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ABSTRACT

Flexible joint assemblies in the primary sodium piping to the large scale LMFBF pressure vessel are designed to accommodate thermal expansion of the piping system.

To monitor the performance of the flexible joint assemblies during reactor operation, sodium leakage and flexible joint motion detection/sensors are specified.

This report describes the mechanical/hydraulic portions only of the leak detection and motion monitoring system. A tentative choice of displacement transducer and its readout equipment are presented. However, the required EI&C portion of the monitoring system are not covered herein.

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1.0 INTRODUCTION

In each of the 3 main coolant loops of a large scale LMFBF are 3 flexible joint assemblies to accommodate thermal expansion of the piping relative to reactor vessel (see Figure 1). The flexible joint is located on the suction side of the sodium pump and is exposed to the high temperature sodium ($\sim 1082^{\circ}\text{F}$).

To monitor the performance of these flexible joints under conditions of reactor pressure, temperature, and piping movement, separate motion detection and measuring system (for movement history) and leak detection system (to determine occurrence of leaks in the bellows) are specified for each flexible joint.

This report briefly describes the flexible joint, the motion and leak detection systems, and the operations of the deflection systems.

2.0 OBJECTIVES

A. LEAK DETECTION SYSTEM

Develop a leak detection system to detect and display occurrence of leaks in the bellows as the flexible joint is flexed (cyclic motion) under operating pressure and high temperature.

B. MOTION DETECTION SYSTEM

Develop a motion detection system to determine and record/display the angular movement of each yoke relative to the gimbal ring as the flexible joint is flexed (cyclic motion) under pressure and high temperature.

FIGURE 1. FLEXIBLE JOINT LOCATIONS IN A
LARGE SCALE LMFBR SODIUM
COOLANT SYSTEM

FIGURE 2 FLEXIBLE JOINT ASSEMBLY

3.0 REQUIREMENTS

A. LEAK DETECTION SYSTEM

- Detect leaks in either the inner or outer bellows, identifying which bellows leaks are not required.
- Flexible joint operating temperature is 1082⁰F maximum.
- Flexible joint internal pressure range is 15 psig maximum.
- Ambient air pressure and temperature are atmospheric and 120⁰F, respectively.
- Leak detection gas shall be argon.
- Readout (display) unit is to be located outside of the piping vault ~50 ft distance.
- Sensitivity 1/2 psi gas pressure drop.

B. MOTION DETECTION SYSTEM

- Detect angular movement of each flange relative to the center gimbal ring.
- Measure motion from 0⁰ to 9⁰ each side of neutral position in about 1/2⁰ increments.
- Sensor design temperature is 500⁰F.
- Sensor to provide signal for remote readout.
- Sensor to be located outside the flexible joint thermal insulation.
- Readout (display) unit to be located outside of the piping vault ~50 ft distance.
- One sensor to be provided at each axis of the gimbal ring; two (2) required.
- Sensor shall be nonmagnetic and operable in sodium.

4.0 DESCRIPTION

A. OVERALL DESCRIPTION

The flexible joint (see Figure 2) consists of the two end yokes, the gimbal ring and pivots, and the two bellows. Extensions on each end of the yoke are pinned to the center gimbal ring to prevent separation of the yokes under internal pressure. The normal angular movement of each yoke, relative to the gimbal ring, is about 3° , but is to be capable of 9° movement.

The two bellows are attached to the yoke end fittings. The inner bellow contains the pressure during normal operation. The secondary bellow provides a backup in the event of failure of the primary bellows. Liners (thermal sleeves) are provided in the interior of the primary bellows to protect the bellows and end fittings from thermal shocks caused by the sudden change in temperature of the flowing sodium.

B. LEAK DETECTION SYSTEM DESCRIPTION

The schematic diagram of the leak detection system is shown in Figure 3. Its function is to detect leaks in either the primary or secondary bellows by a drop in the surveillance gas pressure which actuates an alarm. The system cannot differentiate between a leak in either of the two bellows.

