Records

LIQUID ROCKET PLANT

Winsco Platinum Resistance Temperature
Transducer Model 2610-2

Prepared by
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MASTER

Report 8771:2256

17 December 1963

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Issue Date: 3 December 1963

PRE-IRRADIATION ANALYSIS REPORT NO. 8771:2256

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I. ABSTRACT

Winsco Resistance Temperature Transducer 2610-2 is radiation resistant and should be able to withstand radiation dosages in excess of those prescribed for NERVA (10^{11} ergs/gm(C)-hr and 10^{14} nv fast neutrons). The accumulative neutron damage and gamma heating in the NERVA flux rate will cause errors in temperature readout which may not be tolerable. The error induced by gamma heating may be reduced by re-design of the mandrel on which the resistance wire is wound.

II. SUBJECT DESCRIPTION

Winsco temperature probe 2610-2 is a design which is intended to be radiation hardened and used at liquid hydrogen temperatures.

The resistance element is 0.7 mil platinum wire wound on a solid cylindrical alumina mandrel. The design is for a nominal resistance element of 1000 ohms. The output is to be approximately 6-60 millivolts in the temperature range -430 to -400°F. The resistance of the sensing elements will be about 2.5 ohms at -430°F and 24 ohms at -400°F.

The probe is encased in a stainless steel tube. The total weight of the transducer was given as less than five ounces by the manufacturer.

III. SUMMARY

A. ANALYSIS OBJECTIVE

The purpose of the analysis was to estimate the radiation damage threshold of the transducer, and to estimate probable sensing errors caused by the radiation field.

B. CONCLUSIONS

The threshold dose, based on materials of construction can reach 10^{19} n/cm² and 10^{12} ergs/gram(C). The error induced by gamma heating at the NERVA level may be as high as 3.8°F in a hydrogen bath or 0.18°F if immersed in liquid hydrogen flowing at 400 ft/sec. The error can be reduced by using a mandrel in the sensor which is hollow (smaller mass, increased heat transfer area). Thermal and fast neutron doses of 2.9×10^{18} and 8.2×10^{17} n/cm², respectively, are expected to produce a 1°F error in temperature.

IV. ANALYSES

A. RADIATION COMPATIBILITY OF MATERIALS

The materials of construction of the probe were given by the manufacturer as follows:

Platinum

Alumina (Al_2O_3)

Stainless Steel

Ceramic cement

The materials above have good radiation stability and should not deteriorate in the radiation environment.

Previous work with thermoresistive type units has shown that 10^{16} nvt thresholds were set because of boron contained in a metal-to-glass seal which was used to bond platinum wire to a metal (chrome-iron) mandrel (Ref 1). The above design represents a departure to alleviate the need for boron and to increase the threshold level. Previous irradiations of high temperature ceramics used in conjunction with platinum resistive elements have resulted in estimated thresholds of 10^{19} n/cm² and 10^{12} ergs/gram(C) (Ref 1).

Readout errors will be introduced by gamma and self-heating, and neutron damage of the sensing element.

B. ANALYSIS OF GAMMA AND SELF-HEATING

The sensing element composition was deduced from a verbal description and a transducer outline drawing in the Winsco proposal. A tabulation of the ratio of gamma energy absorption of each material to that of carbon and the gamma energy absorbed by each component in two radiation fields is shown in Table I. The radiation fields are those for 10" North Face centerline of GTR (5.25×10^5 ergs/gram(C)-sec) and the prescribed NERVA dose rate (2.78×10^7 ergs/gram(C)-sec).

IV, B, Analysis of Gamma and Self-Heating (cont.)

TABLE I
GAMMA ENERGY ABSORPTION IN WINSKO (2610-2) TEMPERATURE PROBE

	<u>Weight</u>	<u>E / E₀ (C)</u>	<u>10¹⁰ N.F.C.L of GTR E</u>	<u>NERVA E</u>
	grams		ergs/sec	ergs/sec
Pt Resistance Wire	0.013	1.30	0.87 x 10 ³	4.70 x 10 ⁵
Alumina Mandrel	0.177	1.00	9.30 x 10 ⁴	4.92 x 10 ⁶
SS Shroud	0.036	1.02	<u>1.93 x 10⁴</u>	<u>1.02 x 10⁶</u>
Total Gamma Energy			1.21 x 10 ⁵	6.41 x 10 ⁶
Total Gamma Energy Milliwatts*			12.2	645

The manufacturer provided information that the error introduced by self-heating was 50 milliwatts/°F in a water bath. The heat transfer coefficient evaluated by the following expression gave good correlation with this value, and therefore was used to evaluate the expected error in a hydrogen bath.

$$(h_c D_o / k) = 0.548 \left[(Pr) D_o^3 \rho^2 \beta g (\Delta t) / \mu^2 \right]^{1/4} \quad (\text{Ref 2})$$

where

h_c = free convection heat transfer coefficient, (BTU/hr-ft²-°F)

D = sensor diameter, ft

k = fluid thermal conductivity (BTU/hr-ft²-(°F/ft))

* 1 watt = 9.94 x 10⁶ ergs/sec

IV, B, Analysis of Gamma and Self-Heating (cont.)

