Records

LIQUID ROCKET PLANT

EVALUATION OF ROSEMOUNT ENGINEERING COMPANY
MODEL 134EB RADIATION RESISTANT
CRYOGENIC TEMPERATURE SENSOR
SERIAL NO. 2826

Prepared by
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MASTER

Laboratory Report No. 8771:2365

8 January 1964

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I. INTRODUCTION

At the request of the Instrumentation Development Department 8771, Rosemount Engineering Company designed and fabricated a resistance temperature transmitter (RTT) for evaluation by Aerojet-General Corporation. It was requested that this unit be radiation hardened to be suitable for the NERVA environments, electrically equivalent to the Model 134CT, and mechanically interchangeable with the Model 134CT. The Model 134CT, also manufactured by Rosemount, is qualified for Test Area service.

In September 1962 an evaluation Model 134EB, S/N 2826, was provided. The purpose of this laboratory report is to document the extensive test program to which this RTT has been subjected.

II. SUMMARY

A. THEORETICAL ANALYSIS

Theoretical Analysis Description	Rosemount Spec.	Results	Conclusion
Radiation Effects	Not Specified	<u>Gamma Heating Error</u> +0.0012°F @ -423°F with a gamma integrated dose rate of 10^{17} erg/gm (C)/sec. <u>Neutron Heating Error</u> +0.3°F @ -423°F with an integrated thermal neutron dose of 10^{18} n/cm ² and an integrated fast neutron dose of 10^{17} n/cm ² .	Data must be corrected for neutron effects on all high accuracy measured parameters.
Stem Conduction	Not Specified	<u>Error (68°F Housing) for three stem lengths of</u> +2.21°F with L = 2 in. +0.041°F with L = 3 in. +0.0007°F with L = 4 in. <u>Error (-100°F Housing) for three stem lengths of</u> +1.28°F with L = 2 in.	Stem lengths of 4 inches should be utilized for all high accuracy parameters.

Theoretical Analysis Description	Rosemount Spec.	Results	Conclusion
Stem Conduction Continued		$\pm 0.0238^{\circ}\text{F}$ with $L = 3$ in. $\pm 0.0004^{\circ}\text{F}$ with $L = 4$ in.	
Frictional Heating	Not Specified	<u>Error Due to Flowing Liquid Hydrogen</u> $\pm 0.0003^{\circ}\text{F}$ @ 10 ft/sec. $\pm 0.0011^{\circ}\text{F}$ @ 20 ft/sec. $\pm 0.0015^{\circ}\text{F}$ @ 40 ft/sec. $\pm 0.0055^{\circ}\text{F}$ @ 80 ft/sec. $\pm 0.028^{\circ}\text{F}$ @ 160 ft/sec. $\pm 0.13^{\circ}\text{F}$ @ 320 ft/sec.	Frictional heating error as calculated will present no problem on NERVA parameters.
Self-Heating	Not Specified	$\pm 0.002^{\circ}\text{F}$ with 3 ma	Self-heating error as calculated will present no problem on NERVA parameters.
Transient Response	0.03 sec. maximum with LH_2 flowing at 75 ft/sec.	<u>63.2% Response to Temperature step in flowing liquid hydrogen</u> 0.031 sec @ 10 ft/sec. 0.026 sec @ 20 ft/sec. 0.024 sec @ 30 ft/sec. 0.022 sec @ 50 ft/sec. 0.021 sec @ 100 ft/sec.	Transient response will satisfy NERVA requirements.

B. LABORATORY TESTS

Laboratory Test Description	Rosemount Spec.	Results	Conclusion
Accuracy	Calibration points are defined as: $\pm 0.030^{\circ}\text{F}$ @ -452.1°F $\pm 0.067^{\circ}\text{F}$ @ -320.4°F $\pm 0.077^{\circ}\text{F}$ @ $+32^{\circ}\text{F}$	<u>First Run</u> $\pm 0.0647^{\circ}\text{F}$ @ $-406.9026^{\circ}\text{F}$ $\pm 0.0653^{\circ}\text{F}$ @ $-413.6656^{\circ}\text{F}$ $\pm 0.1190^{\circ}\text{F}$ @ $-420.0227^{\circ}\text{F}$ <u>Second Run</u> $\pm 0.0422^{\circ}\text{F}$ @ $-406.9095^{\circ}\text{F}$ $\pm 0.0579^{\circ}\text{F}$ @ $-413.6600^{\circ}\text{F}$ $\pm 0.0898^{\circ}\text{F}$ @ $-420.0170^{\circ}\text{F}$	Acceptable for NERVA requirements provided individual calibration results are used for data reduction on high accuracy required parameters.

