UNITED STATES ATOMIC ENERGY COMMISSION

MARK A CONTROL ACTUATOR SHAFT
FREEZE-SEAL

By
P. W. Bissonnette
R. D. Vallee

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ABSTRACT

Investigations were conducted to determine the mechanical properties of sodium sheared in a narrow annulus at controlled temperature gradients and shear velocities. The test fixture consisted of a 1-inch diameter stainless-steel shaft centered in a 1.099 inch ID Type-304 stainless-steel tube. Sodium shear values were found to be dependent upon the temperature and shear velocity at a given test condition.

Sodium shear values obtained were found to be consistent, wherever wetting of components had been assured by contact with hot sodium at temperatures above 500°F for periods of one-half hour or greater. Tests conducted showed sodium shear to have occurred internally, rather than at freeze-seal interfaces within the range of shaft velocities tested.

The apparent shear strength of sodium was found to fall off rapidly with successive shearing cycles to steady-state values corresponding to particular shearing velocities. Tests showed that with the freeze-seal at rest, a healing action occurred as a function of time, resulting in substantially complete regaining of initial shear strength.

INTRODUCTION

Reactor control drives require the use of shafts operating in sodium. The Control Shaft Freeze-Seal Test was originated to investigate the feasibility of using frozen sodium as a shaft seal against sodium and helium leakage in a narrow annulus.

Extremely high freeze-seal torques were experienced during the early stages of the investigation, which greatly exceeded expected values and made necessary additional investigation of sodium shear characteristics.

The ability of the reactor to scram is a function of the torque capabilities of the control drive mechanism, Drawing 114D680. Reactor "scram" operations could be prevented or seriously retarded if sodium reaches heights of approximately 10 to 13 inches above the labyrinth-type vapor seal (Drawing M-6A7136), due to surging in the system and accompanied by freezing in the annulus of the control actuator plug, Drawing T-7A7032.

CONCLUSIONS

The following characteristics of sodium have been concluded as a result of the investigations conducted:

1. The shear strength of sodium is temperature dependent, decreasing with increasing temperature. It also appears to be velocity dependent, increasing with increasing shearing velocity.
2. The shear strengths of sodium in a 50 mil annulus at the conditions observed are as follows:

Temperature Gradient	Per cent of Sodium Plug Below Indicated Temperatures	Shearing Velocity of 1-in. Diameter Shaft	Shear Strength (Average) Psi
"A"	55.7% Below 150°F	45°/sec.	75
"B"	81.4% " 150°F	"	83
"C"	94.0% " 150°F	"	95

3. Where wetting occurs, sodium in a narrow annulus will shear within itself, rather than at the sodium-to-steel interface.
4. The apparent shear strength of sodium in a freeze-seal annulus decreases under repetitive cycling of the shaft in alternate directions of rotation.
5. The apparent shear strength of sodium after cycling increases to substantially its original value when allowed to stand idle for a suitable period of time.

INVESTIGATION

Test Fixture

The test fixture consisted of a 1.000-inch-diameter Type-316 stainless-steel shaft centered in a 1.009-inch $\pm$.002-inch ID Type-304 stainless-steel seamless tube. This test fixture is shown by Sketch, Fig.1, page 16 and Photograph KS-1098, page 17. The shaft was ground to a finish of 63 micro-inch. Inner surface of the seamless-tube component was not machined, but, the finish compared closely with a finish of 125 micro-inch. Two ball bearings, seated in flanges, were used to center the shaft in the annulus. The upper bearing was No. ND-77R16, manufactured by New Departure; the lower bearing, which was immersed in sodium, was No. MRC 306R manufactured by Marlin-Rockwell Corporation. The lower bearing is made of tool steel, stabilized for operation up to 1000°F. This bearing, seated in the flange, is shown in Photograph KS-1099, page 18.

A flexible metal hose interconnected the sodium annulus and the variable-height sodium pot. Also, a helium line was installed between the top of the sodium annulus and the top of the variable-height sodium pot. Varying the height of the sodium pot caused the sodium to flow into and out of the annulus, enabling the formation of sodium plugs of various lengths.

Heat to the test fixture was furnished by nichrome heater wire that was wrapped over the entire outer surface of the seamless tube and lower bearing flange. Cooling of the annulus was accomplished by circulating Socony Vacuum heat-transfer oil, heavy grade, through a 1/4-inch copper tube coiled around the test fixture. The coil was located approximately six inches above the lower guide bearing.

The drive train consisted of a 2-hp a-c motor, a Graham transmission, worm gears, and a strain gauge shaft, all interconnected in series with the 1-inch Type-316 stainless-steel shaft. Shearing velocities of from 0 to 45°/sec. were obtainable.

