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III. PROXIMITY SENSOR TESTING

R. M. Jassak

A. INTRODUCTION

During operation of the prototype FFTF sodium pump, it is necessary to know the position of the pump shaft relative to the sodium-lubricated hydrostatic bearing journals. In the course of earlier program phases, a proximity measurement system was manufactured by Mechanical Technology Inc. (MTI) and procured for this application. However, because of the critical importance assigned to this measurement, Westinghouse (EMD) procured another proximity measurement system from Kaman Sciences Corp. for redundancy.

Performance of the Kaman proximity measurement system was known to be affected by the type of media between the gap to be measured. Since Kaman Sciences Corp. did not have liquid sodium testing capabilities, LMEC was requested to evaluate a spare prototype system. Determination of the sodium performance characteristics of the Kaman proximity systems was a necessary requisite for use of four prototype systems in the FFTF prototype pump test program.

B. DESCRIPTION OF TEST ARTICLE

The Kaman prototype proximity measurement system evaluated during this test program was a modified version of their standard commercial system designed to operate in high-temperature nonconducting medias. Various design adjustments were obviously required for use of this system in electrically conductive liquid sodium.

The Kaman system is composed of a Model KD-1901SPL high-temperature noncontacting displacement transducer, a related Model KD-2018 electronic signal conditioner, and a matched interconnecting cable. As delivered, each system is considered matched by virtue of the serial numbers of the individual components.

The KD-1901SPL transducer is an eddy-current device consisting of a variable impedance bridge having dual coils inside a metallic corrosion resistant case. Magnetic fields that penetrate the front of the sensor induce eddy currents in

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adjacent conductive targets resulting in impedance changes to the active coil. Any change in impedance of the active coil is detected by the signal conditioner and converted to a linear output response. In a given installation, sensitivity is primarily dependent on displacement.

The KD-2018 electronic signal conditioner includes the remaining bridge components, linearizing circuitry, and power supply.

As delivered, the Kaman prototype measurement system had received a "best effort" calibration by Kaman Sciences Corp. using a Type 304 stainless steel target (simulating the pump shaft) fronted by brass to simulate sodium in the displacement gap. Since these calibrations were understood to be only an approximation of what system performance would be in liquid sodium, they were not depended upon.

C. DESCRIPTION OF TEST SETUP

Testing of the Kaman Sciences Corp. proximity measurement system described in this report was conducted at the LMEC laboratory, test, and services building (Building 057) in Rig 2 (057-R2). Rig 2 is a static sodium test facility with auxiliary systems for controlled temperature, sodium purification, and maintenance of an inert cover gas in the vessel's ullage volume. A water-cooled lid seals the test vessel and permits mounting of instrumentation and mechanical linkages to a near ambient temperature structure regardless of the temperature of the bulk sodium within. Figure 2-158 shows the general configuration of Rig 2, and Figure 2-159 is a schematic diagram of Rig 2.

The test fixture (Ref. LMEC Drawing 7693-PA-171051) previously used to evaluate the MTI proximity transducer at LMEC was used in slightly modified form during the Kaman proximity test program. Only the transducer mounting bracket and target had to be altered (Ref. LMEC Drawing 7693-PA-171059) for this application. This test fixture is composed of four structural rods and a base plate suspended from the test vessel cover lid. Integral to this assembly is a fixed mounting bracket to attach the proximity transducer and a movable micrometer-driven rod with a Type 304 stainless steel target attached. The general configuration of the cover lid and test fixture assembly is illustrated in Figure 2-160. Figure 2-161 shows a more detailed view of the transducer installation and movable stainless steel target. With this arrangement, the transducer

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Figure 2-158. Rig 2 Test Facility in Building 057

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Figure 2-159. Schematic Diagram of Sodium Test Facility (R2-057)

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Figure 2-160. Cover Lid and Test Fixture Assembly

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Figure 2-161. Proximity Sensor and Target Details

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remains stationary within the bulk liquid sodium and the pump shaft simulating target can be precisely translated to and from the face of the transducer by use of the hand micrometer drive. The actual position of the target relative to the transducer face can be determined directly from the micrometer, but is more easily read from a precision dial indicator mounted on the top of the cover lid.

