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FLOW CONTROLLER EVALUATION
FOR SODIUM SERVICE

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AEC Research and Development Report

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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FLOW CONTROLLER EVALUATION
FOR SODIUM SERVICE

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ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: NOVEMBER 30, 1963

DISTRIBUTION

This report has been distributed according to the category "Instruments" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (23rd Ed.), September 1, 1963. A total of 680 copies was printed.

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ABSTRACT

Tests were conducted to evaluate the performance of a 10-in. flow controller in sodium at temperatures up to 1200°F. Torque tube reliability was determined by extensive mechanical cycling tests and further checking with a helium mass-spectrometer leak detector. Flow control performance and valve vibration characteristics were tested and evaluated and flow rate limits were established. The valve assembly was subjected to a thermal shock test program simulated to represent the most severe conditions likely to be encountered during a minimum 10-yr lifetime.

I. INTRODUCTION

A throttle valve may be used in the primary or secondary system of a sodium cooled nuclear power plant to vary the rate of coolant flow with power level. If the reactor is scrammed and the coolant pumps are turned off, such a valve also may be used to maintain the temperature difference across the core by throttling the flow due to natural convection to match the afterglow energy being generated.

Conventional globe or gate valves are not suitable for this application: globe valves cause a large change in flow rate if adjusted while near the closed position and relatively little change near the open position; gate valves, while they can be adjusted satisfactorily, have a greatly reduced life when operated in a partially opened position due to vibration of the gate in a high velocity stream. In addition, when such valves must operate in a liquid metal environment at high temperature there are added problems of sealing the drive shaft and of overcoming induced thermal stresses. Consequently, a 10-in. flow controller (Figure 1) was designed and built specifically for use with high temperature sodium.

This flow controller is essentially a modified plug valve with one entrance and two exit ports (Figures 2 and 3). The hydraulic characteristics of this valve were determined using water at room temperature by the designer-manufacturer, Ohio Injector Company of Wadsworth, Ohio. In addition, tests of the valve drive were performed and the valve was operated in air at 1000°F. However, it remained to be demonstrated that this flow controller could operate satisfactorily under conditions which might be encountered with sodium as the coolant in a heat transfer system. Therefore, to permit evaluation of this valve in sodium at temperatures up to 1200°F, tests were needed: (a) to establish the reliability of the primary shaft seal, (b) to determine the hydraulic characteristics of the flow-controller, and (c) to evaluate the resistance of the valve assembly to repeated thermal shocks.

The primary shaft seal for this flow controller consisted of a telescoped arrangement of two torque tubes with 1/8-in.-thick walls, which provided a zero-leakage seal to prevent escape of sodium (Figure 4). This seal is more effective than conventional seals such as packing, which would not be leakproof, and is

more durable than thin-walled bellows. Mechanical tests, consisting of operating the controller through its flow range (the number of cycles during the controller life) were needed to determine if the torque-tube seal had been properly designed to have the fatigue life required for long-time operation in sodium at 1000 and 1200°F.

Two exit orifices were contained in the valve part of the flow controller to balance the forces acting on the gate, and thereby improve sodium flow stability. These orifices were contoured to provide nearly linear indication of sodium flow rate. The valve gate-to-bore clearance was determined by throttling range requirements. Flow tests, using high-temperature sodium, were needed to determine: (a) the maximum flow rate the controller could handle without flow instability, (b) the linearity of flow rate with degree of valve opening, and (c) the throttling range.

Because of the high conductivity of sodium and the high temperature coefficient of expansion of the Type 304 stainless steel used for the valve parts, thermal shock effects played a very important role in the valve study. Thermal shocks could be imposed by any sudden change in the temperature of the sodium flowing through the controller. Therefore, thermal shock tests were needed to determine if distortion of valve parts would occur which would either close the valve gate-to-bore clearance to the extent that the valve would bind, or increase the clearance excessively so that the throttling range requirement would not be met. In order to simulate thermal shock conditions more severe than those expected even during abnormal reactor operation, the following tests were specified: 500 thermal shock cycles were to be imposed at -30°F per sec for 5 sec, starting each cycle with an inlet sodium temperature of 1000°F; then 500 thermal shock cycles were to be imposed at -35°F per sec for 5 sec, starting each cycle with an inlet sodium temperature of 1200°F.

II. THE FLOW CONTROLLER

The flow controller is designed for adjusting the flow rate in a circulating sodium system. The major members of the controller are: (a) a cylindrical body with one entrance and two exit ports; (b) an orifice-closing member or gate; (c) a torque tube seal; and (d) valve operating mechanisms (see Figures 1 through 8).

