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SACRAMENTO PLANT

CALIBRATION SYSTEM
FOR
CRYOGENIC TEMPERATURE TRANSDUCERS

Report 9271:2790

25 September 1964

MASTER

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LIQUID ROCKET OPERATIONS

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I. INTRODUCTION

To provide the NERVA test program with a temperature measurement system of sufficient accuracy to satisfy present and future requirements, a cryogenic temperature measuring system was designed and developed employing a platinum resistance thermometer (RTT) as the sensor. This system will be used, for example, to measure the liquid hydrogen pump inlet temperatures which determine the vapor pressure head for calculation of NPSH. Five (5) feet of pump vapor pressure head is represented by a liquid hydrogen temperature change of 0.054°F . In order to establish an adequate design for the NPSH parameter, a temperature measurement accuracy of at least $\pm 0.050^{\circ}\text{F}$ (0.028°K) is considered necessary. This system will be used in other areas of the NERVA Propellant Feed System and the Thrust Chamber Assembly where cryogenic temperatures must be accurately determined.

Calibrations of a reasonable accuracy have been performed in the past by comparison of the test thermometer with a standard thermometer from the National Bureau of Standards in the Aerojet single sensor helium cooled cryostat and the multi-sensor neon double dewar. However, the procedure is time-consuming, costly, and subject to inaccuracies introduced by failure or partial failure of the standard. To insure that the standard remains accurate, continual cross-checking with NBS must be accomplished. This method of calibration is not practical to obtain the large number of highly accurate instruments which will be required to complete this program.

The gaseous helium cooled cryostat used for precision platinum RTT calibration located in our Measurement Standards Laboratory was designed for operation from room temperature down to liquid helium temperatures. It is capable of calibrating one NERVA RTT at a time since its intended purposes were developmental testing of cryogenic sensors and calibration of standard type platinum resistance temperature standards (capsule type). This cryostat is about $\pm 0.03^{\circ}\text{F}$ accurate.

The multi-sensor neon double dewar located in our Transducer Laboratory uses the boiling point of liquid neon as the calibration point for up to five NERVA RTT's at a time. It was intended for mass calibration of RTT's until the NERVA cryostat capable of calibrating 18 RTT's at a time was operational. It's accuracy approaches $\pm 0.03^{\circ}\text{F}$.

A calibration system accuracy within 0.03°F can assure us of a calibrated RTT accuracy of 0.12°F based on a calibrator to RTT accuracy ratio of 1 to 4 which statistically is the lowest ratio with confidence. A more desirable accuracy ratio is 1 to 10. To assure ourselves that each selected NERVA RTT is accurate to $\pm 0.050^{\circ}\text{F}$ (i.e., output signal within 0.050°F of the standardized curve over the range of -425°F to -400°F) a calibration system accuracy of $\pm 0.012^{\circ}\text{F}$ (1 to 4 accuracy ratio) is minimum required and a calibration system accuracy of $\pm 0.005^{\circ}\text{F}$ (1 to 10 accuracy ratio) is desired to eliminate all doubt.

This report discusses the methods which will be used by AGC to provide accurately calibrated sensors in sufficient quantities for successful completion of the required test program.

II. SUMMARY

Three point calibration of up to 18 RTT's at one time to an accuracy of 0.028°K in the liquid hydrogen temperature region will be performed with this system. The calibration will be accomplished by immersion of the RTT's in cryogenic liquids which are at carefully and exactly predetermined temperatures in a multi-chambered cryostat.

The cryostat consists of four concentric steel vessels. The inner vessel will contain the cryogenic liquid for calibrating the RTT's. The space between this vessel and vessel 2 will be evacuated to 10 microns or less pressure. The next space will be filled with liquid hydrogen as a heat shield to provide thermal isolation to the calibration chamber. The outermost chamber will also be evacuated. Each vessel will be joined top and bottom by a flange custom designed for use in this application.

The instrumentation required to check out and support the cryostat operation includes 28 data channels, 19 for calibration of the sensors and 9 for control of the cryostat. Each of the 18 RTT's to be calibrated will have a constant current channel with an accuracy of 0.0028°K and there will be one pressure channel with 0.002 psi accuracy. The 9 control channels will consist of a pressure channel, two level sensors, two vacuum readouts, three channels of heater power, and a stirrer control. The three points for calibration will be the boiling points of liquid hydrogen and liquid neon, and the triple point of neon.

The establishment of the temperature in the cryostat will be accomplished by monitoring and controlling the vapor pressure of the liquid in the cryostat with a precision pressure gage.

The potentiometric method of measurement was chosen for readout of temperature transducers and a digital voltmeter will be used as the readout device. To eliminate thermal errors, the constant current excitation to the transducers is

reversed between two readings made of each data point. All data from the data channels will be printed and punched on IBM cards.

