bearing friction coefficient and friction torque as a function of the temperature and hours at vacuum.																					
J.G. Asquith 2																							
R. L. Detterman 2																							
F.J. Donovan 2																							
R.B. Gordon 2																							
J.D. Gylfe 2																							
R.H. Horton (2) 5																							
W.J. Kurzeka 5																							
L.M. Maki 2																							
T.S. Nakae 5																							
G.F. Queener 5		ABSTRACT The Advanced ZrH reactor Bearings have completed thermal cycle testing and post test inspection. Bearings were thermal cycled between ambient and 1500°F at a vacuum of 10^{-8} torr or lower. Bearing friction torque was recorded at ambient, 800°F, and 1500°F during 27 thermal cycles and approximately 2300 hours at vacuum. Over 1000 hours at 1500°F was accumulated. Maximum friction torque and friction coefficients are given below:																					
O. P. Steele 5																							
<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th>PRESSURE (TORR)</th> <th>TEMPERATURE (°F)</th> <th>MAXIMUM FRICTION TORQUE (IN-LBS)</th> <th>FRICTION COEFF.</th> </tr> </thead> <tbody> <tr> <td>760</td> <td>70</td> <td>23.7</td> <td>0.7</td> </tr> <tr> <td>10^{-10}</td> <td>70</td> <td>24.0</td> <td>0.7</td> </tr> <tr> <td>10^{-9}</td> <td>800</td> <td>15.0</td> <td>0.5</td> </tr> <tr> <td>10^{-9}</td> <td>1500</td> <td>9.5</td> <td>0.3</td> </tr> </tbody> </table>		PRESSURE (TORR)	TEMPERATURE (°F)	MAXIMUM FRICTION TORQUE (IN-LBS)	FRICTION COEFF.	760	70	23.7	0.7	10^{-10}	70	24.0	0.7	10^{-9}	800	15.0	0.5	10^{-9}	1500	9.5	0.3	Bearing conditions following the test were excellent with well developed carbon-graphite transfer films and no signs of Al_2O_3 coating failure. The test also demonstrated the excellence of the TalOW test fixture design in performing at temperatures to 1500°F.	
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I. INTRODUCTION

While retaining the basic features of the SNAP 8 bearings, control drum bearings for the Advanced ZrH Reactor will face more severe environmental conditions. Bearing temperatures will approach 1500°F while operating in the nuclear environment of 2.5×10^{13} nv (> 1.0 mev) in the vacuum of space. Table I lists bearing requirements.

New bearing materials are being investigated which retain the low friction characteristics of the SNAP 8 bearings and will operate at the increased temperature. As a reference bearing design, Al_2O_3 plated on Ta-10W will run against P5 carbon-graphite. As with SNAP 8, a solid carbon-graphite ball with Al_2O_3 coated shaft and socket will be utilized. While alternate material studies are being conducted, the reference bearing is undergoing simulated bearing tests. Testing will consist of:

1. A series of ambient to 1500°F thermal cycles
2. A parametric study to determine the effect of varying thrust and radial loads on bearing performance
3. A 1500°F simulated life test.

This report covers the thermal cycle test.

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TABLE IADVANCED ZrH REACTOR CONTROL DRUM BEARING DESIGN REQUIREMENTS

Environmental

Temperature, °F (maximum)	1350
Temperature, °F (minimum)	30
Pressure, Torr (space)	10^{-12}
Pressure, Torr (ground check out)	10^{-5}
Neutron Dosage, nv >1.0mev	2.5×10^{-13}
Gamma Dosage, rad	10^{12}

Life

Space Operation, hours at 1200 kw	20,000
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Launch

Shock, g	20
Acceleration, g	6
Sinusoidal Vibration, g	5
Random Vibration, g	5

Control Drum Weight

Reflector Assembly, lbs.	60
--------------------------	----

Maximum Expected Drum Bearing Torque (Shafts Vertical 1 "g" axial,
1/4 "g" radial)

System at 70°F, in. -lbs.	25
System at 1350°F, in. -lbs.	12

Clearance (Minimum)

Shaft-to-Ball, inches	.002
Ball-to Socket, inches	.002

Bearing Drive Cycles

Reactor Start Up and Shut Downs	50
Bearing Rotation Cycles	200

II. TEST PROCEDURE AND RESULTS

The test was conducted according to the test procedure of Appendix A. A summary of the test plan follows:

1. System baked out and pumped to 10^{-9} torr
2. Bearing oscillation cycle (35° cw, 70° ccw at $5^{\circ}/\text{sec}$,
25 lbs radial load, 75 lbs thrust load)
3. Bearing oscillation cycle after stabilization at 800°F
4. Bearing oscillation cycle after stabilization at 1500°F
5. Bearing oscillation cycle following 24-hour dwell at
 1500°F
6. Repeat Step 3
7. Repeat Step 2
8. Repeat Steps 1 through 7 to a total of 2000 hours at
vacuum and 24 thermal cycles minimum
9. Inspection of bearing components.