Laboratory Test Description	Rosemount Spec.	Results	Conclusion
Interchangeability	$\pm 0.28^{\circ}\text{F}$ (-425°F) $\pm 0.26^{\circ}\text{F}$ (-424°F) $\pm 0.25^{\circ}\text{F}$ (-423°F) $\pm 0.24^{\circ}\text{F}$ (-422°F) $\pm 0.23^{\circ}\text{F}$ (-421°F) $\pm 0.21^{\circ}\text{F}$ (-420°F) $\pm 0.20^{\circ}\text{F}$ (-419°F) $\pm 0.19^{\circ}\text{F}$ (-418 to -417°F) $\pm 0.18^{\circ}\text{F}$ (-416°F) $\pm 0.17^{\circ}\text{F}$ (-415°F) $\pm 0.16^{\circ}\text{F}$ (-414 to -412°F) $\pm 0.15^{\circ}\text{F}$ (-411 to -410°F) $\pm 0.14^{\circ}\text{F}$ (-409 to -407°F) $\pm 0.13^{\circ}\text{F}$ (-406 to -400°F)	<u>First Run</u> $\pm 0.1246^{\circ}\text{F}$ @ $-406.9026^{\circ}\text{F}$ $\pm 0.1426^{\circ}\text{F}$ @ $-413.6656^{\circ}\text{F}$ $\pm 0.1818^{\circ}\text{F}$ @ $-420.0227^{\circ}\text{F}$ <u>Second Run</u> $\pm 0.1016^{\circ}\text{F}$ @ $-406.9095^{\circ}\text{F}$ $\pm 0.1351^{\circ}\text{F}$ @ $-413.6600^{\circ}\text{F}$ $\pm 0.1882^{\circ}\text{F}$ @ $-420.0170^{\circ}\text{F}$	Acceptable for NERVA requirements.
Repeatability After 18 dynamic engine component tests	$\pm 0.02^{\circ}\text{F}$ (-425 to -400°F)	-0.0225°F @ $-406.9061^{\circ}\text{F}$ -0.0074°F @ $-413.6628^{\circ}\text{F}$ -0.0292°F @ $-420.0199^{\circ}\text{F}$	Acceptable for NERVA requirements.
Self-Heating - Tested in unagitated liquid neon		<u>First Run (-411.029°F)</u> - - - - @ 1 ma $\pm 0.0021^{\circ}\text{F}$ @ 2 ma $\pm 0.0060^{\circ}\text{F}$ @ 3 ma $\pm 0.0082^{\circ}\text{F}$ @ 4 ma $\pm 0.0110^{\circ}\text{F}$ @ 5 ma <u>Second Run (-410.888°F)</u> - - - - @ 1 ma $\pm 0.0017^{\circ}\text{F}$ @ 2 ma $\pm 0.0038^{\circ}\text{F}$ @ 3 ma $\pm 0.0058^{\circ}\text{F}$ @ 4 ma $\pm 0.0093^{\circ}\text{F}$ @ 5 ma	Acceptable for NERVA Requirements

Laboratory Test Description	Rosemount Spec.	Results	Conclusion
Self-Heating Continued		<u>Third Run (-410.888°F)</u> - - - - @ 1 ma +0.0059°F @ 2 ma +0.0114°F @ 3 ma +0.0157°F @ 4 ma +0.0206°F @ 5 ma	
Thermal EMF	30 Microvolts Maximum	0.75 mv @ -420°F	Acceptable for NERVA requirements.
X-Ray	Not Applicable	N/A	N/A
Vibration - Tested by Rosemount Engineering	70 g's (to 2000 cps)	20 to 2000 cps @ 35 g's for 10 minutes - no mechanical resonance.	Acceptable for NERVA requirements.
		20 to 2000 cps @ 50 g's - no mechanical damage.	
		20 to 2000 cps @ 70 g's - no mechanical damage.	

C. DYNAMIC TESTS

Dynamic Test Description	Rosemount Spec.	Results	Conclusion
Test Run Log	Not Applicable	18 dynamic engine component tests (2,448 seconds) without electrical or mechanical failure.	Acceptable for NERVA requirements.
Sensor Error Analysis	Not Specified	<u>Test Run No. 1.2-06-NNP-012</u> ± 0.047°F (1σ) <u>Test Run No. 1.2-06-NNP-013</u> ± 0.056°F (1σ) <u>Test Run No. 1.2-06-NNP-015</u> ± 0.121°F (1σ)	Acceptable for NERVA requirements.
LH ₂ Flow Velocity	Not Specified	50 ft/sec.	Acceptable for NERVA requirements.

III. CONCLUSIONS

Conclusions on each test reported are listed in the summary section and will not be repeated for each individual test. Radiation effects on platinum are only calculated; they must be proven under radiation. Radiation testing is scheduled to be started in the early part of 1964 in the Los Alamos Scientific Laboratory reactor and the General Dynamics (Fort Worth) reactor.

Although the accepted practice is to evaluate at least three of any one type of RTT to provide a basis of selection, it may be concluded that the 134EB is satisfactory for the NERVA requirements. This conclusion is supported by the successful evaluation of six Model 134CT RTT's which are similar in mechanical and electrical characteristics to the Model 134EB.