Pr = Prandtl number ($C_p \rho / k$)

ρ = Fluid density, lb/ft³

β = Coefficient of volumetric expansion

Δt = temperature difference between surface and ambient fluid

μ = Fluid viscosity, (lbm/hr-ft).

The convective heat transfer coefficient from the probe to flowing liquid hydrogen was evaluated by the expression

$$(h D_o / k_f) = .32 + 0.43 \left(\frac{D_o G}{\mu_f} \right)^{0.57} \quad (\text{Ref 2})$$

where the nomenclature is the same as for the preceding expression. The following table shows the computed convective heat dissipation rates from the probe sensor evaluated by the product of ($h_c A \Delta t$) where A is probe area.

TABLE II

HEAT DISSIPATION FROM WINSO RTT PROBE
AS FUNCTION OF HYDROGEN VELOCITY

<u>Velocity</u>	<u>Dissipation From Sensor</u>
ft/sec	mw/°F
0	12
1	162
10	530
50	1222
100	1750
200	2510
400	3600

IV, B, Analysis of Gamma and Self-Heating (cont.)

The self heating of the sensing element in the temperature range -430°F to -400°F will be small. It will be 0.75 milliwatts and would contribute 0.015°F error if immersed in hydrogen bath and $5 \times 10^{-5}^{\circ}\text{F}$ in hydrogen flowing at 400 ft/sec. The principal source of error will be caused by gamma heating in the probe. Comparison of tables I and II show that if the probe is immersed in liquid hydrogen flowing at 400 ft/sec in the NERVA environment, the expected error in the reading will be about 0.18°F . It will be 0.0034°F in the indicated GTR location under corresponding hydrogen flow conditions.

Table I shows that the alumina mandrel is responsible for 77% of the gamma heating. If the error limits for the NERVA environment are not acceptable, redesign of the mandrel will reduce the error.

C. NEUTRON DAMAGE

Neutron capture in the platinum resistance wire will gradually change the resistivity of platinum and hence degrade the sensor accuracy.

1. Thermal Neutron Degradation

The change in resistivity of platinum as a function of thermal neutron bombardment was measured by Ross (Ref 3). The expression for platinum at room temperature is given by

$$\% \Delta \rho / \rho_0 = 19 \times 10^{-22} \phi t,$$

where $\Delta \rho$ is change in resistivity and ρ_0 is original resistivity.

In a $1/v$ absorber which was assumed for liquid hydrogen, the cross section varies inversely with T^2 where T is the absolute temperature.

$$\sigma_{(T)} = \sigma_{20^{\circ}} \sqrt{\frac{293}{T + 273}}$$

The value of $\% \Delta \rho / \rho_0$ is proportional to cross section, hence it can be multiplied by the same value.

The expression for ΔT , the error introduced by a change in resistance caused by thermal neutron damage is

$$\Delta T = (\Delta \rho / \rho_0) (1/\alpha)$$

IV, C, Neutron Damage (cont.)

where α is the temperature coefficient of resistivity. The following table summarizes the expected temperature errors at -430°F and -400°F as results of neutron exposure. The last column is the thermal neutron dose which is expected to result in a 1°F temperature error in the probe reading.

TABLE III

PLATINUM RESISTIVITY CHANGE CAUSED BY THERMAL NEUTRONS

Temperature	$\% \Delta \rho / \rho_0$	$\alpha / ^\circ\text{F}$	$(\Delta T / \phi t)$	$(\phi t / ^\circ\text{F})$
-400°F	$60.5 \times 10^{-22} / \phi t$	.00126	4.78×10^{-20}	2.09×10^{19}
-430°F	$80.5 \times 10^{-22} / \phi t$	.0002354	3.42×10^{-19}	2.92×10^{18}

If the liquid hydrogen is at -430°F , a 1°F error is expected by a total dosage of 2.9×10^{18} neutrons/cm².