A. VALVE BODY AND EXIT PORTS

The two exit ports (one of which is visible in Figure 3) are positioned at opposite sides of the valve body and are contoured to provide an approximately linear relationship between flow rate change and unit change in flow indicator position. Valve body walls are of uniform thickness, 5/8 in., to avoid stress risers which could cause wall distortion as a result of thermal shock. Valve body design conforms to ASME unfired pressure vessel code and also conservatively exceeds ASA B 16.5 minimum wall thickness requirements for 300 lb class; Type 304 material (ASTM A240) permits a rating of 300 psi at 1000°F, whereas the functional test specification was 100 psi maximum at 1000°F.² In addition, the body could withstand a maximum operating pressure of 100 psi at 1200°F because of the large safety factor introduced, and reduction of only 6% in material yield point from 1000 to 1200°F.

B. GATE

The gate (Figure 2) consists of two cylindrical sections connected to the drive shaft which alter the degree of opening of the two exit ports positioned 180° apart. As the gate rotates, the opening area of one of the exit ports is kept approximately the same as the opening area of the other exit port; balancing of fluid forces acting on the gate is thus accomplished. Adjustment of the exit port openings is provided by rotation of the gate through 30° in either direction about the mid-position. The gate is attached to a drive shaft by a pin which would shear and prevent drive shaft yielding upon application of excessive force.

C. TORQUE TUBE SEAL

The torque tube arrangement (Figure 4) allows drive shaft and gate rotation and also serves as a sodium seal. This seal construction is made practical by the limited 60° gate rotation, and the low applied torque resulting from the balancing of fluid forces on the gate providing for the use of small diameter,

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Figure 1. Complete Flow Controller

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Figure 2. Valve Assembly

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Figure 3. Valve Bore

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Figure 4. Flow Controller Bonnet Assembly

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Figure 5. Gate to Drive Shaft Connection

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Figure 6. Valve Body

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Figure 7. Valve Inlet Port

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Figure 8. Gate and Bonnet Assembly

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low-stressed torque tubes. A sodium freeze seal (backup seal) is also utilized. If there is a fracture of the torque-tube metal, any sodium leaking into the upper bonnet cavity would freeze in the small annular clearance between the drive shaft and shaft guide; external cooling fins ensure freezing of the sodium. An increase in shaft operating torque would indicate occurrence of a leak.

D. VALVE OPERATING MECHANISMS

Rotation is accomplished by the valve operating mechanism either manually or with an electric motor drive. During manual operation, 23 turns of a 6-in. diameter handwheel are required to adjust the valve from fully opened to fully closed. The electric motor drive permits a fast operation of 2 sec and a slow operation of 1 min for a single traverse. Motors are 110-volt, single-phase, 1/3-hp and 1/8-hp respectively. The electric motor drive and the manual drive are additive and noninterfering; either may be operated in either direction with the other running or stopped and no resetting is required.

The flow controller was designed for operation in the horizontal position, with the bonnet assembly perpendicular to the ground plane and above the valve body to permit complete drainage. The required positioning of the flow controller is shown in Figure 9. Valve operation in a vertical position appears to be practical if provision is made for fluid drainage and support of the long bonnet assembly.

E. IMPORTANT VALVE DESIGN FEATURES

Important features of the valve design are as follows:

- 1) The division of entering sodium into two approximately equal-weight streams which, by balancing of fluid forces acting on the gate, minimizes gate vibration and resulting flow instability.
- 2) The use of the torque-tube seal which was made practical by the small angular (60°) rotation of the drive shaft for complete flow control, and the balancing of fluid forces acting on the gate.
- 3) The use of exit orifices contoured to provide an approximate linear relationship between flow rate and angle of drive shaft rotation.
- 4) The utilization of uniform wall thickness in the valve body and gate to minimize occurrence of stress risers and resulting wall distortion under thermal shock conditions.

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Figure 9. Valve in Sodium Loop — Thermal Shock Tests

III. MECHANICAL CYCLING TESTS

Mechanical cycling tests were performed on the test bonnet assembly to establish the reliability for sodium service of the torque-tube seal on the drive shaft. To demonstrate its reliability, this assembly was operated through 2000 complete openings and 2000 closings at elevated temperatures in a flowing sodium system.