533 008

Instrumentation

The instrumentation is shown in Photograph KS-1100, page 19.

Torque determinations were obtained from a resistance-bridge strain-gage network, consisting of four SR-4 strain units mounted on a 1-inch-diameter mild steel shaft, transmitting power to the test shaft. The strain gage was arranged so that a torque in either direction would cause an unbalance of the bridge circuit. A Brush Universal Analyzer, Model BL-320, and a Brush Oscillograph, Model BL-202, were used to indicate the torque applied to the 1-inch-diameter stainless-steel test shaft submerged in the annulus containing sodium.

Temperature determinations were obtained by making use of conventional I.C. thermocouples. The thermocouple tips were spaced two to three inches apart and were capacitance-welded axially along the outer surface of the stainless-steel freeze-seal tube. Thermocouple emfs were recorded on a Brown Strip Chart Recorder.

Relative Position of the strain shaft was obtained by means of a continuous rotation Model FH "Helipot" potentiometer, geared one-to-one to the strain shaft. The d-c voltage from the potentiometer brush arm was connected to a Brush d-c amplifier, Model BL-932, and a Brush Oscillograph, Model BL-202 for position recording.

Shearing Velocity of the 1-inch stainless-steel shaft was determined through the synchronized time axis of the recorder chart and the recording of potentiometer voltage output described above under Relative Position.

Test

Each component of the test fixture was degreased using trichlorethylene as a cleaning agent. Prior to filling with sodium, the fixture was mass-spectrometer leak-checked. The temperature of the test fixture was then

raised to 300°F and held at this condition for a period of approximately three hours. Purging of the test fixture with helium also took place during the drying out period.

Initially, the test fixture was filled with approximately 10 lb of sodium. During this operation, the temperature of the sodium and the test fixture was held at 300°F. As the variable-height sodium pot was raised, sodium flowed into the annulus formed by the 1-inch stainless-steel shaft and the stainless-steel tube to provide the test freeze-seal. When the sodium in the annulus reached a predetermined height, the valve in the interconnecting line between the variable-height pot and the annulus was closed. Prior to test shearing of the sodium freeze-seal, the temperature gradient along the sodium annulus was established and all necessary instrumentation was readied for operation.

Solid sodium freeze-seal lengths were determined in two steps. The position of the lower end was determined from temperature readings by means of thermocouples located along the annulus and the lower end of the freeze-seal was assumed to be at the point where the temperature was at the sodium melting point of 208°F. Location of the upper end of the freeze-seal was determined by probe measurements. The freeze-seal lengths investigated varied between five and twenty-five inches in length.

Testing was conducted at three different sets of temperature conditions shown by Graphs "A", "B", and "C" of Fig. 5, page 20. The testing of each test freeze-seal was accomplished in accordance with Table II, page 15. A test cycle is defined as a 180° rotational motion of the 1-inch stainless-steel shaft. The cycles ran alternately clockwise and counterclockwise. Cycling data at each of the temperature gradients was obtained at three different shaft rotational velocities, namely, 40 cycles each at 7.8, 24,

and 45 degrees per second. Wetting between sodium and the stainless-steel components of the test freeze-seals was insured by holding the sodium temperature at 500°F for periods of one-half hour.

After completing the 120 cycling operations, melting of the solid sodium in the annulus was accomplished by raising the test-fixture annulus temperature to 300°F and maintaining that temperature for a minimum period of one hour. A predetermined temperature gradient was again established and shearing cycles as noted above, on a new sodium freeze-seal, were repeated a sufficient number of times to obtain average results. The results are provided in Table I, page 14.

Shaft-Wetting by Sodium - During preliminary testing of the freeze-seal assembly, shaft torques were found to be extremely variable and to have lower values than expected. Investigation disclosed this to have been caused by non-wetting of the Type-317 stainless-steel shaft. It was found that heating of the shaft to a temperature of 500°F for one-half hour produced realistic values to be expected in actual operations.

Sodium has an affinity for oxygen, which increases with temperature. For a given degree of shaft cleanliness, the time required for sodium-wetting is a function of the temperature--the higher the temperature, the less the time required.

An experiment was performed which clearly demonstrated the effect of wetting on a stainless-steel shaft. Two 3/8-inch OD stainless-steel rods cut from the same bar stock were cleaned with trichlorethylene and immediately thereafter were driven approximately 6-inches into solid sodium at a room temperature of approximately 80°F. Photograph KS-1102, page 21, shows the rods prior to insertion in the sodium.