Argon is supplied at low pressure to the inner bellows. The system has the necessary pressure regulating valve, gages, relief valves, pressure alarm switch, flowmeter, solenoid valves, and flow restrictor.

FIGURE 3

SCHEMATIC DIAGRAM OF A
2 PSIG ARGON SUPPLY SYSTEM TO
BELLOWS ANNULUS (CONTINUOUS
PRESSURE MEASUREMENT)

The function of most of the equipment is self-explanatory, however, the function of the flow restrictor, flowmeter, and solenoid valve are:

The flowmeter is used to display the amount of gas passing through the system to indicate the size of the leak - whether a pinhole or a large crack has occurred.

The flow restrictor is used to prevent a large flow of argon gas entering the sodium coolant.

The solenoid valve is used to prevent backflow of sodium into the leak detection system in the event there is a primary bellows leak and the pressure control valve malfunctions or the line breaks.

C. MOTION DETECTION SYSTEM

The installation of the motion detection system is shown on Figure 4. The main components are; a target, transducer, and readout instrumentation. The target is fastened to the yoke assembly and the transducer is attached to the gimbal ring. Relative movements between the two are given in mils (thousands of an inch) on the readout instrument. The mils are converted to degrees. The relative positions and motion diagram of the target and the transducer are shown on Figure 5.

The transducer works on the eddy current principle. A change in gap changes the inductance with a corresponding change in the bridge circuit amperage which is displayed on the readout.

The transducer is located mid-range of its total movement relative to the target, thus, movement from or to the target will show a change on the readout scale.

A tentative choice of transducer and readout equipment is given in Attachment A.

FIGURE 4 MOTION DETECTION MEASURING SYSTEM
ONE REQUIRED AT EACH AXIS OF THE
GIMBAL RING (2 TOTAL)

FIGURE 5 TARGET AND TRANSDUCER MOTION
DIAGRAM

5.0 OPERATION

A. LEAK DETECTION SYSTEM

Figure 6 shows the pressures across the bellows for normal operation.

The leak detection system is charged with argon and stabilized at about 2 psig. After the sodium reaches the operating temperatures, Valve Number 1 is closed. The pressure will remain the same in the system between Valve Number 1 and the bellows, unless there is a leak in the bellows or a temperature-caused pressure change.

A leak in either the primary or secondary bellows will cause the pressure to drop to 0 psig or .5 psig on the gage, depending on the sodium pressure. As the pressure switch is set to activate at a pressure lower than 2 psig, a drop in pressure to .5 psig will set off the alarm.

A rise in sodium temperature, beyond the normal temperature, will raise the pressure which is of no importance and the alarm is not activated. However, if the pressure increases to 5 psig, the pressure relief valve will open. Lowering the sodium temperature will cause a decrease in pressure. The gage is carefully watched and the system repressured by opening Valve Number 1 if the decreasing pressure approaches the alarm set point.

B. MOTION DETECTOR SYSTEM

The flexible joint is positioned in the neutral position and the electronic bridge system adjusted so the readout is in mid-position of the scale, thus, movements of the joint, either side of neutral, will give corresponding displacements on the readout instrument.

FIGURE 6 PRESSURE ACROSS THE BELLOWS ASSEMBLY
* PRESSURE WAS TAKEN FROM DESIGN REQUIREMENT REPORT N112T1240003

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ATTACHMENT A

KD-1901

NI12T1210001

PAGE 1

HIGH TEMPERATURE DISPLACEMENT TRANSDUCER

GENERAL SPECIFICATIONS*

RANGE: 0 – 0.100 inches, Magnetic Target
0 – 0.200 inches, Non-magnetic Target

INPUT: AC – 110 Vac, 60 Hz

OUTPUT: 1Vdc Nominal

DYNAMIC RESOLUTION: 0.1% full scale

OPERATING TEMPERATURE RANGE: – 100°F to 1100°F continuous.
Short term operation to 1200°F.

