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Bow Tests

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- * Bournia, A.
- * Bifano, N. J.
- Brussalis, W. G.
- Esselman, W. H.
- Faught, H. F.
- Gallagher, J. G.
- Jackson, L. F.
- * Lee, A. Y. ←
- * Libbing, S. V.
- Retallick, F. D.

- * Rieke, K. L.
- Roman, W. G.
- * Rowan, W. J.
- Schreiber, J. J.
- Spurrier, F. R.
- * Thompson, D. C.
- Watjen, E. A.

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INSULATED CONTROL DRUM BOW TESTS
(EML-88)

Submitted By:
ENGINEERING MECHANICS DEPARTMENT
Westinghouse Electric Corporation
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pennsylvania 15236

PREPARED BY:

I. N. Kallin

I. N. Kallin

Support Structure & Cryogenic Experiments

APPROVED BY:

N. J. Bifano

N. J. Bifano, Supervisor

Support Structure & Cryogenic Experiments

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N. J. Bifano *12/13/65*
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ABSTRACT

Control drum thermal bow tests were performed to evaluate the effectiveness of a thermal barrier proposed for reducing the maximum drum bow developed during reactor startup. The barrier tested was a titanium sheet held in contact with the slotted drum surface adjacent to the control vane. Cavities chemically etched in the surface of the barrier in contact with the drum provided a 0.010 stagnant gas gap between the drum and barrier. Bow measurements of an NRX-A3 type control drum were made with and without a thermal barrier to directly evaluate the reduction in bow attributable to the barrier. The NRX-A3, EP-IV test run startup conditions were simulated in the tests in order to correlate the laboratory test results with those obtained during reactor testing. In the EP-IV run, a flow ramp of 1.0 lb/sec^2 and an initial drum temperature of 590°R produced drum rub. In the laboratory test without a barrier, drum rub also occurred. Although the maximum bow in this test was limited to 0.072 because this was the clearance between the drum and simulated sector, it was estimated from the drum temperatures measured that a bow of 0.094 would have occurred if there had been sufficient clearance. Under the same flow and initial drum temperature conditions, the maximum bow measured with the thermal barrier was 70 per cent lower. Three tests with the barrier installed and with the drum initially at room temperature showed that the maximum bow did not vary significantly from 0.018 inches when the ramp rate was varied from 0.4 lb/sec^2 to 3.0 lb/sec^2 .

Additional tests of the NRX-A5 and A6 control drum configuration, which incorporates a cooling slot diametrically opposite the control vane cavity, have been carried out. The results of these tests indicate that this cooling slot is even more effective in reducing bow than the thermal barrier. These tests will be described in a report which will be issued in March.

This work was performed under EML-88 "Insulated Control Drum Bow Tests".

CONCLUSIONS

1. Under the approximate startup test conditions of the NRX-A3, EP-IV test run (1.0 lb/sec² gaseous inlet flow ramp, 590°R initial drum temperature) the bow of an NRX-A3 type drum is about 0.094 inches.
2. Under the same conditions, the bow of an NRX-A3 type drum with a chemically machined titanium thermal barrier installed can be reduced to about 0.026 inches.
3. The maximum thermal bow of a drum with a thermal barrier installed and initially at room temperature will be about 0.018 inches for any flow ramp in the range of 0.4 lb/sec² to 3.0 lb/sec².

INTRODUCTION

This report summarizes the control drum bow tests conducted to measure the thermal bow of a control drum under simulated reactor start-up conditions and evaluate the effects on bow of a "thermal barrier" insulating shield installed in the control plate area.

During some of the NRX-A1 and A3 reactor startups, high control drum torques were observed, and there is evidence to indicate these torques were due to thermal bowing and rubbing of the drums at the bore of the sector (see TME-745 and 1253). Tests of a single control drum at WANL (see TME-977) showed that the bow was indeed caused by the thermal shock of the cryogenic startup gas flow on a drum initially at room temperature. A certain amount of bow during startup would be expected since the drum has a cooling passage system which is designed to remove the large heat flux generated in the control plate region at full power. During startup, the power level is low, but since the flow passages are the same, a large flow of coolant gas occurs on the side of the drum which holds the control plate. This chills the beryllium material adjacent to the control plate passage causing it to contract more than the material across the drum diameter from the plate where the low gas flow causes the temperature to stay nearer room temperature. This temperature gradient causes the drum to bow.