A. TEST PROCEDURE

The tests consisted of 1000 cycles at 1000°F and 1000 cycles at 1200°F in sodium. Cycling of the torque-tube seal was accomplished by use of the two-speed drive assembly furnished with the flow controller. Each cycle consisted of rotating the drive shaft twice from the fully opened to the fully closed (60°) position and return; the fast speed (2 sec for a single traverse from open to closed) was used for the first closing and opening, and the slow speed (1 min for a single traverse) was used for the second closing and opening of each cycle. The drive assembly was controlled by a combination of timers and relays which were adjustable to give a dead time of about 2 min at each end of the valve travel.

To perform these tests the flow controller bonnet containing the torque-tube seal to be tested was installed in an existing test loop. Isolation valves were installed on each side of the bonnet assembly to permit pressure testing of the torque-tube seal without damaging other parts of the loop not suitable for the high leak-test pressure of 100 psig. The pressure test consisted of draining the loop, closing the isolation valves, and pressurizing the lower bonnet chamber through the assembly vent tube to 100 psig with argon gas. The vent was then valved off, and the pressure was observed for 15 min to ascertain if there was any drop in pressure due to gas leakage. This procedure was repeated after each 200 cycles of the 1000 and 1200°F tests.

B. TEST RESULTS

No leakage was observed, indicating that the torque tube was not damaged. After completion of the tests, a check was made with a helium mass-spectrometer leak detector which verified the pressure test indication that failure had not occurred in the torque tube.

IV. FLOW CONTROL PERFORMANCE

Tests were performed to determine the flow characteristics of the controller.

A. FLOW CONTROL TESTS

For these tests, the flow controller was installed in an existing 12-in. test loop made up of 12-in.-diameter pipe and containing a free-surface mechanical pump. Before sodium filling, the flow controller was preheated to approximately 400°F, well above the 208°F melting temperature of sodium. After sodium flow was established, the system temperature was raised both by the external heaters and the mechanical input of energy from the pump impeller.

While checking the pressure gages at a sodium temperature of 450°F, the controller was closed (using the slow speed drive) for the first time against the flow of high velocity sodium. During this operation the loop reacted violently to a shock, sodium surged the full length of the controller's vent freeze seal and out the pressure tube into a length of installed plastic hose to a height approximately 1 ft above the bonnet, such a surge could not be duplicated during further operation of the controller.

It is postulated that before the controller was installed in the loop, foreign matter had lodged in the small clearance space (0.006 in.) between the gate and the valve bore, which caused binding of the gate. When the operator was rotated in the valve-closing direction, the gate could not follow until sufficient torque was built up in the drive shaft to release the bind, and permit the gate to snap to the closed or nearly closed position; this could explain the mechanical shock. The valve binding could not be attributed to valve body distortion because at this stage in the tests the valve had been slowly heated to only 450°F.

Only the slow operating speed of the flow controller was utilized during the flow tests with sodium. This was necessitated by the nature of the system, as any sudden flow stoppage would cause undesirable level surges in the free-surface pump. However, in previous tests performed by the designer-fabricator, Ohio Injector Company, with water flow in the loop equivalent to sodium flow of 25 ft/sec, the device was closed in approximately 2 sec using the 1/3-hp high-speed drive. In the Ohio Injector Company report,² it is stated: "The performance of the 10-in. prototype proves that two second operation is a reasonably

obtainable fast closing speed. However, with most of the fluid deceleration occurring during the last 0.5 sec of the operation, the pressure surge generated may be rather formidable."

Flow control performance was determined at temperatures of 600, 825, and 1000°F, and at flow rates from 3400 to 5800 gpm. The tests were characterized by the flow supplied to the valve at the start of each run while the valve was fully open. At each maximum flow rate selected, the test consisted of throttling the flow by positioning the valve in 10% increments from fully opened to fully closed and return, and measuring the flow rate at the various valve positions. All data points are contained in the band shown in Figure 10. There was no trend in the the shape of the curve indicating any changes due to variation in either sodium temperature or the characterizing flow rate. Scatter in the data appeared to be due to fluctuation in sodium pressure or difficulty in precise adjustment of the position indicator. The flow rate vs degree-of-valve opening was reasonably linear except in the 60 to 100% open position region. In these positions, a relatively small change in position caused a proportionately larger change in flow.

The throttling characteristics of the valve could not be determined at the time the flow tests were conducted; one of the pressure units was damaged shortly after installation so that pressure drop data could not be obtained. Even if the gage had not been damaged, true pressure losses across the controller could not have been obtained because of expansion and contraction losses in the 10 by 12 in. reducers on both ends of the valve. Consequently, the throttling characteristics of the valve were determined after completion of the thermal shock test program, with sodium at 1000°F and approximately constant pressure drop across the valve.