NON-LINEARITY: Less than $\pm 1\%$ full scale at any particular temperature over
operating range

TEMPERATURE COEFFICIENT: Zero shift – $<0.01\%/^{\circ}\text{F}$
Sensitivity shift – $<0.01\%/^{\circ}\text{F}$

FREQUENCY RESPONSE: 0 – 2.5 kHz (–3dB)

CABLE: Stainless steel sheathed mineral insulated – 5 feet standard to
maximum of 40 feet

CASE MATERIAL: Corrosion resistant high temperature alloy, all welded
and hermetically sealed

TARGET MATERIAL: Conductors – Magnetic and Non-Magnetic

HUMIDITY EFFECT: None

OPERATING MEDIA: Borated water, superheated steam, high temperature gases
and all non-conducting media compatible with corrosion
resisting super alloys

OPERATING PRESSURE RANGE: To 3500 psi

*Specifications subject to change without notice.

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KD-1901 HIGH TEMPERATURE DISPLACEMENT TRANSDUCER

KD-1901-200m 304 SS S/N 2645 304 S. S. TARGET

KD-1901 HIGH TEMPERATURE DISPLACEMENT TRANSDUCER

KD-1901-5mm 316 SS S. N 2766 316 S. S. TARGET

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DISPLACEMENT TRANSDUCER, CABLING AND KD-2018
SIGNAL CONDITIONING ELECTRONICS WITH POWER SUPPLY**

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APPLICATION		KD-2018 ELECTRONICS	

KAMAN EDDY-CURRENT DISPLACEMENT TRANSDUCERS

The eddy-current-principle noncontact-type displacement transducer has many basic advantages. Surface condition, parallelism, and intervening medium are not critical. A simple metal foil can convert any object into a suitable target.

FIGURE 1. Multi-Vit displacement measurement system.

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Measuring Systems
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THE DISPLACEMENT MEASUREMENT SYSTEMS SHOWN IN FIGURE 1 MAKES NON-CONTACTING MEASUREMENT OF THE DISTANCE BETWEEN THE FACE OF THE DISPLACEMENT TRANSDUCER AND AN ELECTRICALLY CONDUCTING SURFACE OR "TARGET," USING EDDY-CURRENT TECHNIQUE. THIS NON-CONTACTING TYPE OF DISPLACEMENT MEASUREMENT HAS MANY APPLICATIONS IN RESEARCH, DEVELOPMENT, AND PRODUCTION. PAGE 7

The first systems were developed to study in-flight structural distortions in a missile nose cone. That application involved a flat aluminum "target" - i.e., certain small areas of the structure under study. Subsequent applications have included measurement of the vibration induced in the barrel of a gun when it is fired (cylindrical steel target), and the distortion of ice samples when subjected to stress (target of aluminum foil bonded to ice). Wide variations in the material and configuration of the target are possible. The performance of the transducer system will be affected by the target used.

The system operates on the eddy-current loss principle. A bridge circuit is activated by a one-megahertz carrier. Two arms of the bridge (two coils) are in the transducer (Figure 2). Magnetic flux lines emanating from the transducer at a 1-MHz rate pass into the conductive surface being sensed, and produce eddy-currents.

As a conductive surface moves closer to the transducer, more eddy currents are generated, and the losses within the bridge circuit become greater. As the conductive surface moves away from the transducers, the losses become less. These impedance variations are converted to DC voltage proportional to the distance being sensed. Because of the high (1-MHz) frequency of the eddy currents, they penetrate the conductive surface only a few thousandths of an inch. Displacement of conductive surfaces as thin as 0.71 mil have been measured successfully.

A patented dual-coil impedance-bridge circuit provides unique features found in no other non-contacting displacement transducer system. The first coil is the active element which senses the target movement; the second coil, in the opposing arm of the impedance bridge, serves as a compensating coil to balance and cancel most of the effects of temperature change. This arrangement provides for a stable system.

The range of an individual sensor depends on the size of the sensor. Systems are available with full scale ranges of 0.0 to 0.005 inch up to 0.0 to 1.000 inch.