IV. DISCUSSION

A. TEST ITEM DESCRIPTION

The Model 134EB platinum resistance temperature transducer, manufactured by Rosemount Engineering Company, Minneapolis, Minnesota, is an immersion type unit designed for measurements in the temperature range of -425°F to $+75^{\circ}\text{F}$. It is suitable for use in most hydrocarbons, gaseous or liquid air, oxygen, nitrogen, hydrogen, or helium. Since this unit is also designed to operate in a radiation environment, all materials used in construction are radiation resistant. The temperature sensing element consists of a 90% platinum and 10% rhodium cylindrical mandrel which is wound with pure (99.9%) platinum wire that is fully supported by a ceramic insulation (containing only 0.05% B_2O_3) and protected by a perforated stainless steel guard tube.

The Model 134EB (a radiation resistant Model 134CT) is electrically and physically interchangeable with the Model 134CT temperature sensor. The basic difference between these two sensors is in the construction materials that are necessary for radiation resistant design. This difference necessitated the removal of the teflon bushing that supports the element mandrel at the sensor tip and the replacement of teflon insulation with a fiberglass for the internal wires. To insure the unsupported mandrel would meet vibration requirements, the mandrel used with the Model 134CT was shortened from 1.25 inch to 0.85 inch. The basic requirement that the platinum wire sensing area is to be contained in the last 1.0 inch of the sensor remains for each sensor. The Model 134EB, however, retains the identical resistance to temperature relationship with an ice point resistance of 1380 ± 1.0 ohms and a residual resistance at the liquid helium boiling point (-452.1°F) of approximately 0.08% of the ice point value.

The resistance of platinum has a positive slope, varying directly with temperature although non-linear. The Model 134 type platinum sensor, being essentially a single variable resistor (variable with temperature), is normally excited with a constant current power supply; with current held constant the sensor output voltage varies directly with changes in resistance. The electrical circuit has four wires, two for excitation and two for output signals.

Figure 1 is a photograph of the evaluated 134EB and Figure 2 is the Specification Control Drawing provided by Rosemount.

B. THEORETICAL ANALYSIS

1. Radiation Effects

A study has been made of the effects of irradiation on the performance of the Model 134EB (Reference 1). A gamma heating error of $\pm 0.0012^{\circ}\text{F}$ was indicated for a true temperature of -423°F . Because of neutron irradiation, an error of $\pm 0.3^{\circ}\text{F}$ is also anticipated. The effects of neutron irradiation upon resistivity are very indeterminant and the latter figure should be considered maximum. The conditions assumed for the study were as follows:

- (a) Fluid: LH_2 ; steady flow at a velocity of 200 ft/sec.
- (b) Temperature: -423°F
- (c) Element location: Along diameter of 7 in. dia. pipe.
- (d) Integrated thermal neutron dose: 10^{18} n/cm².
- (e) Integrated fast neutron dose: 10^{17} n/cm².
- (f) Gamma dose rate: 10^{17} erg/gm (C)/sec.

2. Stem Conduction

An analysis of stem conduction effects (Reference 2) indicates the error to be independent of velocity for all flows above normal free convection flow. Typical errors for various RTT lengths L are given in the following table:

Head Temperature		L (Inches)	Error ($^{\circ}\text{F}$)
($^{\circ}\text{F}$)	($^{\circ}\text{R}$)		
68	528	2	+ 2.21
		3	+ 0.041
		4	+ 0.0007
	360	2	+ 1.28
		3	+ 0.0238
		4	+ 0.0004

STEM CONDUCTION CALCULATED DATA

3. Frictional Heating

Studies of the orders of magnitude of the anticipated temperature errors, caused by frictional effects in high velocity LH_2 flows, indicate a small error because of RTT size for laminar flow (Reference 3). In turbulent flow the error may be expected to vary directly with the diameter. Anticipated errors for a 134EB are given in the following table:

Velocity (fps)	Error (°F)	Flow Type
10	+ 0.0003	Laminar
20	+ 0.0011	Laminar
40	+ 0.0015	Transitory
80	+ 0.0055	Turbulent
160	+ 0.028	Turbulent
320	+ 0.13	Turbulent

CALCULATED FRICTIONAL HEATING ERROR

4. Self-Heating

Results of a study (Reference 4) investigating self-heating in the 134EB indicate it to be relatively free from error because of this effect. The error may be considered constant for all flow rates and proportional to the second power of the element current. The self-heating factor may be expected to be of the orders of 1.2×10^{-1} watts/°F under no flow conditions and 3.5×10^{-1} watts/°F under flow conditions. When in flow, an error of 2×10^{-4} °F may be anticipated for an element current of 3 milliamperes.

5. Transient Response

Calculations have been made by Rosemount Engineering Company (Reference 5) to estimate the time required to respond to a temperature change of flowing liquid hydrogen. These calculations are based upon an actual test of a 134EB type element in Dow Corning Silicon Oil, DC 200, (with a density of 1.5 C STK, at a temperature of 170 ± 10 °F, and flowing at 3 ± 0.5 ft/sec.) while measuring the change in resistance. Tabulated below are the results of this calculation for 63.2% response to a temperature change in flowing liquid hydrogen at -420°F.