The values of $\Delta \rho / \rho_0$ obtained by Ross were based on a long (April 1957-Oct 1958) period after irradiation to anneal out lattice defects and hence are a measure of the effect of transmutation on the resistivity. The effect of the lattice defects at the time of irradiation may cause a larger error. A larger error has, in fact, been reported (Ref 4). It was stated in Ref 4 that platinum resistance wires irradiated to 2×10^{19} neutrons/cm² resulted in a resistivity decrease of .72%. Compared to the values reported by Ross this is a factor of twenty lower for the flux required to produce one degree error in the sensor. It should be noted that the resistivity was reported to decrease where the effect of transmutation is to increase the resistivity. A direct comparison of results is not valid, because original reports which presumably contain conditions of test are not presently available to the writer. The information is included to show that carefully planned irradiation tests of the transducer are essential for error analysis purposes.

2. Fast Neutron Degradation

The increase of platinum resistance as the result of fast neutron bombardment can be estimated similarly to the method of estimation of thermal neutron damage. The value obtained is, however, based on several assumptions whose accuracy has not been established by experiment.

The temperature error is represented by

$$\Delta T_{11} = \frac{(\Delta \rho / \Delta V) N \sigma}{\rho_0 \alpha} \quad (\text{Ref 5})$$

IV, C, Neutron Damage (cont.)

where

$(\Delta\rho)/\Delta V$ = change of resistivity per vacancy created

$N\sigma$ = total vacancies created

N = fast neutron dose (ϕt)

σ = fast neutron cross section, = 7 barns

α = temperature coefficient of resistivity at irradiation

temperature, $\left| \frac{(R_T/R_0)_{T+x} - (R_T/R_0)_{T-x}}{2x} \right|$

ρ = resistivity at reference temperature, 9.825×10^{-6} ohm-cm @ 32°F

The above expression is based on the assumption that one vacancy is created for each fast neutron captured and that the fast neutron capture cross section is invariant with temperature; record of experimental verification is not known. Some experimental work has been done to establish the change of resistivity of platinum as a function of the vacancies, but the experimenters caution that their results contain uncertainties and often disagree with values of other experimenters.

The uncertainty in the value of $(\Delta\rho/\Delta V)$ was emphasized in Ref 6. The authors estimated $(\Delta\rho/\Delta V) = 4 \times 10^{-4}$ for platinum and stated that it could easily be off by a factor of three in either direction. They stated that they did not propose to identify the annealing process with any similar process such as irradiation. However they did state that their values of quenching energy were within the experimental error limits of the value 1.2 ev reported by another experimenter (Dugdale) for platinum irradiated at room temperature.

The following table estimates the change in output of the platinum temperature probe as a function of fast neutron exposure. The last column shows the fast neutron dose which is expected to cause one degree temperature error in the probe.

TABLE IV

PLATINUM RESISTIVITY CHANGE CAUSED BY FAST NEUTRONS

<u>T°F</u>	<u>α</u>	<u>N/°F</u>
-400	.00126	4.7×10^{18}
-430	.0002354	8.2×10^{17}

IV, C, Neutron Damage (cont.)

The effect of neutron irradiation is to increase the platinum resistivity, therefore sensors which are degraded will record temperatures that are higher than the actual temperature.

3. Induced Activity

The manufacturer stated that the transducer is made of 300 series Stainless Steel. For purposes of estimating induced activity, the steel was assumed to be type 304, and it was assumed that there are a maximum of 125 grams in the transducer. At the end of the irradiation the induced activity will be approximately 9.3×10^{-2} curies. The individual components and their contributions are as follows:

<u>Component</u>	<u>% Composition</u>	<u>Activity Curies</u>
Iron	70	1.3×10^{-4}
Chromium	18	3.7×10^{-3}
Manganese	2	8.9×10^{-2}
Ni	10	5.8×10^{-4}
Pt		8.0×10^{-5}

V. PERFORMANCE REQUIREMENTS

Prediction of errors introduced by degradation of Winsco RTT probe 2610-2 are based on uncertainties which have been stated in the foregoing sections. Substantiation can be obtained by testing the probe in radiation fields. Tests should be arranged so that the cumulative damage and readout error caused by neutrons can be measured, and so that gamma heating of the probe can be explored. The rate of heat dissipation by hydrogen flowing past a probe could be determined in a non-radiation environment. This data could be used to extrapolate the EIT 503 data where the gamma heating will not be appreciable to the NERVA environment where it is expected to be appreciable.

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