An insulating thermal barrier was designed which would cover the drum surface in the control plate region. This barrier provides a 0.010 inch insulating gap of essentially stagnant gas. To determine its effectiveness at reducing bow, it was decided to test the insulated drum at WANL and to compare the results with those of a non-insulated drum subjected to the same test conditions.

TEST EQUIPMENT AND PROCEDURE

Helium gas was used to simulate the hydrogen gas flows which occur during reactor startup. Due to the differences in the properties of helium and hydrogen, the helium mass flows required were 2.6 times as high as the hydrogen flows simulated.

The flow system and test setup are shown schematically in Figures 1 and 2. Gaseous helium is drawn from a large truck at 2400 psi and piped to a liquid nitrogen cooled heat exchanger (Figure 3), where a manually operated valve is used to avoid overpressuring the heat exchanger tubing. Safety relief valves for the heat exchanger tubing are set at 1170 psi. The heat exchanger cooling coils are immersed in liquid nitrogen for the tests. A very large cooling coil surface is necessary, not for gaseous helium-to-copper heat transfer, but for copper-to-boiling liquid nitrogen conduction where the heat transfer is very poor.

Downstream of the heat exchanger is another manually operated valve, this valve being used to control the flow through the test chamber. The operator of this valve controls the flow ramp by varying the valve opening so that the system flow equals the desired instantaneous flow as indicated by a ramp line on a time driven X-Y recorder. The ordinate cross bar on the X-Y recorder is actuated by an electrical signal proportional to measured actual flow, and the operator makes continuous adjustments of the valve to keep the ordinate pen on the desired flow ramp line.

From the flow control valve, the helium is piped to the test chamber. The chamber appears on the drawing shown in Figure 15. Prior to each test run, this section of piping is prechilled by flowing liquid nitrogen in through the bleed valve at the bottom of the

test chamber and out another bleed valve located near the heat exchanger. The flow measuring nozzle has a short rounded entrance orifice; and during practically all of the flow time, it runs choked.

The flow passages inside the test chamber were insulated using wood, and the outer volumes where instrumentation was located were dead-ended so that all of the flow existing from the chamber had to go out through the control drum passages (Figure 15). Pieces of wood were machined to fit most of the empty volume in the test chamber in order to minimize the gas plenum in the flow system.

During the testing, the control drum was rotated about 360° back and forth from the " $\theta = 0^\circ$ " position. The speed was about $180^\circ/\text{sec}$. Strain gaged beams made of titanium were mounted as shown in Figure 15 in order to measure the bow of the drum. Each transducer was calibrated in place. The temperature effect on sensitivity was measured and found to be negligible. The bow values in the test results were all obtained from the same transducer which was mounted at $\theta = 90^\circ$ at the center station of the drum. Other transducers at the center station gave about the same magnitude of deflection. Although the maximum bow was assumed to occur at the center station, it is possible that the actual plane of maximum bow could be at a different station. However, it was felt that the maximum bow measured at the drum mid-section would not differ significantly for the actual maximum bow. This procedure of measuring bow while the control drum is rotating provides a means of measurement with respect to the drum bearings' centerline instead of with respect to the transducer base. The necessary assumption is that the transducer base does not move (i.e., the titanium supporting barrel does not bow) during the one second the control drum takes to rotate. The transducer base was estimated to move less than 0.001 in/sec . The transducer recorder gives an approximate sine wave trace, the peak-to-peak measurement being the double amplitude or "full indicator reading" of the bow. In the results, the single amplitude of the bow is reported. It is felt that the reported values are within 0.005 of the actual bows which occurred.