D. GENERAL TEST DATA

The test facility was formally activated on May 29, 1975. In the interest of obtaining baseline out-of-sodium data, a calibration was conducted with argon cover gas in the vessel. Subsequently (on the same date), the test vessel was filled with sodium. While sodium was never removed from the test vessel through the end of calendar year 1975, the system was allowed to freeze (return to ambient temperature) on October 3, 1975, to allow for previously scheduled facility modifications. On November 20, 1975, bulk sodium in the test vessel was elevated in temperature (remelted) to allow further testing.

By the end of calendar year 1975, the Kaman Model KD-1901SPL transducer had experienced considerable in-sodium exposure and the results are summarized in Table 2-9.

Table 2-9 . Summary of Transducer Sodium Exposure

Sodium Temperature °F (°C)	Time	
	Hours	Days
300 to 950°F (149 to 566°C)	1,776	74
1050°F (566°C)	2,304	96
Ambient temperature (frozen)	1,032	43
Total time in liquid sodium	4,080	170

The Kaman Model KD-2018 electronic signal conditioner was operated throughout the same test period, which was ~215 days. During this test interval, 75 calibrations were performed on the Kaman proximity measurement system in various physical configurations (described later) and at various sodium temperatures.

E. DETAILED TEST RESULTS

While it was originally intended that a single predesignated test sequence be performed, various configuration and performance problems caused testing to be conducted in separate phases. For clarity of presentation, each phase will be discussed independently.

1. Initial Tests - Non-prototype Configuration

When the five matched prototype Kaman proximity measurement systems were delivered to LMEC, some confusion existed regarding which four systems were designated for the FFTF prototype pump. Because of urgent pump assembly schedules, four KD-1901SPL transducers were immediately installed in the pump. The remaining unit (SN 7817) was designated for in-sodium calibration.

During precalibration checkouts, it was learned that the wrong proximity system had been designated for in-sodium calibration. Only two of the five signal conditioners were master units (with oscillators), while the remaining three were slave units. Transducer SN 7817, which had been assigned for in-sodium calibration, had a slave signal conditioner. Because of the urgent need for in-sodium performance verification, initial testing was conducted using the master signal conditioner (SN 7816) to drive the SN 7817 slave unit. Subsequently, personnel from Kaman Sciences Corp. visited LMEC and were able to convert the SN 7817 signal conditioner into a master. However, since initial data used the slave/master signal conditioner combination, a complete cycle of testing was conducted using this combination with the understanding that data would be generally representative.

An additional configuration problem uncovered early in the test program was that the interconnecting cables delivered with the proximity measurement systems were only 50 ft (15 m) long, whereas ~200 ft (61 m) would be required in the FFTF prototype pump test application. Because the cable is an integral part of the external bridge network in the Kaman system, a change in length would affect performance characteristics. However, since initial testing could not be delayed, the originally supplied 50-ft (12 m) cable was used, and the required 200-ft (21 m) cables were ordered from Kaman with the understanding that the tests would be repeated to determine the effect of the longer cable.

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To reiterate, the first proof-of-principle tests were conducted using a non-standard slave/master signal conditioner combination and a short 50-ft (15 m) interconnecting cable.

Prior to filling the test vessel with sodium, a calibration was made at 400°F (204°C) in the argon cover gas to establish an out-of-sodium baseline. The measurement system performed in accordance with the manufacturer's predictions. Sensitivity was somewhat low and the electrical output decreased with an increase in displacement.

The test vessel was then filled with sodium and a calibration was made at 400°F (204°C) to compare data with the out-of-sodium baseline and to acquire the first temperature increment in the planned sodium calibrations. Figure 2-162 shows in-sodium and out-of-sodium calibration data, as well as the supplier's original 400°F (204°C) brass calibration. It will be noted in the sodium test data that overall sensitivity increased and electrical output increased with an increase in displacement. This is also in general agreement with the manufacturer's predictions.

Subsequent calibrations were made at ascending temperatures of 600, 860, and 1050°F (316, 460, and 566°C) in accordance with LMEC Test Procedure TP-30-CE-003. These data are presented in Figure 2-163. A review of these data indicate rather severe temperature effects on both system zero and overall sensitivity.