Pre-test and post-test measurements, bearing clearances and weights are given in Appendix B. The bearing Purchase Orders, Material Certifications, and other pertinent data are given in Appendix C. Details of the test and test fixture calibration are recorded in AI Laboratory Notebooks B155701 and B293601.

A. Thermal Cycle Test

A series of thermal cycles were run between ambient and 1500°F . Bearing friction-torque was recorded at ambient, 800°F , and 1500°F of each thermal cycle during increasing and decreasing temperature ramps. Bearing temperature was stabilized at 800°F for approximately 20 minutes prior to taking data and was maintained at 1500°F for a minimum 20 hours between increasing and decreasing portions of each cycle. Bearings completed a total of 27 thermal cycles during 2300 hours at 10^{-9} torr and accumulated 1050 hours at 1500°F during the test. A total of 180 bearing drive cycles, each 35° cw and 70° ccw, were run totaling 283 inch of bearing travel. During lifetime operation of the Advanced ZrH Reactor,

bearings are expected to experience approximately 900 inch travel. Thermal cycle data is shown in Figure 1 as a function of time at vacuum. Friction torque and the corresponding bearing friction coefficient are plotted for each actuation at ambient, 800°F, and 1500°F. After approximately 300 hours, the 800°F and 1500°F data appear to stabilize. Data shows considerable scatter, but remains constant within the scatter band for the remainder of the test. Maximum friction torques were 24.0 in-lbs at ambient, 15.0 in-lbs at 800°F, and 9.5 in-lbs at 1500°F. Table II shows maximum and minimum torque values and percentage scatter for data at each temperature.

TABLE II
THERMAL CYCLE FRICTION TORQUE SUMMARY

Temperature	Friction-Torque (in-lbs)			
	Maximum	Minimum	Scatter Band	
			Mean	Percent Deviation
Ambient	24.0 (0.75)	12.5	18.3	+ 32%
800°F	15.0 (0.45)	5.5	13.5*	+ 11%
1500°F	9.5 (0.28)	3.4	7.9*	+ 20%

(.xx) corresponding friction coefficient

* mean calculated after stabilization: Minimum at 800°F = 12.0 in-lb
Minimum at 1500°F = 6.2 in-lb

B. Post-Test Inspection

Figure 2 shows the post-test bearing set. Pre-test and post-test condition of the thrust face of the P5 carbon-graphite ball is shown in Figure 3. Note the heavy and continuous wear marks on the post-test ball due to contact with the thrust sleeve. Post-test condition of the ball O.D. and mating Al₂O₃ coated Ta-10W socket halves are shown in Figure 4. Marks on the ball surface are due to machining and are not the consequence of testing. The concentric rings of carbon-graphite transfer-film on the sockets are the results of rotation between the ball and socket.

Pre-test and post-test condition of the Al₂O₃ coated Ta-10W test

ADVANCED ZrH REACTOR BEARINGS

UHV THERMAL CYCLE TEST

RADIAL LOAD: 25 LBS

THRUST LOAD: 75 LBS

VACUUM: 10^{-5} TORR

KEY:

○ - AMBIENT

△ - 800°F

— 1500°F

FIGURE 1

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ADVANCED ZrH REACTOR BEARING THERMAL CYCLE TEST
27 Thermal Cycles between 70°F and 1500°F
2000 Hrs. at 10^{-9} torr - 1050 Hrs. at 1500°F

SOCKET P/N 7647-262104-3
S/N 007&008

BALL P/N 7647-26102-3
S/N 002

SHAFT P/N 7647-262129-31A

WASHER P/N 7647-262120-3

Figure 2

P5 Carbon Graphite Ball - Thrust Face

Pre-Test Condition

Post-Test Condition

Figure 3

Ball and Socket Assembly - Post Test Condition

P5 Carbon-Graphite Ball

Al_2O_3 Coated Ta-10W Socket Halves

Figure 4

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shaft is shown in Figure 5. A slight, but uniform carbon-graphite transfer-film is present on the post-test shaft. Inspection of the shaft under a 90 power microscope shows no sign of cracking or failure of the Al_2O_3 coating. Figure 6 shows pre-test and post-test condition of the thrust sleeve. Heavy and uniform carbon-graphite transfer-film on the post-test sleeve corresponds to the post-test ball condition of Figure 3. Examination of the thrust sleeve Al_2O_3 plating shows no sign of cracking or failure.

