WANL-TMI-1483

DETERMINATION OF MINIMUM INSULATION RESISTANCE REQUIREMENTS
FOR OUTER REFLECTOR GAS TEMPERATURE THERMOCOUPLES

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June 11, 1965

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DETERMINATION OF MINIMUM INSULATION RESISTANCE REQUIREMENTS
FOR OUTER REFLECTOR GAS TEMPERATURE THERMOCOUPLES

SCOPE:

This report describes the analysis performed in determining the lowest permissible insulation resistance for the exposed junction copper/constantan thermocouples required to measure outer reflector drum annulus, drum vane and beryllium exit gas temperatures.

INTRODUCTION:

On June 4, 1965, a meeting* was held by representatives of Sensor Application Engineering, Reactor Assembly, Quality Control and Reliability and Quality Assurance to determine an investigation procedure for checking the possible cause of low I. R. (insulation resistance) of the NRX/EST outer reflector exposed junction thermocouples. The insulation resistance of these six thermocouples, WANL part number 945C906H01, had decreased below the 50 megohms point which is specified as being the lowest acceptable limit. Since the NRX/EST outer reflector has been assembled and the instrumentation seal block brazed these thermocouples cannot be removed and baked out to improve the insulation resistance.

It was agreed at the June 4 meeting, that no direct physical action should be taken in the area around the fragile exposed junction unless the insulation resistance reaches a value so low that it is detrimental to test data.

It should be pointed out that although the 50 megohm value is specified as the lowest acceptable limit for the exposed junction thermocouple, certain thermocouples could have a lower than 50 megohm insulation resistance and still provide valid data. The minimum limit is basically dependent on thermocouple type, location in the core and I. R. distribution in the thermocouple. It is impractical to specify various I. R. requirements for each thermocouple since any one type of thermocouple may be installed at various locations in the core. The 50 megohms limit was chosen as standard because it appears sufficient for all types of thermocouples and is a practical value to obtain.

* IC-4638 (ISFS-1022), "Investigation Procedure of Low Insulation Resistance of NRX/EST Outer Reflector Exposed Junction Thermocouple per FDDR No. 2608," dated June 4, 1965.

I. R. DETERMINATION:

A detailed look into the effects of insulation resistance (I. R.) upon the thermocouple operation shows that this is a multiple and complex area in which different phases must be considered. For example, consider the possible thermoelectric effect between the copper or constantan conductors and the stainless sheath as shown in Figure 1 below.

Figure 1

It can be seen that a voltage drop could exist due to thermoelectric effect between the thermocouple conductor and the stainless sheath. This would either add to or buck the actual output, depending mainly on the I. R. and Δ temperature, at points 1 and 2 and the conductor material. To be able to actually predict this effect would be very difficult since the I. R. at various points inside the sheath cannot be directly measured. For practical purposes, effects of this nature will be considered negligible, however, it should be kept in mind that these effects are possible and could cause an error.

Neglecting any side effects, the basic equivalent DC circuit for the thermocouple is shown in Figure 2 below.

Figure 2

where: E_{out} = thermocouple thermoelectric output.

E_{in} = voltage input to the amplifier.

R_1 = equivalent thermocouple conductor resistance.

R_2 = insulation resistance.

R_3 = amplifier input impedance.

It can be seen that when the insulation resistance (R_2) is excluded, the circuit is basically a voltage divider with the input to the amplifier being $E_{out} \times \frac{R_3}{R_1 + R_3}$. When R_1 is much less than R_3 , practically all the thermocouple output is dropped across R_3 and fed to the amplifier. When the insulation resistance is included, it parallels the input impedance and produces an equivalent resistance equal to the product over the sum of R_2 and R_3 . It can be seen that if the insulation resistance decreases, this equivalent resistance will decrease and less voltage will reach the amplifier.

The relationship between the insulation resistance and percent of thermocouple output reaching the amplifier is as follows: (Refer to Figure 2)

1. Assume $R_1 = 50$ ohms (This is typical for the conductor resistances of the subject thermocouples.)

R_2 = Variable (The insulation resistance that is measured on the subject thermocouples is not actually measured between conductors as shown by R_2 in Figure 2. In order for a measurement to be made between conductors, the junction would have to be opened which is impractical. The actual measurement is made between conductors and the metal sheath. This was found to be a good representative of the conductor to conductor insulation.)

$R_3 = 60,000$ ohms (This is typical for the amplifiers.)

$$2. \quad E_{in} = E_{out} \times \frac{R_2 R_3}{R_2 + R_3} \quad / \quad \frac{R_1 + R_2 R_3}{R_2 + R_3}$$

$$3. \quad E_{in} = E_{out} \times \frac{R_2 R_3}{R_2 + R_3} \times \frac{R_2 + R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

$$4. \quad E_{in} = E_{out} \times \frac{R_2 R_3}{R_2 (R_1 + R_3) + (R_1 R_3)}$$

$$5. \quad \% E_{out} \text{ reaching } E_{in} = \frac{E_{in}}{E_{out}} \times 100$$

$$6. \quad \% E_{out} \text{ reaching } E_{in} = \frac{E_{out} \times R_2 R_3}{R_2 (R_1 + R_3) + (R_1 R_3)} \times \frac{1}{E_{out}} \times 100$$

$$7. \quad \% E_{out} \text{ reaching } E_{in} = \frac{(60 \times 10^3) (R_2)}{R_2 (60.05 \times 10^3) + 3 \times 10^6} \times 100$$

Figure 3 graphically shows the relationship between the insulation resistance and the percent of thermocouple output reaching the amplifier for the previous assumed criteria. It should be noted that for other types of thermocouples such as chromel/alumel, the conductor resistance (R_1) is larger which would cause the effects of a decreasing I. R. to become more pronounced. From Figure 3 it appears that below 500K ohms the percentage of output to the amplifier starts to decrease more rapidly.