LH ₂ Velocity (ft/sec)	63.2% Response (Sec)
3	0.048
10	0.031
20	0.026
30	0.024
50	0.022
100	0.021
150	0.020
200	0.020

CALCULATED TRANSIENT RESPONSE DATA

C. LABORATORY TESTS

1. Accuracy and Interchangeability

Cryogenic calibration measurements were obtained at the Measurement Standards Laboratory (MSL), Department 3780, by inserting the subject test unit in

the helium-cooled copper block of a laboratory cryostat adjacent to a standard L&N 8164 platinum thermometer. A G-2 Mueller Bridge was used for resistance measurements. The MSL measurement setup is shown in Figure 4. The MSL system calibration accuracy is estimated to be better than 0.01°F .

A three point calibration in the temperature region of -400 to -425°F was performed to verify conformance of the unit to the interchangeability limits of the average resistance-temperature curve in accordance with the 134EB specification control drawing. This calibration was also used to establish the accuracy of the calculated resistance-temperature curve supplied by Rosemount for this unit. Rosemount computes individual resistance-temperature curves for each sensor by utilizing the three point calibration (LHe, LN_2 and ice points) method as suggested by R. J. Corruccini of the National Bureau of Standards. This method of computing curves for cryogenic platinum sensors is fully described in Reference 6.

The results of Aerojet-General calibration at MSL of the Model 134EB are tabulated below and graphically presented in Figure 5. The indicated Rosemount error is a deviation in the -425 to -400°F temperature range of the Rosemount individually computed curve from the actual curve as determined by Aerojet-General calibration.

Run No.	L&N Standard Thermometer		134EB Accuracy		134EB Interchangeability		REC Spec. Limits
	($^{\circ}\text{F}$)	($\sim$)	AGC Measured ($^{\circ}\text{F}$)*	Deviation ($^{\circ}\text{F}$)	AGC Measured ($^{\circ}\text{F}$)**	Deviation ($^{\circ}\text{F}$)	
1	-406.9026	22.5863	-406.8379	0.0647	-406.7780	0.1246	± 0.14
	-413.6656	14.3642	-413.6003	0.0653	-413.5230	0.1426	± 0.16
	-420.0227	8.7947	-419.9037	0.1190	-419.8409	0.1818	± 0.21
2	-406.9095	22.5448	-406.8673	0.0422	-406.8079	0.1016	± 0.14
	-413.6600	14.3622	-413.6021	0.0579	-413.5249	0.1351	± 0.16
	-420.0170	8.7769	-419.9272	0.0898	-419.8288	0.1882	± 0.21

ACCURACY AND INTERCHANGEABILITY TEST DATA

2. Repeatability

Subsequent to eighteen dynamic engine component tests, which is equivalent to temperature cycling from ambient air to liquid hydrogen temperatures 18 times, S/N 2826 was submitted for recalibration from which repeatability could be

* Data reduced by Calibration Data Sheet

** Data reduced by Specification Data Curve

defined. Tabulated below are results of this Aerojet-General recalibration at MSL utilizing essentially the same measurement system as with calibration.

Average Standard Temperature (°F)	REC Curve Error (Recalibration) (°F)	REC Curve Error (Calibration) (°F)	Repeatability Error (Recal.-Cal.) (°F)	Specification Required Repeatability Limit (°F)
-406.9061	0.0422	0.0647	-0.0225	± 0.02
-413.6628	0.0579	0.0653	-0.0074	± 0.02
-420.0199	0.0898	0.1190	-0.0292	± 0.02

REPEATABILITY TEST DATA

3. Self-Heating

Self-heating tests were performed at MSL on S/N 2826 using non-agitated liquid neon contained in a commercial double dewar assembly. The inside dewar containing the liquid neon was jacketed by liquid nitrogen in the outer dewar. The sensor was pre-cooled in liquid nitrogen prior to testing. During immersion (total or to the face of the hex nut) in liquid neon the measurement current was varied from 1 ma to 5 ma in 1 ma steps. Prior to the initial readings at 1 ma and after each 1 ma step, the test sensor was allowed to stabilize, stabilization taking approximately 2 to 4 minutes each time. The liquid neon temperature was monitored by an L&N 8164 temperature standard. Both standard and test sensor resistance measurements were obtained with G-2 Mueller Bridges. Results of the self-heating tests are tabulated below.

Run No.	S/N 2826 Meas. Current (ma)	L&N 8164 Standard Temp. (°F)	S/N 2826 Test Sensor Res. (Ω)	$+\Delta R$ (Ω)	S/N 2826 134EB Slope (Ω /°F)	$+\Delta F$ (°F)	Cumulative With 1 ma as a Reference $+\Delta F$ (°F)
1	1.0	-411.029	17.4539				
	2.0		17.4564	0.0025	1.1763	0.0021	0.0021
	3.0		17.4610	0.0046		0.0039	0.0060
	4.0		17.4636	0.0026		0.0022	0.0082
	5.0		17.4669	0.0033		0.0028	0.0110
			Total ΔR = +0.0130		Total ΔF = +0.0110		
2	1.0	-410.888	17.4196				
	2.0		17.4216	0.0020	1.1763	0.0017	0.0017
	3.0		17.4241	0.0025		0.0021	0.0038
				0.0024		0.0020	0.0058