A plot of flow coefficient vs degree of valve opening is shown in Figure 11. In this plot, data after completion of the thermal shock tests are compared to results obtained by the manufacturer prior to any of the testing in sodium. The manufacturer's data were obtained using water and have been converted to equivalent values for sodium in Figure 11. The two curves run nearly parallel for valve positions in the region from full open to 25% open. At valve positions from 25% open to full closed, the flow coefficient (C_v) values were higher for the sodium test and was 33 compared to 6 at the valve full closed position. This difference can be explained by considering the valve bore-to-gate (diametral)

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Figure 10. Sodium Flow Through Valve

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Figure 11. Flow Controller Throttling Characteristics

clearance at the time each test was made. Originally the average clearance was 0.011 in., after remachining (see Section V-C) the clearance was 0.017 in., and by the end of the thermal shock program the clearance was 0.026 in. The effect of clearance area on flow is proportional to $(0.026/0.011)^2 = 5.58$, and this value checks with the C_v ratio $33/6 = 5.50$. After remachining, calculated $C_v = 6 (0.017/0.011)^2 = 14.3$. Thus, based on constant ΔP , the throttling range was originally $1850/6 = 308$ to 1, after remachining $1850/14.3 = 130$ to 1, and by the end of the thermal shock program $1850/33 = 56$ to 1.

Test requirements of approximate linearity in flow control and a minimum throttling range of 20 to 1 indicate the throttling range requirement was based on constant ΔP . On this basis, the flow controller met the throttling range requirement.

In nuclear reactor piping systems the pressure drop across the valve is not constant, being low at high sodium flow rates and appreciably higher at low flow rates, and this can result in a lower throttling range; the exact value dependent upon the particular conditions selected.

B. VALVE VIBRATION TEST

During the flow control tests, vibration of the valve was noted, and tests were performed to determine the conditions under which vibration was initiated. During 5000 gpm tests at 825°F, no vibration was observed throughout the operating range of the valve. Vibration was observed during 5400 gpm tests at 825°F; this instability was most pronounced in the 80% open position (about 3800 gpm) and persisted until the valve was closed to the 40% open position (about 1000 gpm). Using 1000°F sodium, flow instability in the controller was less pronounced. During 6500 gpm tests, vibration was not encountered until the valve was closed to the 70% open position (3900 gpm). The valve full-open sodium flow rate was gradually reduced until at 5300 gpm the flow became stable at all controller operating positions. This indicates that stable flow in the controller may not be achieved with flow rates in the fully opened position >5300 gpm at 1000°F, or 5000 gpm at 825°F. Therefore, the unit is not recommended for full-open flows >5000 gpm in the temperature range of 825 to 1000°F.

C. TEST CONCLUSION

Flow capacity of the controller can apparently be improved by increasing the rigidity of the drive shaft; the divided flow and hydraulic forces that are not

completely balanced evidently induce torsional vibrations in the shaft and gate. Ridgidity of the drive shaft (to reduce vibrations) can be improved by a moderate increase in shaft diameter because torque capacity increases as the fourth power of the diameter. A proportionately-small increase in torque-tube (and shaft length) is required because stress level is directly proportional to the ratio of diameter to length. Therefore, with minor design changes the controller would be suitable for >5000 gpm. The same reasoning would permit use of this general design in larger sizes or larger pipeline sizes.

V. THERMAL SHOCK TEST

Thermal shock testing is probably the most important phase of the valve test program. Because a valve which is subjected to repeated thermal shock in the piping system of a reactor may become inoperative due to distortion of valve parts, it is desirable to evaluate the ability of the flow controller to withstand such shock.

A. TEST PROGRAM

The thermal shock test program was performed in two phases; in which the thermal shocks were applied with the flow controller in the full-open position. During the Phase I tests, 500 thermal shocks were applied at $30^{\circ}\text{F}/\text{sec}$ for 5 sec from 1000 to 850°F inlet-sodium temperatures. During the Phase II tests, 500 thermal shocks were applied at $35^{\circ}\text{F}/\text{sec}$ for 5 sec from 1200 to 1025°F inlet-sodium temperatures. These test conditions were selected as representative of the most severe conditions likely to be encountered by the flow controller in a reactor system during a minimum lifetime of 10 yr.

