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ENGINEERING DEPARTMENT 795-

TECHNICAL DATA RECORD

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SUBJECT:

Strain Gage Installation on Main Secondary Sodium System of SRE

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I STATEMENT OF PROBLEM

Shortly before the main secondary sodium system of the SRE was preheated and sodium admitted to the system, the Instrumentation Unit at Santa Susana was requested by SRE personnel to assist in installing strain gages and measuring equipment so that strain measurements could be made on the system during these operations. At this time, the Instrumentation Unit at Santa Susana was investigating the application of commercial strain gages for high temperature use (i.e., to about 1100°F) and had some slight understanding of the problems and difficulties involved.

George E. ...
Opt. ...

II. Summary of Results and Recommendations

Although the strain data gathered during the preheating run is not valid because of the two effects discussed (temperature dependence of gage readings below the fusing point of the cement and effect of the wet insulation on the leads), the gages are believed to indicate the true strain to a fair degree of accuracy now that the system has operated at a temperature above the cement fusing point.

A summary of findings on these gages is contained in: "High Temperature Strain Gage Test", IOL from J. Edwards to L. Glasgow, dtd. 26 Jun 57.

III. Discussion and Sample Calculations

The gages used are Baldwin-Lima-Hamilton, type HFN-2. The gage material is Nichrome-V foil, approximately 0.0005-inch thickness with a nominal resistance of 120 ohms; each envelope of 10 gages has a tolerance of ± 0.2 ohms around the average value of the gages in that for particular envelope. The gage factor is 2.2 ± 0.1 .

The exact location of the gages was specified by K. Foster of the SRE group and is shown in Figure 1. Considerable difficulty was encountered in bonding the gages in place due to the restricted working space available. The photograph, Figure 2, shows some of the gages after installation. Note that the Superex heat insulation around the exchanger was cut away to permit placement of the gages and was later replaced.

The procedure followed in placing the gages was to first apply by brush a thin layer of ceramic paste bonding cement, (Allen Type P-1, supplied by BLH for this purpose). This layer was dried under a heat lamp at about 150°F for at least six hours. The gages were then placed in position and the bonding layer of cement was brushed on. This was then dried at 150°F for an additional period of at least six hours.

Each gage location consists of an active gage bonded to the member undergoing strain and a temperature-compensating gage bonded to a small stainless steel tab. The tab is welded to the system along one edge so that it is subjected to very closely the same temperature as the active gage but it is not subjected to strain. These two gages then form two arms of a Wheatstone bridge, the other two arms consisting of two external resistors. Although a "common dummy" connection is often used when multiple active gages are employed at very closely the same temperature, each active gage in this installation was provided with its own compensating gage. The main reasons for doing this are to eliminate contact resistance (variable) in a switching device, which must be in series with an arm of the Wheatstone bridge, and to insure that the temperature difference between the active gage and the temperature-compensating gage is minimized.

The lead-out wires connected to the gages are high temperature wires of four different types; all of which are known to retain their insulation

- * The four types of #22 wire used because of their availability at the time are:
  1. Thermoelectric Co. Type DTP solid copper with unsaturated fiberglass covering.
  2. Phelps-Dodge Copper Products Corp. solid bare copper with Double Maglas insulation.
  3. Varflex Corp. stranded copper with Varglas Silicone insulation.
  4. Anaconda Copper Co. solid copper with Double Silotex insulation.

qualities to at least 800°F. The wire size used is #22; bundles of about 40 wires each were placed inside a length of braided shield for mechanical protection and for electrical shielding.

Connections between the strain gage terminals and the lead out wires were made by a short length of nichrome ribbon, as shown in Figure 3. The ribbon was silver soldered to the copper conductors on one end; the other end was spot welded to the short tabs of the strain gage wire. This final weld is a delicate operation, even on a laboratory desk; it is especially so in the highly congested area in which the gages were placed. It is probably this weld that accounted for the loss of several gages before and after startup. Fiberglass sleeving was slipped over each nichrome ribbon for electrical insulation, and the lead wires were fastened to the vessel or piping so as to remove any tension on the connections to the gages.