SYSTEM OPERATION

A displacement measurement system is comprised of a transducer and associated electronics. The heart of the system is the impedance bridge, excited by a 1-MHz carrier signal. The two coils in the transducer

form two arms of the bridge. The coil impedances determine the 1-MHz output from the bridge, and the target determines the coil impedances (particularly the impedance of the "active" coil). The resulting 1-MHz bridge output is demodulated and linearized, and becomes the system's analog electrical output, which varies directly with the displacement of the target.

An important factor in determining system performance specifications is the magnitude of the output of the 1-MHz bridge - i.e., its change in voltage as the target traverses its full range. The following discussion examines the ways that the size, shape and material of the target affect the bridge output and, ultimately, the system performance.

EFFECT OF TARGET MATERIAL

1. *Change in Impedance.* Conductive targets tend to reduce the impedance of the transducer coils because eddy currents are setup in the target in such a way as to oppose the 1-MHz magnetic field that creates them. Conversely, targets of magnetic materials tend to increase the impedance by presenting the field with a low-reluctance path. The change in impedance resulting from these two tendencies is shown in Figure 3.

As might be expected, the more conductive the target, the more the impedance is reduced; and the more permeable the target, the more the impedance is increased.

NOTE: The values given in Figure 3 for resistivity (ρ) and permeability (μ) are reference-book values which are not necessarily quantitatively accurate at 1-MHz, but which are used for relative comparisons between materials. Both ρ and μ may change appreciably with minor changes in chemical composition, heat treating, etc.

2. *Change in Bridge Output.* The change in coil impedance over the calibrated range of the target is related to bridge output. From Figure 3, it would be expected that aluminum and the .80-Ni/.20-Fe alloy would have a large output relative to the other materials; as shown in Figure 4; this is indeed the case. Moreover, it is apparent from Figure 4 that ordinary materials such as copper and aluminum are about as good as the theoretical perfect conductor ($\rho = 0$) would be expected to be.

Also, some targets, such as 1030 steel, perform better than might be expected from examination of Figure 4. This is true because Figure 4 shows only the change in magnitude of the impedance, although both magnitude and phase angle of the impedance are changed by the target and sensed by the bridge circuit. It happens that 1030 steel produces a relatively large phase angle change in the impedance; hence it produces more output than expected.

FIGURE 2. Elements of sensor.

FIGURE 3. Effect of target material on impedance change in active coil.

FIGURE 4. Bridge output.

3. *Change in System Output.* Compensation for poor targets frequently can be made by special calibration of the system for a particular target.

Changing targets after the system has been calibrated may affect various performance parameters depending (among other things) on which of the available electronic systems is being used. Some qualitative feel for the effect may be gained from Figure 4; for instance, one would expect (and get) little change between copper and aluminum targets.

TARGET THICKNESS

Density of the 1-MHz eddy currents is maximum at the surface of the target and rapidly falls off below the surface. At 1 "skin depth," the density is only 36% of the density at the surface; at 2 skin depths, 13%, and so on.

Skin depth at 1-MHz for a given material is a function of its resistivity and permeability, as shown in Figure 5. It would be expected that, since the eddy currents penetrate into the target, some minimum target thickness would be required for good operation. For good conductors like aluminum, however, bridge output is virtually independent of target thickness down to about one-quarter of a skin depth.

This suggests that the target thickness requirements will seldom be a limiting factor in use of displacement measuring systems. However, the thickness should, where possible, be kept much thicker than this minimum (say, two or three skin depths) to avoid variations due to small changes in resistivity, thickness, temperature, etc. Also, it is possible to get undesirable effects if the coil "looks through" a very thin target and detects another conductor behind it.

A flat, circular aluminum target that is equal in diameter to the transducer is essentially as good a target as an infinite plane of the same material. As shown in Figure 6, output falls off rapidly for targets of smaller diameter, and is down about 50% when target diameter is 50% of transducer diameter.

TARGET ALIGNMENT

Figure 7 shows the effect of off-setting the target from the transducer centerline. In this case the target is of the same diameter as the transducer. It can be seen that the target size should be large enough to completely cover the diameter of the transducer under conditions of maximum offset.