Run No.	S/N 2826 Meas. Current (ma)	L&N 2826 Standard Temp. (°F)	S/N 2826 Test Sensor Res. (Ω)	$+\Delta R$ (Ω)	S/N 2826 134EB Slope (Ω /°F)	$+\Delta F$ (°F)	Cumulative With 1 mas as a Reference $+\Delta F$ (°F)
	4.0	-410.888	17.4265				
	5.0	↓	17.4306	0.0041	1.1763	0.0034	0.0093
			Total $\Delta R = +0.0110$		Total $\Delta F = +0.0093$		
3	1.0	-410.888	17.4094				
	2.0	↓	17.4164	0.0070	1.1763	0.0059	0.0059
	3.0		17.4229	0.0065	↓	0.0055	0.0114
	4.0		17.4279	0.0050		0.0042	0.0157
	5.0		17.4337	0.0058		0.0049	0.0206
			Total $\Delta R = +0.0243$		Total $\Delta F = +0.0206$		
NOTE: All measurements were made with sensor immersed to face of hex on the housing.							

SELF-HEATING TEST DATA

4. Thermal EMF

Requirements for the Model 134EB RTT specify that the thermal EMF at the sensor receptacle pins shall not exceed 30 microvolts with the sensor immersed to the face of the hex nut in the working fluid, and shall be allowed to come to equilibrium for a period of one minute. The following data indicates the thermal EMF output generated by the sensor without external excitation while installed in the copper block of the helium-cooled laboratory cryostat. However, in this case the sensor was allowed to come to complete thermal equilibrium and the sensor output to reach complete stabilization; under these ideal conditions the test results indicated negligible thermal EMF effect at the test temperature of -420.07°F.

Pin Combination (+ to -)	Thermal EMF Measured (Microvolts)
A-B	0
A-C	0
A-D	-0.5
B-A	-0.75
B-C	-0.25
B-D	-0.5

Pin Combination (+ to -)	Thermal EMF Measured (Microvolts)
C-A	-0.5
C-D	Ø
D-A	-0.5
D-B	-0.75
D-C	

THERMAL EMF TEST DATA

5. X-Ray

A photograph copy of an x-ray negative of Model 134EB, Serial No. 2826, is presented in Figure 6 for engineering information. The x-rays were taken after a successful performance, both electrically and mechanically, of this unit for eighteen dynamic engine component tests.

6. Vibration (Rosemount Engineering Company)

The significant information from an informal report of a vibration test conducted by Rosemount on the Model 134EB evaluation unit, Serial No. 2826, is presented in the following paragraph.

"The sensor was mounted horizontally and subjected to sine wave vibration from 20 to 2,000 cps starting at 35 g. The sensor was cycled up and down at a 5 minute up and 5 minute down rate at room temperature. No resonant points were noticed by means of a visual examination performed using a strobe light. The amplitude was increased to 50 g on the second cycle and to 70 g on the third cycle. No visible damage resulted from the test; however, there was a slight shift of sensor resistance at the ice point as indicated by recalibration of the sensor at that point after the conclusion of the vibration test."

D. DYNAMIC TESTS

1. Potentiometric RTT Measurement System

Precision temperature measurements are obtained with the Model 134 type sensor in conjunction with a constant current measurement system which is outlined in the diagram of Figure 7. Using this system dynamic data is obtained in the Test Area through designation over the temperature region of -425 to +75°F by three standardized data reduction curves (codes K, L and N) which follow the standardized platinum resistance curve and are compensated for amplifier shunting effects. A twenty-four channel constant current system, consisting of six for Code K, six for Code N, and twelve for Code L, is in service in Test Zone "C" where the Model 134EB unit was used. Complete information, regarding the installation and data used by the LRP Test Area, of the comparable 134CT unit is provided in Reference 7.

2. Test Run Log

Tabulated below is the LRP Test Area use of the Model 134EB (S/N 2826) on "C" Zone Test Stand No. 7 (C-7). This unit performed satisfactorily,

both mechanically and electrically, in measuring the suction line fuel temperature (Tfs) on eighteen turbopump assembly test runs for a cumulative firing time of approximately 2,450 seconds.

Item No.	Test Run Number	Date	Test Stand	Duration (Seconds)	Parameter	Redundant Sensor	
						Model	Ser. No.
1	1.2-06-NNP-001	12/22/62	C-7 ↓ <				

TEST RUN LOG DATA

3. Sensor Error Analysis

Error analysis of C-7 turbopump tests No. 1.2-06-NNP-012, -013, and -015 indicated the results tabulated below. The Model 134EB, S/N 2826, as parameter Tfs-6A is compared to redundant Model 134CT 250 sensor, S/N 2660, installed as Tfs-6B.

Test Run No.	Summary Time (Seconds)	Arithmetic Mean $\bar{x}$ (°F)	Standard Deviation (°F)
1.2-06-NNP-012	60-88	+ 0.040	± 0.047
1.2-06-NNP-013	63-173	+ 0.025	± 0.056
1.2-06-NNP-015	0-130	+ 0.024	± 0.121

SENSOR ERROR ANALYSIS DATA

4. LH₂ Flow Velocity

During engine component testing Model 134EB sensor endured dynamic liquid hydrogen flow rates of as much as 50 feet per second for sustained periods as long as 100 seconds.