Referring to Figure 3, with an I. R. of 500K ohms, 99.906% of the thermocouple output will reach the amplifier. What this corresponds to in temperature error can be determined from Figure 4 which shows the actual calibration information on the subject thermocouples. For the lower temperature range shown in Figure 5, there is a relatively small degree of thermocouple voltage change in respect to a temperature change. In this range any reduction in insulation resistance will produce a greater percent error than in the higher more linear temperature range. For example, an insulation resistance of 500K ohms could produce the following error at a temperature of 35°R:

1. $-6.202\text{MV} \times 99.906\% = -6.196\text{MV}$ to the amplifier.
2. -6.196MV corresponds to 38°R on the curve in Figure 5 (Group IV).
3. Therefore an error of +3°R or approximately 0.5% of full range.

As the temperature of the subject thermocouples increases, the error decreases for a constant I. R. value. This is mainly due to a larger thermocouple voltage change taking place in respect to temperature change.

For the same insulation resistance (500K ohms) but with a higher temperature range, the following error could be produced: (Taking 300°R for example)

1. $-3.559\text{MV} \times 99.906\% = -3.555\text{MV}$ to the amplifier.
2. This corresponds to a temperature of 300.28°R.
3. Therefore an error of +0.28°R or 0.045% of full range was produced.

The following table shows the possible error produced at low and relatively high temperatures for various insulation resistance values:

Temperature	Degrees Error/Percent Error of Full Range			
	*I. R. = 50 megohms	I. R. = 1 megohm	I. R. = 500K ohms	I. R. = 1K ohms
35°R	+2°R/0.31%	+3°R/0.48%	+3°R/0.48%	+55°R/8.85%
300°R	+0.26°R/0.041%	+0.26°R/0.041%	+0.28°R/0.045%	+14.5°R/2.33%

*Minimum amount permissible as specified by control process specification

Table I

It appears that with ambient conditions, the subject thermocouples could operate throughout most of its range without producing significant error with a minimum I. R. of 500K ohms. With a decrease in temperature from ambient, the resistance of the thermocouple conductors decreases which lessens the I. R. effect at a given value. Available Plum Brook and GTR reports indicate that radiation also has an effect on the insulation resistance.* It appears that the general trend of the insulation resistance during a reactor run was an initial decrease with reactor startup which generally leveled off during the run and then increased after reactor shutdown. If the 500K ohm I. R. region (which appears to be satisfactory for ambient conditions) were to drop during irradiation, a significant error could result. Therefore, it appears necessary to increase the ambient requirement to 1 megohm minimum to allow as a safety factor for irradiation decrease.

*Ref.:

WANL-TME-638, "Summary of NERVA Instrumentation Review Meeting at WANL, December 17 - 19, 1963," dated 1/2/64.

WANL-TME-691, "NRX-A Candidate Diagnostic Transducers Irradiated at Plum Brook Reactor Facility, Cycles 4 (PB No. 1W)," dated 4/6/64.

CONCLUSIONS AND RECOMMENDATIONS:

Based on this analysis, an insulation resistance of one megohm minimum is permissible for the subject thermocouples. This is assuming that other thermoelectric effects (such as those between the copper-constantan and stainless steel sheath) are negligible and also that irradiation will not cause a decrease in I. R. less than 500K ohms. It is recommended that actual tests on the effects of insulation resistance on sensor performance be continued in respect to the irradiation, temperature, and other related effects.

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INSULATION RESISTANCE (OHMS)

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PERCENT OF TIC OUTPUT REMAINING AMPLIFIED

Fig 3

THERMOCOUPLE CALIBRATION DATA

Thermocouple Type Cu/Con Group III NRX A-4

WANT		NBS Standard Curve			
Temp. °R	Output MV	Temp. °R	Output MV	Temp. °R	Output MV
		8	-6.553	760	6.647
		20	-6.242	780	7.208
		35	-6.202	800	7.776
		40	-6.186	820	8.352
		60	-6.101	840	8.935
		80	-5.990	860	9.525
		100	-5.855	880	10.123
		120	-5.699	900	10.726
		140	-5.525	920	11.336
		160	-5.335	940	11.953
		180	-5.128	960	12.575
		200	-4.905	980	13.203
		220	-4.667	998.8	13.798
		240	-4.413	1000	13.838
		260	-4.144	1020	14.477
		280	-3.859	1040	15.122
		300	-3.559	1060	15.773
		320	-3.245	1080	16.429
		340	-2.917	1100	17.089
		360	-2.575		
		380	-2.220		
		400	-1.852		
		420	-1.472		
		440	-1.078		
		460	-0.673		
		480	-0.255		
		492	0		
		500	+0.171		
		520	0.609		
		540	1.057		
		560	1.517		
		580	1.987		
		600	2.467		
		620	2.958		
		640	3.458		
		653.5	3.798		
		660	3.967		
		680	4.486		
		700	5.014		
		720	5.550		
		740	6.094		

SET-UP RANGES
35°R to 653.5°R
35°R to 998.8°R