B. TEST PROCEDURE

In Figures 9 and 12 the flow controller is shown installed in a 6-in. bypass loop attached to an existing 6 by 8-in. pump test loop. Valve heating to shock test temperature was accomplished by circulating sodium with an electromagnetic pump through a 50-kw immersion heater in the 2-in. pipeline. Two pneumatically-operated gate valves were installed in the system, a primary valve in the pump test loop and a secondary valve in the test valve bypass loop. By adjustment of external pipe heaters, the stagnant sodium contained in the upstream piping was heated with a temperature gradient from shock-test temperature at the immersion heater to the lower sodium temperature in the pump loop. This temperature gradient in the sodium was needed to obtain the desired linear temperature-time relationship during the thermal shock tests.

Automatic thermal shock cycling was accomplished in the following manner:

- 1) Circulation of heated sodium through the valve raised the valve body and gate temperatures at about $8^{\circ}\text{F}/\text{min}$ to shock test temperature. During this time the primary gate valve was open and the secondary gate valve closed, resulting in the normal flow path for sodium in the pump test loop.

Na FLOW PATH
(CONTROLLER VALVE HEATING)

Na FLOW PATH
(THERMAL SHOCK)

7519-54486

Figure 12. Thermal Shock Testing – Sodium Flow Paths

- 2) At shock test temperature (1000°F for Phase I or 1200°F for Phase II), a time-delay relay disconnected the immersion heater and permitted valve-body and inlet-sodium temperatures to equalize; the length of the time delay was established by observing that time at which strain gages indicated no strain change.
- 3) Then, the secondary gate valve opened and the primary gate valve closed, which permitted colder sodium in the pump test loop to enter the bypass loop. The sodium in the upstream piping was forced through the valve, causing the valve inlet-sodium temperature to fall at a uniform rate of $30^{\circ}\text{F}/\text{sec}$ from 1000 to 850°F in 5 sec (Phase I) or $35^{\circ}\text{F}/\text{sec}$ from 1200 to 1025°F in 5 sec (Phase II). Finally, passage through the valve of sodium from the pump loop at a temperature of just under 850°F for Phase I, or 1025°F for Phase II, completed the thermal shock. The temperature-time shock patterns obtained (Figure 13), follow closely the desired linear path.
- 4) The primary gate valve opened, the secondary gate valve closed, and valve heating was renewed to start a new cycle.

All operations were accomplished automatically. Valve-body temperatures throughout the shock half of the cycle were recorded daily; the temperature-time pattern was consistently repeated.

C. PHASE I THERMAL SHOCK TESTING

The required sodium cooling rate at the valve inlet of $30^{\circ}\text{F}/\text{sec}$ for 5 sec from 1000 to 850°F was established by gradually increasing the cooling rate; once the proper cooling rate was established, thermal shock testing was allowed to proceed automatically.

After 17 thermal shocks, a sodium leak was discovered between the bonnet and the valve body, as shown in Figure 14. This connection had not been welded by the manufacturer and because of the tight fit leakage was not evident until the 17th cycle. The leak was eliminated by draining the sodium, cleaning the joint, and then welding as specified by the manufacturer's drawing.

Thermal shock testing then proceeded uneventfully for 400 shocks. At the end of 100, 200, and 300 shocks, the torque required to operate the handwheel of the flow controller was measured, and no change was observed, indicating

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Figure 13. Thermal Shock Rate

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Figure 14. Sodium Leak at Bonnet to Valve Body Connection

that the torque-tube was undamaged. After 400 shocks, however, when the torque test was performed, an increasing amount of force was observed on the handwheel in the last few degrees to complete closure. Handwheel rotation in the valve-opening direction failed to open the port (no indication of sodium flow was obtained) and finally snapped the pin connection (see Figure 5) between the drive shaft and the gate; the maximum torque on the handwheel observed was 150 in.-lb.

After draining the sodium, the flow controller was removed from the loop and steam cleaned to remove traces of sodium and sodium oxide. Measurements indicated zero clearance between the leading gate edge and the valve body. An impact against the gate web was required to free the valve gate from its tightly bound closed position.

The valve was disassembled and measurements were made of bore and gate diameters. Greatest distortion was observed in the bore of the valve body; the bore diameter had been reduced by 0.010 in. in the area coinciding with the leading edge of the gate after closure of the ports. The leading edge of the gate had increased 0.002 in. in diameter. The resultant clearance was thus reduced to zero. Warpage had caused the bore to become approximately elliptical in shape, with bore diameter reduction occurring in the exit port cutout area. Warpage was caused by either: (1) relief of strains induced by welding, or (2) thermal shock testing. Valve repair and continued testing were required before it could be ascertained which of these two factors was the principal cause of warpage.