In the course of making these ascending temperature calibrations, test personnel observed short-term instability in the proximity system output signal while dwelling at specific temperatures. Measures were taken to document this instability and its source in parallel with conducting temperature calibrations. By connecting the bulk sodium temperature and the proximity system output signal on a two-pen strip chart recorder, a direct correlation was made. Figure 2-164 shows the in-phase cyclic variation of sodium temperature and Kaman output signal. Techniques for controlling the bulk sodium temperature were refined so that variations were reduced to $\sim 1^\circ\text{F}$ (0.56°C)/hr. All descending temperature calibrations made after 1050°F (566°C) were performed with a more uniform sodium temperature, and are presented separately in Figure 2-165. The calibrations presented in Figure 2-165 are believed to be more representative because of the more uniform sodium temperature.

Figure 2-162. Calibrations of Kaman Proximity System SN 7817 at 400°F (204°C) with Argon, Sodium, and Brass

Figure 2-163. In-Sodium Test Data at Ascending Temperatures —
Kaman Proximity System SN 7817

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Figure 2-164. Drawing of Strip Chart Tracing Showing Cyclic Variation of Sodium Temperature and Kaman Output Signal

Figure 2-165. In-Sodium Test Data at Descending Temperatures - Kaman Proximity System SN 7817

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LMEC received the new 200-ft (61 m) interconnecting cables while still in the process of conducting the initial temperature calibrations. Upon completion of the first calibration cycle, back-to-back calibrations were conducted at 300°F (149°C) using the 50-ft (15 m) and 200-ft (61 m) cables, respectively. These data are presented in Figure 2-166. It will be noted that the 200-ft (61 m) cable caused a more negative output signal at zero displacement and the overall sensitivity of the system increased. Since the interconnecting cables between the sensor and signal conditioner form a part of the bridge network, changes in operating characteristics would be expected by the manufacturer.

2. Calibration of Prototype Configuration

Having conducted a complete cycle of ascending and descending temperature calibrations with the 50-ft (15 m) cable and sync-master/sync-slave signal conditioner combination, subsequent calibrations were made with the SN 7817 sync-slave converted into a sync-master. A complete set of ascending temperature calibrations were conducted over the range of 300 to 1050°F (149 to 566°C) using the converted sync-master signal conditioner. While only the 200-ft (61 m) cable configuration is of direct interest, parallel data were also taken at each temperature with the 50-ft (15 m) cable. Figure 2-167 presents the data acquired with the 200-ft (61 m) cable. Although the data presented in Figure 2-167 are not grossly different from initial calibrations, they represent the first calibration information for the Kaman proximity measurement system in the true prototype configuration.

Upon completion of the ascending temperature calibration cycle, the test facility was allowed to dwell at 1050°F (566°C) in preparation for a long-term stability evaluation. While in this high-temperature dwell period, a long-term drift characteristic was observed. By carefully controlling the bulk sodium and KD-2018 signal conditioner temperatures, it was noted that ambient temperature variations influence system output by affecting the interconnecting cable electrical characteristics. Figure 2-168 presents the proximity system output signal plotted against varying ambient temperatures. These data were acquired under the following conditions:

- 1) Ambient temperature increased over an interval of ~ 9 hr.
- 2) The target was fixed at a displacement of 0.032 in. (0.81 mm).

Figure 2-166. Calibrations of Kaman Proximity System with 50-ft (15 m) and 200-ft (61 m) Cables at 300°F (149°C)

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Figure 2-167. Temperature Calibrations in Ascending Increments of Kaman Proximity System with 200-ft (61 m) Cable

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Figure 2-168. Output Signal Variation with Ambient Temperature

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3) Bulk sodium temperature was maintained between 1049 and 1050°F (565 and 566°C).

4) The KD-2018 electronic signal conditioner environment was maintained between 88 and 91°F (31 and 33°C).

With all major test objectives fulfilled, it was decided to conduct a long-term, in-sodium, high-temperature stability test on the Kaman Model KD-1901SPL transducer. The test facility was maintained at 1050°F (566°C) from July 7, 1975 through October 3, 1975. On October 3, 1975 the stability test was interrupted to perform previously scheduled facility modifications. It is noteworthy that sodium in the test vessel was not drained but merely cooled to room ambient temperature and allowed to freeze.