One of the specimens, designated as "A", was at room temperature at the time it was driven into the sodium. Specimen "A" was removed from the sodium

by hand with exertion of little effort approximately one minute after insertion. No sodium had clung to the specimen, as shown by Photograph KS-1103, page 22. The second specimen, designated as "B", was heated to a red heat by means of a Prestolite torch and immediately driven into the sodium. The removal of specimen "B" was begun immediately after insertion and necessitated the use of an 8-inch pipe wrench with considerable twisting accompanied by pulling for accomplishment. After removal, it was observed that a layer of sodium approximately 1/8-inch thick had clung to the specimen, as shown in Photographs KS-1101 and KS-1104, pages 23-24. Shearing of the sodium had taken place during the removal of specimen "B", rather than a simple sliding of the specimen as was the case with specimen "A".

"Healing" of Sodium - The term "healing" implies rearrangement of the sodium molecules into a homogeneous condition following earlier shearing of the freeze-seal.

It was observed during testing that freeze-seals regained a considerable amount of resistance to shearing after standing idle. One freeze-seal, after having been sheared and cycled 120 times under conditions of temperature gradient "A", was permitted to stand idle at the above conditions for 11-1/2 days (The total percent of torque decrease at completion of the 120th cycle obtained for this sodium plug was 40%). A torque measurement taken after the 11-1/2 day waiting period indicated that the torque had risen to 98.5% of the original amount necessary for shear at the initial shear velocity.

In a second case, a freeze-seal 7.3 inches in length was held at a temperature of 208°F at its base and 75°F at its upper end. Shearing of the sodium plug at a shaft velocity of 22°/sec was accomplished at intervals

of time as noted on Graph, Fig. 11, page 26. A study of the curve indicates that the amount of healing occurring is a function of the time the sheared freeze-seal is allowed to stand idle.

In view of the healing characteristics of solid sodium, test results indicate that if a comparable freeze-seal is operated under the same temperature gradient at which this test was made, 100% of the torque required for initial shear must be available for successive shears if a time lapse of approximately 40 hours has occurred.

TABLE I
TEST RESULTS

Temperature Gradient See Curve	% of Freeze- Seal Below Indicated Temperatures	Shearing Velocity deg/sec (1" dia. Shaft)	Shear Strength* psi	Average Shear Strength psi
"A"	55.7% Below 150°F	45	80.1 75.7 74.0 74.3 82.3 71.1 67.9	75
"B"	81.4% Below 150°F	45	80.9 77.6 88.6 85.3 79.0 81.8 83.7 88.0 83.4 81.9	83
"C"	94% Below 150°F	45	94.8 103.6 95.1 94.4 93.9 89.7 86.9 100.0 96.6	95

*All shear values have been calculated on the basis that shear took place within the sodium.

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TABLE II
TORQUE DECREASE

40 Cycle Groups	Temperature Gradient	Velocity deg/sec	Average % of Torque Decrease Due to Cycling	% of Total Torque Decrease 1st 40 Cycles
1st	"C"	45	21.1	30-48
2nd		24	—	
3rd		7.8	—	
1st	"B"	45	9.1	27-48
2nd		24	—	
3rd		7.8	—	
1st	"A"	7.8	1.8	27-40
2nd		24	3.5	
3rd		45	7.7	

Figure 1

1" DIAMETER CONTROL SHAFT FREEZE SEAL TEST

539-016

R.D. VALLEE

Type 304 S.S. Tube

Thermocouples

JB-599

ANNULUS ASSEMBLY KS-1098

16
17

Lower Bearing

Lower Flange

JB-600

KS-1099

LOWER BEARING SEATED IN FLANGE

539-17

Strain Shaft

Brush Instruments

INSTRUMENTATION AND CONTROL PANEL

JB-1269

KS-1100

539-18
019

DECLASSIFIED

Temperature of

539-635

JB-1294

TYPE 304 S.S. RODS PRIOR
TO INSERTION IN SODIUM

KS-1102

20
021

JB-1296

KS-1103

TYPE 304 S.S. ROD, SPECIMEN "A"
AFTER REMOVAL FROM SODIUM

CLASSIFIED

022

JB-1295

TYPE 304 S.S. ROD, SPECIMEN "B" AFTER REMOVAL FROM SODIUM KS-1101

22

TYPE 304 S.S. RODS AFTER REMOVAL
FROM SODIUM SPECIMEN "A" (LEFT)
SPECIMEN "B" (RIGHT)
(ENLARGED)

KS-1104

JB-1297

Figure 10

R.L. Waller 537-005

Figure 11

R. D. Waller

539 625
539-24