Gas pressure was measured at the flow measuring nozzle mentioned above, and also at the piping about three feet upstream of the control drum entrance. Differential pressure was measured between the control drum entrance and exit. Gas temperatures were measured

at the control drum inlet, at the exit of each of the four separate flow passages (three passages inside the drum and the annulus passage around the drum), and at the flow measuring nozzle. Copper-constantan (Cu-Con) thermocouples were used throughout the test system. The pressure transducers were strain gage type, and they were calibrated in place prior to the test. The measured temperatures and pressures should be within 5 per cent of the actual values.

Nine thermocouples were installed in the drum as shown in Figure 15. Precision thermocouple wire was used and the welded beads were inserted in small holes and potted in place with a mixture of 35 per cent fine silver powder and 65 per cent GA-5 epoxy cement. This method had been found to be very reliable and very fast acting. When used with light-beam galvanometer recorders, it is estimated that the time constant of this temperature measurement is less than 0.10 sec.

The thermocouple wires were carried down the length of the drum in specially machined grooves as shown in Figure 15. They were then bundled into a pigtail and carried out through the hole at the center of the drum nozzle end bearing shaft. A loop of the pigtail was left slack to allow flexibility when the drum was rotated. In order to compensate for blockage of the hole through the bearing shaft, the hole was bored out to a larger diameter. The pigtail was then carried up through the insulation around the drum support barrel and the individual thermocouple wires were passed through the passage vessel via "Conax" fittings.

The drum rotation was accomplished by using a reversible electric motor connected through a 60:1 speed reducer and a pair of position limit switches at the drum actuator shaft. The motor uses an electrically operated brake to achieve fast reversal of rotation. In order to measure drum frictional torque, a short section of the drum actuator shaft was machined down to a diameter which would be more highly stressed, and then instrumented with resistance wire strain gages to form a torque transducer. The strain gage leads were provided with a coil of slack wire, and then carried out of the test chamber using "Conax" fittings. The penetration of the torque shaft through the test chamber wall without gas leakage was accomplished by using two bellows type face seals. The seals are pressure loaded and utilize a rubbing surface of stainless steel against graphite.

RESULTS

The major test results are presented in Figures 7 through 14. Run 7, the data for which is shown in Figures 7, 10 and 11, was an attempt to simulate the conditions which occurred in the NRX-A3, EP-IV test run. The drum was preheated to 130°F and a linear ramp of about 1.0 lb/sec² was used. Run 8, the data for which is shown in Figures 8, 12 and 13, is a similar run, except that in this case the thermal barrier was installed to reduce bow. Figure 7 shows the inlet gas temperature, simulated full reactor flow rate, drum bow, and actuator torque for Run 7, all plotted versus time in seconds. At about $t = 13.5$ seconds, the drum bow was so great that the drum started to rub against the simulated sector. The measured bow at this time was 0.072 inches. At about $t = 23$ seconds, the bow had decreased enough so that the rubbing ceased and the drum again turned freely. During this time period, the deflection of the drum could not be measured directly since the deflection transducers were mounted to the surrounding simulated sector which was itself being deflected by the rubbing forces. The "free" bow, which would have been measured if the clearance had been greater, was computed by using the drum temperature measurements at the drum center station. This value is shown in Figure 7 as the dashed line continuation of the measured bow curve. It is seen that a maximum value of 0.094 inches is reached. The computation of free bow was made by using the temperatures and known coefficients of expansion at the drum center station to form a factor which could be used to ratio any actual bow measurement made before rub started. In this case, the bow measurement of 0.072 inches, made just prior to rub, was ratioed. The parameter used to form these ratios was:

$$P = \frac{(T_1 - T_R)}{(T_2 - T_R)} \left[\frac{\alpha_1}{2} - \frac{\alpha_2}{2} \right]$$

where: T_1 = temperature at drum center station, 180° from control plate
 T_2 = temperature at drum center station, 0° from control plate
 T_R = room temperature
 α_1 = mean linear coefficient of thermal expansion from T_R to T_1
 α_2 = mean linear coefficient of thermal expansion from T_R to T_2

The torque is shown in Figure 7 as an indicator of rub, however the absolute magnitude of torque measured should not be compared with reactor torque measurements since the simulated sector used in the laboratory had a greater resilience to the interference force than an actual sector. The actual sector is stiffer and would offer more resistance to the rubbing and sliding forces. A second test run, also without the thermal barrier and under approximately the same test conditions is reported in Figure 14 to show that this rub was reproducible. It is felt that the drum inlet temperature is more reliable in this run than in Run 7.