READ-OUT SYSTEM:

The device used to read the strain on any given gage was a CEC Type 1-118 Carrier Amplifier. This was chosen because of its general versatility, wide range of gain and attenuation control, ease of adaptation for use as a multi-channel device, and because of its availability at the time. In the usual application of this amplifier, one active transducer of the four-arm bridge type is connected to each channel. However, for this application, a switching and balance panel was devised so that each of the 33 strain gages in the system could be individually balanced and its reading monitored by manually positioning the master selector switch. The circuitry involved here is shown in simplified form in Figure 4. The components shown in the dashed-line box are those associated with each active gage, and all of the leads coming out of the box are switched by the gage selector switch.

In the operation of this amplifier, a carrier voltage of 3-kc is applied to the bridge; the error voltage, also a 3-kc signal, is fed to the input of the amplifier through an input transformer, balance arrangement, and attenuator switch, as shown in Figure 4. The strain signal then modulates the 3-kc carrier voltage and is amplified, then demodulated and fed to the output meter, or to a galvanometer element where used in conjunction with a recording oscillograph.

Figure 5 is a photograph of the switching and balance panel in place at the reactor building. The Carrier Amplifier is mounted atop the balance panel; the leads from the strain gages enter the panel at the right in the photograph.

CALIBRATION

Several methods of calibrating the readings from installed gages are available. The best way, where practicable, is to make a direct calibration by subjecting the member on which the gages are located to an accurately known strain. For gages installed on fixed structures, as in this case, a direct calibration is not practicable and other means must be used. The following methods were employed:

METHOD #1 The gage factor (that is, the ratio of the resistance change in ohms/ohm to the strain in inches/inch) is about 2 for these gages. Thus, the change in the resistance of a nominal 120-ohm gage, when subjected to, say, 100 μ inch/inch of strain, is $120 \times 2 \times 100 \times 10^{-6} = 0.024$ ohms.

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Also, when the calibrating resistor of 82K in the amplifier is switched in parallel with one of the bridge arms as shown in the sketch, Figure 3, and with the bridge balanced, 52 units of deflection are observed with the attenuation switch in the "1" position. A resistor of 82K in parallel with 120 ohms is equivalent to a series resistor of 0.180 ohm. Thus, if 0.180 ohm in series corresponds to 52 units of deflection, then $100 \mu\text{ inch/inch}$ of strain corresponds to $52 \times \frac{0.024}{0.18} = 6.94$ units of deflection; then 100 units of deflection, which is a full-scale reading, corresponds to $\frac{100}{6.94} \times 100 \mu\text{ inch/inch} = 1450 \mu\text{ inch/inch}$ of strain. If the attenuation switch is placed at "2", then full-scale deflection would be $2900 \mu\text{ inch/inch}$, and so on for higher values of strain.

METHOD #2

The manufacturer's specification on the carrier amplifier is that 1.875 mv of input gives full-scale output with full gain and with an attenuation setting of "1". It is easy to calculate, as above, that $100 \mu\text{ inch/inch}$, say, of strain corresponds to 0.024 ohm of series resistance. This, in turn, would result in a bridge output voltage of $2.5 - 5 \times \frac{120}{240.024}$, or 0.3 mv, for an applied bridge voltage of 5 volts. Since we were using about 40% of full gain, the 0.3 mv of amplifier input would produce $\frac{0.3}{1.875} \times 100 \times 0.4 = 6.4$ units of deflection, corresponding to $100 \mu\text{ inch/inch}$ of strain. Full-scale deflection, then, would be $100 \mu\text{ inch/inch} \times \frac{100}{6.4}$ of $1560 \mu\text{ inch/inch}$.

The two figures agree reasonably well, so that 1500 $\mu\text{ inch/inch}$ was considered to be the full-scale reading with an attenuation setting of "1" during these tests. With any other attenuation setting, that setting must be used as a multiplier for the full-scale value given above.

THE DATA:

Data were recorded on those strain gages which appeared to operate satisfactorily for a 50-hour interval, beginning at 6PM on 11 March, 1957.

A plot of the readings of the gages at location "4" is shown in Fig. 6. The readings of these gages are typical of all the others. It can be seen that enormously high strains were observed, ranging up to values, in some cases, above $25,000 \mu\text{ inch/inch}$, both tensile and compressive. Although ingenious explanations were offered for the general shape of the curves, it was not considered believable that the amplitude of the strains could have even approached the values observed. The data were therefore rejected as incorrect and attempts were made to determine why such large apparent strains had been recorded, if indeed the strain values had been much lower.

EVALUATION OF POSSIBLE SOURCES OF ERROR:

A general discussion between W. Anderson of General Engineering, K. Foster of the SRE, and J. Edwards and L. Inglis of the Instrumentation Unit, brought out several possible sources of error.