TARGET PARALLELISM

The target must be parallel with the face in order to use the entire range. However, if the expected excursions of the target are less than full range, some non-parallelism can

exist without the target striking the transducer. The transducer tends to sense the average distance to the target, so that the effect of non-parallelism is small up to about 20°.

DISCONTINUOUS TARGET

The eddy currents in the target flow in a circular pattern. A radial discontinuity in the target upsets this flow, in effect greatly increasing the resistivity of the material. A circular discontinuity concentric with the current pattern would have relatively little effect.

Conversely, the flux lines in the target have a radial pattern, so a radial discontinuity would be expected to have less effect than a circular one, which would have the effect of decreasing permeability.

TARGET FINISH AND CLEANLINESS

Neither the finish nor cleanliness of the target have an appreciable influence on its effectiveness. There is generally no perceptible difference between smooth and scratched-up targets; oil, grease, or dirt on the target (which may happen in many applications) similarly have little or no effect.

Cracks in the target, if deep enough, may stimulate a complete discontinuity in the target, with the results discussed in the preceding. Cracks shallower than a couple of skin depths seem to have little effect. Rotating shafts and similar objects are a special case in which the transducer looks, in effect, at many different areas of the shaft in rapid succession. Small variations in different areas of the shaft may be readily detectable. For work of extreme accuracy, this may be troublesome. One solution is to apply a uniform plating of a good conductor.

EFFECT OF TEMPERATURE

Resistivity is a function of temperature. Thus the temperature of a target will affect bridge output. For instance, if the temperature of an aluminum target is increased by 500°F, its resistivity is increased to about 6 micro-ohm-cm and (according to Figure 2) bridge output is reduced by about 2%, or .004%/°F. Nonmagnetic targets of higher resistivity are somewhat more sensitive to the effects of temperature but, in general, the temperature of the target does not have a strong effect.

The behavior of magnetic targets with temperature changes is more complex because both resistivity and permeability are affected. In general, magnetic targets tend to be more affected by temperature, possibly because increasing resistivity not only reduces the eddy current effect, but also increases the skin depth; in effect, a thicker magnetic target results, which is similar to

increasing permeability. As shown in Figure 2, both of these effects tend to increase impedance. Also, for the usual magnetic targets, bridge output is less than for good conductors; therefore, percentagewise, variations are greater.

INTERVENING MEDIUM

In most applications, the medium between the transducer and target is air at ambient pressure. However, any medium that is not too lossy at 1-MHz (such as water or oil) can be inserted instead.

Displacement transducers have been used to study the thickness of the oil film surrounding a rotating shaft, and for underwater measurements. The entire transducer can be mounted under water if necessary. In a typical system, the difference between air and water will be perceptible at a displacement of one-half inch, but the effect on performance specifications is slight.

USE OF ALUMINUM FOIL TARGETS

The preceding suggests that ordinary kitchen aluminum foil (about 0.7-mil thick) is an adequate target for a displacement-measuring system. Furthermore, any object can be converted into an efficient target by simply bonding foil to it in the area of interest. A wide variety of applications for this technique is possible, as suggested in Figure 8. Aluminum foil with adhesive backing is available commercially and is a convenient material for this purpose. The foil may be considerably thicker than kitchen foil.

It should be remembered, when using thin foils, that increasing temperature both increases the resistivity of the material and makes the foil effectively thinner by increasing the skin depth. Foils can be expected to be much more sensitive to temperature effects than thick targets.

Where the use of foils is not suitable for environmental or other reasons, plating with a good conductor such as copper may be preferable.

SUMMARY

1. The surface condition of the target and its cleanliness are not critical.
2. Parallelism between target and transducer is not critical, nor is target flatness.
3. Target and transducer can be immersed in water or other media.
4. Objects not suitable in themselves as targets can be easily converted to good targets by the use of stick-on metal foil or metal plating.
5. Special factory calibration can provide accurate displacement measuring systems for poor targets.

FIGURE 5. Skin depth at 1 MHz.

FIGURE 6. Output for various target diameters.

FIGURE 7. Effect of target misalignment.

FIGURE 8. Possible applications of thin targets.

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