LIST OF REFERENCES

*

1. Memorandum 8771:1871, Predicted Irradiation Effects Upon Rosemount 134EB Temperature Sensor, to H. R. Harper from A. E. Lehmborg, dated 4 September 1963.
2. Technical Report No. 8771:2074, A Study of Probe Stem Conduction, Prepared by A. E. Lehmborg, dated 18 October 1963.
3. Technical Report No. 8771:1944, Calculation of Temperature Sensor Error Introduced by Frictional Heating, Prepared by A. E. Lehmborg, dated 17 September 1963.
4. Technical Report No. 8771:2103, A Study of Self-Heating and Energy Transfer Between an RTT Sensing Element and Single Phase Liquid Hydrogen, Prepared by A. E. Lehmborg, dated 28 October 1963.
5. Technical Report No. REC 126327A, Model 134EB Time Constant Data for Liquid Hydrogen, by Lyle Lofgren, Rosemount Engineering Company, dated 27 December 1963.
6. Memorandum No. 8771:1186, Interim Evaluation Report - Platinum Resistance Temperature Sensors, Model 134CT250, to D. M. Wheeler from H. C. Chandon and E. R. Nolte, dated 14 March 1963.
7. Memorandum No. 8771:1542, Interim Development Report for NERVA Sub-sub Task 2.4.9 - Cryogenic Temperature Sensors for LRP Test Area, to G. R. Deppe from E. R. Nolte, and H. C. Chandon, dated 4 June 1963.

FIGURE 1

Model 134EB, S/N 2826, Photograph

SPECIFICATIONS

1.0 **SCOPE:** The Model 134EB is designed for temperature measurements in the range from -400°F to +425°F. It uses a precision platinum resistance sensing element which is fully supported and mounted in ceramic insulation, and protected by a stainless steel guard tube. This sensor is suitable for use in most hydrocarbons, gaseous or liquid air, oxygen, nitrogen, hydrogen, or helium, and is designed to be radiation resistant.

2.0 DESIGN AND PERFORMANCE CHARACTERISTICS:

2.1 **General Performance Characteristics:** The Model 134EB will meet all of the requirements of AGC Specification Drawings 240635 and 240636 and SEC Proposal 65389.

2.2 **Resistance-Temperature Relationship:** Each sensor will meet the relationship shown on AGC Drawing 240636 which is repeated below in Table I.