The valve body warpage was corrected by machining to provide a 0.017-in. gate-to-bore clearance. The flow controller was reassembled, placed in the test loop, and heated for 24 hr with 750°F sodium; this temperature is high enough to relieve any residual strain, but it is not high enough to decrease the yield point of the material sufficiently for distortion to occur. This procedure assured that any warpage observed later would not be due to relief of residual strains initially present, but could be attributed only to thermal shock effects. Phase I testing was then completed to the required 500 thermal shocks by performing 100 additional shocks. Torque tests, made after 25 and 100 shocks, gave no indication of either valve binding or torque-tube rupture.

D. PHASE II THERMAL SHOCK TESTING

The modified flow controller was routinely subjected to the required 500 thermal shocks at 35°F/sec for 5 sec from 1200 to 1025°F inlet-sodium temperatures. No difficulty was experienced in this phase of thermal shock testing even though it involved a more severe cooling rate and higher shock temperature than Phase I. Torque tests performed after 25, 50, 100, 200, 300, 400, and 500 shocks showed no indication of either valve binding or torque-tube rupture.

E. MEASUREMENTS AND OBSERVATIONS

After completion of the thermal shock tests, the sodium was drained and the flow controller was removed from the test loop, cleaned, and disassembled. Detailed measurements made of valve bore and gate diameters, compared to similar measurements made after re-machining to remove distorted bore material, yielded the following information:

- 1) Despite the more severe thermal shock conditions imposed by 500 thermal shocks at 1200°F, the average decrease in bore diameter of 0.004 in. was small compared to the decrease of 0.010 in. which occurred after 400 thermal shocks at 1000°F. This indicated that relief of strains induced by welding, and not thermal shock testing, was the major cause of the bore wall distortion which caused valve binding.
- 2) The valve gate, which had been relatively unaffected by 1000°F thermal shock testing, decreased in all measured diameters. The decrease was not uniform, varying from 0.002 to 0.017 in., apparently resulting from the more severe thermal shock effects caused by testing at 1200°F.
- 3) The possibility of valve binding vanished as the bore-to-gate clearance (0.017 in. after re-machining) increased to an average value of 0.026 in. in the valve operating region.

The flow controller was inspected before removal of the bonnet and gate assembly from the valve body. The valve, at the closed indicator position, was observed to be partially open with about 3/8 in. of the contoured exit port opening

visible behind the gate. No effort was made to complete the valve closure. Approximately 12 hr later the valve had completely closed. Apparently, frozen sodium trapped in the drive shaft-to-torque-tube annulus hydrolyzed in the humid atmosphere and released the valve bind. Immediately after observing the partial open valve condition, the possibility was considered that the 150-in.-lb torque, applied to the handwheel at the time of valve binding and shearing of the gate-to-drive shaft connecting pin, might have caused yielding in the drive shaft. This possibility was ruled out by a calculation which showed a resulting stress of only 1800 psi which was low compared to the yield point of the Type 304 stainless-steel shaft material.

A study of measurements of torque required to operate the handwheel, made at test startup and after each 100 thermal shocks, yielded the following information:

- 1) The neutral point in the torque-tube was found to be at the 60% position. A torque-tube, cycled mechanically and operating in the plastic range at the extremities of the stroke, would be expected to seek a neutral location near the mid or 50% dial indicator position because of material yielding. This could indicate that the torque-tube neutral position was originally near 60°, and that the applied stresses were entirely in the elastic range. Calculated stresses were also found to be under the material yield point. This probably accounts for the trouble-free operation of the torque-tube.
- 2) The torque applied by the torque-tube on the handwheel was about 8-in.-lb/10% change in the indicator position; the frictional torque component was about 29 in.-lb.
- 3) Torque readings repeated consistently when taken after each 100 thermal shocks, but were about 50% higher under startup conditions, i. e., at start of 1000°F testing and after re-machining of the valve-bore. The observed torque increase may have been caused by frozen sodium, or by sodium oxide deposited by cold trap action under idling conditions in the torque-tube-to-shaft annulus. The frozen sodium would be melted or oxide dissolved by sodium surges caused by thermal shock cycling. Provided this speculated condition did exist, the bonnet section surrounding the torque-tube should be insulated.

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