Throughout this test interval, system calibrations were conducted either two or three times each week. Of several parameters which might be monitored to indicate stability performance, average sensitivity was selected as most representative. System electrical output at zero displacement was rejected because of a degree of uncertainty regarding mechanically setting zero displacement. The electrical output at a maximum displacement of 0.032 in. (0.81 mm) would also be affected by errors in the zero setting along with other thermally induced errors. Figure 2-169 presents the average sensitivity derived for each calibration run. It will be noted that average sensitivity is based on the net electrical change between 0.008 and 0.028 in. (0.203 and 0.711 mm) displacement divided by the net difference in displacement. This increment was selected because it is somewhat representative of the operating range for the prototype FFTF pump application. Also, an initial offset of 0.008 in. (0.203 mm) tends to minimize the effects of inconsistent zero settings. Figure 2-169 data have not been corrected for effects induced by changes in bulk sodium temperature or changes in ambient temperature.

Reference to Figure 2-169 will indicate a trend of increasing system sensitivity with time throughout the stability test program. It will also be noted in Figure 2-169 that data acquired for the 75th through the 88th day have a noticeably increased slope.

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Figure 2-169. High-Temperature Stability Test - Average Sensitivity vs Time

Upon completion of facility modifications, testing of the Kaman proximity measurement system resumed in 057-R2 on November 20, 1975. Sodium in the test vessel was remelted and gradually brought to an equilibrium temperature of 300°F (149°C). Subsequently, calibrations were conducted at 300, 400, 500, 600, 730, 860, 950, and 1050°F (149, 204, 260, 316, 460, 510, and 566°C).

After completion of one set of ascending temperature calibrations over the range of 300 to 1050°F (149 to 566°C), average sensitivity data was compared with similar data acquired in June and July 1975. Table 2-10 summarizes average sensitivity data, at the same bulk sodium temperatures, for both test periods. While no gross shifts are noted, there appears to be a modest 1 to 4% increase in sensitivity for the most recent calibration data. An exception would be those data for 500°F (260°C), whereas recent data shows a decrease in sensitivity relative to June and July data. It appears that one of the two sets of data are faulty, with the June and July data being most suspect, based on a comparison of the change in average sensitivity between the next higher and lower temperature calibrations run during that period.

Table 2-10. Summary - Average Sensitivity

Sodium Temperature °F (°C)	Average Sensitivity* vdc/0.001 in. (vdc/10 ⁻² mm)	
	June/July Data	Nov./Dec. Data
300 (149)	0.077 (0.03032)	0.078 (0.03071)
400 (204)	0.066 (0.02598)	0.068 (0.02677)
500 (260)	0.062 (0.02441)	0.058 (0.02284)
600 (316)	0.049 (0.01929)	0.050 (0.01969)
730 (388)	0.041 (0.01614)	0.041 (0.01614)
860 (460)	0.033 (0.01299)	0.034 (0.01339)
950 (510)	0.029 (0.01142)	0.030 (0.01181)
1050 (566)	0.0254 (0.01000)	0.0262 (0.01032)

*The difference in electrical output over the range of 0.008 to 0.028 in. (0.203 to 0.711 mm) displacement, divided by that displacement, 0.020 in. (0.508 mm).

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F. CONCLUSIONS

While the foregoing test program demonstrated the Kaman eddy current type proximity measurement system was functional in liquid sodium, undesirable performance characteristics were observed which make it somewhat less than ideal in its present prototype configuration. These observations are summarized as follows:

- 1) Because of its basic design concept, the subject proximity system is essentially nonfunctional unless operated in the presence of liquid sodium. This feature precludes pretest system (dry) checkout and calibration, with varying consequences, dependent on the specific application.
- 2) By conducting temperature calibrations, it was determined that the Kaman systems output signal was greatly affected by transient or steady-state changes in sodium temperature. This temperature sensitivity requires readjustment or recalibration at different operating temperatures to ensure system accuracy.
- 3) Because the interconnecting cables form a part of the external bridge network, changes in their electrical characteristics due to ambient temperature variations caused a moderate change in system output. Long cable runs are common in typical applications. Furthermore, the ambient temperature within typical facilities is not closely regulated with a resultant additional source of measurement error.
- 4) Long-term stability testing indicated an apparent time-dependent increase in system sensitivity.

However, in spite of these undesirable characteristics, the prototype Kaman proximity system appears to be the best system available at this time, based upon operating experience with the FFTF prototype pump. Because of operational problems encountered with the MTI proximity system, the Kaman system has been used for all pump shaft position measurements during testing of the FFTF prototype pump conducted at the LMEC Sodium Pump Test Facility (SPTF). This judgement is based on current operational capabilities and not the ultimate potential of either system.

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