TABLE I

RESISTANCE VS TEMPERATURE RELATIONSHIP

Temperature (°F)	Resistance (ohms)	Interchangeability (±%)	Temperature (°F)	Resistance (ohms)	Interchangeability (±%)
75	1510.0	1.1	-325	574.76	0.81
70	1495.6	1.1	-320	570.55	0.81
65	1480.9	1.1	-315	562.50	0.81
60	1465.3	1.1	-310	556.22	0.81
55	1450.1	1.1	-305	549.72	0.82
50	1434.9	1.1	-300	543.30	0.82
45	1419.6	1.1	-295	537.02	0.82
40	1404.4	1.1	-290	530.62	0.82
35	1389.2	1.1	-285	524.19	0.82
30	1373.9	1.1	-280	517.73	0.66
25	1358.6	1.1	-275	511.23	0.66
20	1343.3	1.1	-270	504.71	0.66
15	1328.0	1.1	-265	498.14	0.66
10	1312.7	1.1	-260	491.54	0.66
5	1297.4	1.1	-255	484.91	0.66
0	1282.1	1.1	-250	478.25	0.67
-5	1266.7	0.92	-245	471.56	0.67
-10	1251.4	0.92	-240	464.89	0.67
-15	1236.0	0.92	-235	458.25	0.66
-20	1220.6	0.92	-230	451.65	0.66
-25	1205.2	0.93	-225	445.12	0.66
-30	1189.8	0.93	-220	438.65	0.66
-35	1174.3	0.93	-215	432.26	0.65
-40	1158.9	0.93	-210	425.99	0.65
-45	1143.4	0.93	-205	419.86	0.64
-50	1127.9	0.93	-200	413.99	0.65
-55	1112.5	0.93	-195	408.32	0.61
-60	1097.0	0.93	-190	402.05	0.60
-65	1081.4	0.93	-185	395.05	0.58
-70	1065.9	0.93	-180	388.14	0.58
-75	1050.3	0.93	-175	381.22	0.56
-80	1034.8	0.93	-170	374.29	0.55
-85	1019.2	0.94	-165	367.42	0.49
-90	1003.6	0.94	-160	360.53	0.46
-95	987.96	0.94	-155	353.60	0.42
-100	972.32	0.94	-150	346.50	0.37
-105	956.67	0.94	-145	339.21	.22
-110	941.00	0.94	-140	331.98	.21
-115	925.31	0.94	-135	324.73	.21
-120	909.60	0.94	-130	317.49	.21
-125	893.87	0.94	-125	310.21	.20
-130	878.13	0.94	-120	302.93	.20
-135	862.36	0.95	-115	295.65	.20
-140	846.58	0.96	-110	288.31	.19
-145	830.77	0.96	-105	280.93	.19
-150	814.94	0.96	-100	273.50	.19
-155	799.10	0.97	-95	266.09	.19
-160	783.23	0.97	-90	258.65	.19
-165	767.32	0.97	-85	251.14	.20
-170	751.48	0.96	-80	243.65	.19
-175	735.60	0.96	-75	236.17	.19
-180	719.70	0.96	-70	228.70	.19
-185	703.74	0.96	-65	221.22	.19
-190	687.77	0.96	-60	213.73	.19
-195	671.76	0.96	-55	206.22	.19
-200	655.74	0.96	-50	198.73	.19
-205	639.74	0.96	-45	191.22	.19
-210	623.75	0.96	-40	183.73	.19
-215	607.71	0.96	-35	176.22	.19
-220	591.65	0.96	-30	168.73	.19
-225	575.58	0.96	-25	161.22	.19
-230	559.50	0.96	-20	153.73	.19
-235	543.41	0.96	-15	146.22	.19
-240	527.32	0.96	-10	138.73	.19
-245	511.23	0.96	-5	131.22	.19
-250	495.14	0.96	0	123.73	.19
-255	479.05	0.96	5	116.22	.19
-260	462.96	0.96	10	108.73	.19
-265	446.87	0.96	15	101.22	.19
-270	430.78	0.96	20	93.73	.19
-275	414.69	0.96	25	86.22	.19
-280	398.60	0.96	30	78.73	.19
-285	382.51	0.96	35	71.22	.19
-290	366.42	0.96	40	63.73	.19
-295	350.33	0.96	45	56.22	.19
-300	334.24	0.96	50	48.73	.19
-305	318.15	0.96	55	41.22	.19
-310	302.06	0.96	60	33.73	.19
-315	285.97	0.96	65	26.22	.19
-320	269.88	0.96	70	18.73	.19
-325	253.79	0.96	75	11.22	.19
-330	237.70	0.96	80	3.73	.19
-335	221.61	0.96	85		.19
-340	205.52	0.96	90		.19
-345	189.43	0.96	95		.19
-350	173.34	0.96	100		.19
-355	157.25	0.96	105		.19
-360	141.16	0.96	110		.19
-365	125.07	0.96	115		.19
-370	108.98	0.96	120		.19
-375	92.89	0.96	125		.19
-380	76.80	0.96	130		.19
-385	60.71	0.96	135		.19
-390	44.62	0.96	140		.19
-395	28.53	0.96	145		.19
-400	12.44	0.96	150		.19
-405	-3.65	0.96	155		.19
-410	-19.76	0.96	160		.19
-415	-35.87	0.96	165		.19
-420	-51.98	0.96	170		.19
-425	-68.09	0.96	175		.19
-430	-84.20	0.96	180		.19
-435	-100.31	0.96	185		.19
-440	-116.42	0.96	190		.19
-445	-132.53	0.96	195		.19
-450	-148.64	0.96	200		.19
-455	-164.75	0.96	205		.19
-460	-180.86	0.96	210		.19
-465	-196.97	0.96	215		.19
-470	-213.08	0.96	220		.19
-475	-229.19	0.96	225		.19
-480	-245.30	0.96	230		.19
-485	-261.41	0.96	235		.19
-490	-277.52	0.96	240		.19
-495	-293.63	0.96	245		.19
-500	-309.74	0.96	250		.19
-505	-325.85	0.96	255		.19
-510	-341.96	0.96	260		.19
-515	-358.07	0.96	265		.19
-520	-374.18	0.96	270		.19
-525	-390.29	0.96	275		.19
-530	-406.40	0.96	280		.19
-535	-422.51	0.96	285		.19
-540	-438.62	0.96	290		.19
-545	-454.73	0.96	295		.19
-550	-470.84	0.96	300		.19
-555	-486.95	0.96	305		.19
-560	-503.06	0.96	310		.19
-565	-519.17	0.96	315		.19
-570	-535.28	0.96	320		.19
-575	-551.39	0.96	325		.19
-580	-567.50	0.96	330		.19
-585	-583.61	0.96	335		.19
-590	-600.72	0.96	340		.19
-595	-616.83	0.96	345		.19
-600	-632.94	0.96	350		.19
-605	-649.05	0.96	355		.19
-610	-665.16	0.96	360		.19
-615	-681.27	0.96	365		.19
-620	-697.38	0.96	370		.19
-625	-713.49	0.96	375		.19
-630	-729.60	0.96	380		.19
-635	-745.71	0.96	385		.19
-640	-761.82	0.96	390		.19
-645	-777.93	0.96	395		.19
-650	-794.04	0.96	400		.19
-655	-810.15	0.96	405		.19
-660	-826.26	0.96	410		.19
-665	-842.37	0.96	415		.19
-670	-858.48	0.96	420		.19
-675	-874.59	0.96	425		.19
-680	-890.70	0.96	430		.19
-685	-906.81	0.96	435		.19
-690	-922.92	0.96	440		.19
-695	-939.03	0.96	445		.19
-700	-955.14	0.96	450		.19
-705	-971.25	0.96	455		.19
-710	-987.36	0.96	460		.19
-715	-1003.47	0.96	465		.19
-720	-1019.58	0.96	470		.19
-725	-1035.69	0.96	475		.19
-730	-1051.80	0.96	480		.19
-735	-1067.91	0.96	485		.19
-740	-1084.02	0.96	490		.19
-745	-1100.13	0.96	495		.19
-750	-1116.24	0.96	500		.19
-755	-1132.35	0.96	505		.19
-760	-1148.46	0.96	510		.19
-765	-1164.57	0.96	515		.19
-770	-1180.68	0.96	520		.19
-775	-1196.79	0.96	525		.19
-780	-1212.90	0.96	530		.19
-785	-1229.01	0.96	535		.19
-790	-1245.12	0.96	540		.19
-795	-1261.23	0.96	545		.19
-800	-1277.34	0.96	550		.19
-805	-1293.45	0.96	555		.19
-810	-1309.56	0.96	560		.19
-815	-1325.67	0.96	565		.19
-820	-1341.78	0.96	570		.19
-825	-1357.89	0.96	575		.19
-830	-1374.00	0.96	580		.19
-835	-1390.11	0.96	585		.19
-840	-1406.22	0.96	590		.19
-845	-1422.33	0.96	595		.19
-850	-1438.44	0.96	600		.19
-855	-1454.55	0.96	605		.19
-860	-1470.66	0.96	610		.19
-865	-1486.77	0.96	615		.19
-870	-1502.88	0.96	620		.19
-875	-1518.99	0.96	625		.19
-880	-1535.10	0.96	630		.19
-885	-1551.21	0.96	635		.19
-890	-1567.32	0.96	640		.19
-895	-1583.43	0.96	645		.19
-900	-1599.54	0.96	650		.19
-905	-1615.65	0.96	655		.19
-910	-1631.76	0.96	660		.19
-915	-1647.87	0.96	665		.19
-920	-1663.98	0.96	670		.19
-925	-1680.09	0.96	675		.19
-930	-1696.20	0.96	680		.19
-935	-1712.31	0.96	685		.19
-940	-1728.42	0.96	690		.19
-945	-1744.53	0.96	695		.19
-950	-1760.64	0.96	700		.19
-955	-1776.75	0.96	705		.19
-960	-1792.86	0.96	710		.19
-965	-1808.97	0.96	715		.19
-970	-1825.08	0.96	720		.19
-975	-1841.19	0.96	725		.19
-980	-1857.30	0.96	730		.19
-985	-1873.41	0.96	735		.19
-990	-1889.52	0.96	740		.19
-995	-1905.63	0.96	745		.19
-1000	-1921.74	0.96	750		.19