These may be listed as:

1. Temperature difference between active and compensating gage, or thermocouple action at one or more of the high temperature wire junctions.
2. Necessity of rebalancing amplifier as the temperature varies.
3. Effect of the wet insulation mix used to seal the Superex blocks which were removed in order to mount the gages and later replaced.

These are discussed in turn:

1. The possibility of thermocouple action is ruled out on the basis that the copper lead wires are brought into the "hot zone", that is, under the Superex installation. Under this condition, there can be no net thermal emf generated regardless of the number or kind of metallic junctions interposed, so long as all junctions are at the same temperature.

Due to the temperature vs. resistance characteristic of nichrome there can be an appreciable apparent strain indication from a relatively small temperature difference between the active and temperature-compensating gage.

Temp-Resistance
Characteristic of
Nichrome V.

From the curve above, which shows the variation of resistance over the range of interest, it can be seen the difference in resistance between two 120-ohm gages when subject to 10°F temperature difference will be about $\frac{10}{630} \times 0.075 \times 120 + 0.143$ ohms. This corresponds, as shown in the section on calibration to about 600 μ inch/inch of strain.

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2. Preliminary results of strain gage tests made on gages bonded to a test specimen of stainless steel indicated that the electrical balance of the amplifier changes rather drastically when subjected to large temperature changes before the ceramic bonding cement is fused. The reason for this is believed to be that the resistance to ground, and perhaps the capacitance as well, of the gages is dependent on the temperature of the cement. Curves in the reference report demonstrate this effect and indicate that the setting of the amplifier balance at room temperature may lead to errors at temperatures up to the fusing point of the cement (about 580°F) on the order of 100% of the true strain.

3. An unfortunate occurrence immediately before the pre-heat operation started, was that the metal protection tubes, through which the lead wires from the strain gages to the external amplifier passed in order to penetrate the Superex insulation, were filled with a wet type insulation mix. This mix was drying out during the first few hours of the run, providing a variable resistance to ground.

The effect of this drying out process was simulated in the laboratory by merely passing wires to the gages on the test specimen through a tube, packing it with wet insulation mix of the same kind used on the heat exchanger, making a zero balance on the amplifier, and observing the resultant indication on the output meter. This is shown in Figure 7. This curve is so similar to the curves shown in Figure 6 that it is concluded that the initial rapid changes in apparent strain are almost certainly due in considerable measure to this effect.

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Plan view of sodium inlet line
to main intermediate heat exchanger.

Elevation of sodium inlet
line to exchanger

Note: At each location, there are three individual strain gages
with the direction of the gage grid at 0°, 45° and 90°.

FIGURE 1.

GAGE LOCATION

on the

MAIN INTERMEDIATE HEAT EXCHANGER

<u>Location</u>	<u>Gage No.</u>	<u>Selector Sw. Position No.</u>	<u>Location</u>	<u>Gage No.</u>	<u>Selector Sw. Position No.</u>
1	25	1	7	34	19
	26	2		35	20
	38	3		36	21
2	17	4	8	29	22
	18	5		31	23
	19	6		33	24
3	20	7	9	2	25
	21	8		3	26
	24	9		4	27
4	14	10	10	5	28
	15	11		6	29
	16	12		7	30
5	11	13	11	8	31
	12	14		9	32
	13	15		10	33
6	27	16			
	28	17			
	30	18			

FIGURE 2 A

GAGES AT LOCATION NO. 4

177B

Fig. 2A

810-10

FIGURE 2B

GAGES AT LOCATION NO. 5

810-12

2.B. Graves at Location No. 5

FIGURE 3

**CABLE USED FOR CONNECTING
STRAIN GAGES TO AMPLIFIER**

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Fig. 3 Cable used for Connecting Strain Gages to Amplifier.

Figure 4. Simplified Circuitry of Connections to Carrier Amplifier

FIGURE 5A

**FRONT VIEW OF AMPLIFIER
AND BALANCE PANEL**

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FIGURE 5B

**BACK VIEW OF BALANCE
AND SWITCHING PANEL**

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Figure 8B Back View of Balance and Switching Panel

Figure 6. Gage Readings at Location No. 4

Figure 7. Apparent Strain Observed on Test Specimen not Subjected to Strain, but with Leads Packed with Wet Insulation Mix