All parts of the bearing set are in excellent condition with no signs of excessive wear or detrimental effects of the thermal cycling. Pre-test and post-test bearing set dimensions, clearances, and weights are given in Appendix B. The most significant change was the doubling of the ball-to-socket clearance from 0.0020 inch to approximately 0.0047 inch. This change does not reflect in a change of bearing friction torque.

Al_2O_3 Coated Ta-LOW Off Set Test Shaft

Figure 5

Al_2O_3 Coated Ta-10W Thrust Sleeve

Pre-Test Condition

Carbon-Graphite Transfer Film

Post-Test Condition

Figure 6

III. TEST FACILITY AND EQUIPMENT

A. System Description

Testing of the Advanced ZrH Reactor bearing to 1500°F at 10^{-9} torr has required the design and fabrication of new test fixtures capable of reproducing space-thermal environments for periods up to 20,000 hours. Tests are conducted in the 2400 liter/sec ion-pumped system shown in Figure 7. Friction torque, temperature, and load data is printed and stored in the Dymec Data System. To withstand test loads and temperatures, the entire test support fixture, Figure 8, was fabricated from Ta-10W alloy. Radial and thrust loads are applied to the test bearing the sealed bellows. The heater and reflector assembly, also specifically designed for the ZrH bearing test are capable of maintaining temperatures in excess of 1800°F. The reflector assembly is fabricated from tantalum sheet. The heater, Figure 9, is fabricated from .001 inch tantalum strip and supported by an alumina sleeve. Testing of the prototype heater is discussed in Reference 2. During thermal cycling temperatures are controlled by an SCR cam controlled programmer. The test bearing and support assembly shown in Figure 10 is carried by fixture bearings within the heater envelope. The torque arm is connected through the bellows assembly to the externally mounted force transducer shown in Figure 11. The bearing shaft is rotated through the magnetic drive unit and the force transducer measures the bearing sockets resistance to movement.

B. System Calibration

Prior to initiation of the bearing test, the assembled bearing and test fixture was completed checkout for system error. Figures 12 and 13 show the 10% error band for a 50 lb force transducer and a 10 lb force transducer. Use of the 50 lb transducer, needed for the 800°F and 70°F data measurements, results in less than 10% error above 6 lbs force. Substitution of the 10 lb transducer greatly decreases the potential error in the range of 6 lbs force or less (7.5 in-lbs or less friction torque). Details of calibration are recorded in AI Laboratory Notebook B293601.

Advanced ZrH Reactor Bearing Test Setup

Temperature Controller

Ion Pump

Test Chamber

Data System

Figure 7

719-P

Figure 9

Test Bearing and Support Assembly

Figure 10

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Test Chamber Friction-Torque and
Bearing Drive Instrumentation

Figure 11

ADVANCED 2TH BEARING TEST
CALIBRATION OF SYSTEM
SOLE TRANSDUCER
TEN PERCENT ERROR BAND SHOWN

FIGURE 12

ADVANCED ZFH BEARING TEST
SYSTEM CALIBRATION
10LB TRANSDUCER
TEN PERCENT ERROR BAND SHOWN

FIGURE 13

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IV. CONCLUSION

The Advanced ZrH Reactor Bearings have completed 2200 hours at vacuum accumulating 1050 hours at 1500°F through 27 thermal cycles. The Al_2O_3 against P5 carbon-graphite bearings operated with steady friction-torque throughout the test and post-test inspection showed no signs of bearing failure or deterioration. Carbon-graphite transfer films, desirable for low friction coefficients, were developed on both socket and shaft Al_2O_3 surfaces. Maximum friction torque under 25 lb. and 75 lb. radial and thrust loads was 9.5 in-lbs. at 1500°F, 15.0 at 800° F, and 24.0 at ambient. Corresponding friction coefficients show torque to be of the same magnitude as experienced during SNAP 8 bearing tests of similar design.

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