FIGURE 3

Model 134EB Transient Response In Flowing Liquid Hydrogen

FIGURE 4

Low Temperature Calibration Test Equipment Setup

NOTES:

- ⊙ AVERAGE CURVE DATA
- ⊙ REC CALCULATED DATA
- ⊠ AGC CALIBRATION DATA
- △ AGC RECALIBRATION DATA

FIGURE 5

Graphical Presentation of Accuracy and Interchangeability Data

FIGURE 6

Model 134EB, S/N 2826, X-Ray

Digital Counts	Narrow Range-Code K -425 to -400°F		Intermed. Range-Code N -425 to -300°F		Wide Range-Code L -425 to +75°F	
	Temperature	Sensitivity	Temp.	Sensitivity	Temperature	Sensitivity
10000	-400.00°F	2.0 m°F/DC	-300.00°F	10.0 m°F/DC	+ 75.00°F	50.31m°F/DC
9000	-401.96°F	2.1 m°F/DC	-309.86°F	9.8 m°F/DC	+ 24.68°F	49.75m°F/DC
8000	-404.05°F	2.2 m°F/DC	-319.76°F	9.9 m°F/DC	- 25.06°F	49.15m°F/DC
7000	-406.31°F	2.4 m°F/DC	-329.74°F	10.0 m°F/DC	- 74.22°F	48.51m°F/DC
6000	-408.76°F	2.7 m°F/DC	-339.78°F	10.1 m°F/DC	-122.73°F	47.80m°F/DC
5000	-411.48°F	3.1 m°F/DC	-350.02°F	10.4 m°F/DC	-170.53°F	47.01m°F/DC
4000	-414.59°F	3.7 m°F/DC	-360.66°F	10.9 m°F/DC	-217.55°F	46.14m°F/DC
3000	-418.28°F	4.8 m°F/DC	-371.96°F	11.8 m°F/DC	-263.69°F	45.20m°F/DC
2000	-423.07°F	5.6 m°F/DC	-384.53°F	13.7 m°F/DC	-308.87°F	45.67m°F/DC
1000	-	-	-400.28°F	19.1 m°F/DC	-354.75°F	48.15m°F/DC
204	-	-	-423.00°F	55.5 m°F/DC	-	-
45	-	-	-	-	-423.00°F	253.97m°F/DC

FIGURE 7

Platinum Resistance Temperature Measurement System