In the test reported in Figure 8, approximately the same test conditions were applied to a control drum in which the thermal barrier was installed (see Figures 4, 5 and 6). The maximum bow for this test was only 0.026 inches. The torque was nearly constant at about thirty inch pounds, and most of this torque is attributable to friction from the laboratory bow measurement transducers. Also shown in Figure 8 is the temperature difference between the barrier itself and the drum surface beneath it, that is, the temperature drop across the 0.010 inch insulating gap. This temperature drop reaches a maximum of about 260°R about eight seconds after the start of flow. This large temperature drop is a measure of the high effectiveness of the barrier at insulating the control plate passage surface.

Figures 10, 11, 12 and 13 present other gas temperature and material temperature data for the two test runs described above. The locations of these thermocouples are shown in Figure 15.

Three other tests were run on the drum with the thermal barrier installed. These tests, reported in Figure 9, were performed with the drum initially at room temperature, and only the flow ramp rate was varied among the three tests. As shown in Figure 9, the 0.4 lb/sec^2 ramp rate produced about 0.016 inch maximum bow, the 1.25 lb/sec^2 ramp rate produced also about 0.016 inch maximum bow, and the 3.0 lb/sec^2 ramp rate about 0.018 inch maximum bow. This shows that the insulated drum, tested from initially room temperature, is basically ramp insensitive as far as bow is concerned.

FIGURE 1
CONTROL DRUM BOW TEST SETUP SCHEMATIC DIAGRAM

FIGURE 2
CONTROL DRUM BOW TEST SET-UP

FIGURE 3
HEAT EXCHANGER TANK
-10-

FIGURE 4
THERMAL BARRIER

FIGURE 5
CONTROL DRUM, THERMAL BARRIERS,
AND CONTROL PLATES

FIGURE 6
THERMAL BARRIER LOCATION

FIGURE 7 LABORATORY DRUM BOW TEST RESULTS

FIGURE 8 LABORATORY DRUM BOW TEST RESULTS

FIGURE 9 LABORATORY DRUM BOW TEST RESULTS

FIGURE 10 GAS TEMPERATURES AT INLET AND OUTLET OF CONTROL DRUM

FIGURE 11 MATERIAL TEMPERATURES

FIGURE 12 GAS TEMPERATURES AT INLET AND OUTLET OF CONTROL DRUM

FIGURE 13 MATERIAL TEMPERATURES

FIGURE 14 LABORATORY DRUM BOW TEST RESULTS

FIGURE 15
ENLARGED SECTION OF TEST RIG
ASSEMBLY DRAWING

SECTION 174
(SEE TABLE FOR MOUNTING)

SECTION 174
STATION 174
(SEE TABLE FOR MOUNTING)

SECTION 174
STATION 174
(SEE TABLE FOR MOUNTING)

SECTION 174
STATION 174
(SEE TABLE FOR MOUNTING)

SECTION B-B
TYPICAL
AIR-TO-MOUNTING

LOCATION	SECTION 7/C	SECTION 7/C	SECTION 7/C
1. 10' 10" 26' 10" 44' 10"	1. 10' 10" 26' 10" 44' 10"	1. 10' 10" 26' 10" 44' 10"	1. 10' 10" 26' 10" 44' 10"
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SECTION C-C
TYPICAL
AIR-TO-MOUNTING

SECTION D-D
TYPICAL
AIR-TO-MOUNTING

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