The cryostat will be stored in an assembled state. To perform a calibration, the cryostat will be partially disassembled until the ports for the installation of the transducers into vessel 1 are accessible. The transducers will be installed, the cryostat reassembled, and all chambers pressure tested. The chambers will be suitably purged, filled with liquid hydrogen or evacuated in alternate chambers, and vessel 1 pressure will be precisely monitored. The RTT's will then be calibrated at the boiling point of hydrogen. After purging and refilling with neon, the RTT's will be calibrated at the boiling point of neon and then at the triple point of neon. The vessels will be warmed during purging operations after the neon calibrations, the cryostat will be partially disassembled, the sensors removed, and the cryostat reassembled for storage.

III. TECHNICAL DISCUSSION

The calibration of platinum RTT's to a high degree of accuracy in the liquid hydrogen temperature region will be accomplished by immersion in carefully controlled baths of liquid hydrogen and liquid neon at their normal boiling points, and neon at its triple point.

The temperatures of these substances under these conditions is known precisely, as has been determined by the National Bureau of Standards in NBS Report Number R-293 and by E. R. Grilly of the University of California at the Los Alamos Scientific Laboratory in his report on "The Vapor Pressure of Solid and Liquid Neon". The temperature of liquid hydrogen at its normal boiling point is 20.39° Kelvin. The temperature of neon at its triple point (324.78 mm hg) is 24.544°K. Liquid Neon at its normal boiling point is 27.092°K.

Three point calibration of up to 18 RTT's at one time to an accuracy of 0.028°K will be accomplished by development and operation of the following equipment.

A. CRYOSTAT

Design of a cryostat to perform the above calibrations has been completed and fabrication will be initiated when the funds have been released.

The cryostat, as shown in Figure 1, will consist of four concentric vessels made of 304 Stainless Steel. The outer chamber, formed by the walls of vessels three and four, will be capable of sustaining a vacuum of less than 10 microns. The chamber formed by the walls of vessels two and three will hold liquid hydrogen and will be capable of withstanding pressures of up to 75 psia. The volume between vessels one and two will also be evacuated to less than 10 microns.

To maintain the least possible heat leak to the inner vessel, the number of direct connections from ambient sources has been kept to a minimum.

Design calculations to determine vessel wall and head thickness were made based upon the general requirements of Section VIII, Subsection A, Part UG of the ASME Code for unfired pressure vessels.

The type of flanges used to join the vessels was selected after the following considerations:

1. They shall be capable of easy disassembly.
2. They shall be light in weight to keep the support system small.
3. They shall not be easily susceptible to damage which would impair the gasket sealing ability.

The first flange considered was the Conoseal type. This flange is widely used by NERVA in its engine systems. It is light in weight and easily disassembled. However, it is expensive to fabricate because of the close tolerances and high finish required (32 microinches) on its sealing surfaces. The high finish makes it susceptible to damage, such as scratches, from repeated assembly and disassembly of the vessels. Damage of this nature would require refinishing or, if severe enough, possible replacement of the flange. It was because of the likelihood of damage that this type of flange was rejected.

The second flange considered was Grayloc. This type of flange is easily disassembled and isn't susceptible to damage. It is, however, large and heavy. The Grayloc company was contacted as to the availability of light weight flanges. They informed us that the nature of their flange sealing method prevented the use of light weight flanges. Another problem would be the physical size of the Grayloc Clamp. For example, a clamp for a twelve inch diameter pipe has an outside dimension of twenty-six inches. If this type flange were used the vessel could easily double and possibly triple in diameter. This made the flange prohibitive, and it was rejected.

The third type of flange considered and finally selected to be used, was custom designed per Appendix II of the ASME Code for unfired pressure vessels. This flange is light in weight, durable, and easily disassembled though there are more bolts to remove than on the other flanges mentioned. The flange is designed for a soft metallic gasket such as aluminum.

The inner support system for the vessels is of thin wall tubing which also serves as the vent line for the inner vessel. Stabilizers of teflon are attached to the bottom of each vessel to resist any side loading that may occur. The stabilizers will not come in contact with one another and will not provide a heat path into the vessels.

A multi-layer super insulation has been developed by AGC and could be made available for insulation of the chamber between the third vessel and the outer vessel. This insulation, in conjunction with a high vacuum, would furnish the best possible insulation for the liquid hydrogen intermediate chamber, since the vessels are to be dismantled after each test and powdered insulation would not be practical.

Temperature gradients within the cryogenic bath in the inner chamber will be controlled by the installation of a copper block and the possible use of a mechanical or electrical thermal mixing device.

Provisions will be made for the mounting of eighteen platinum RTT's. Initially, six sensors (spaced in such a way that the data obtained will determine the stability and gradient structure in the calibration dewar) will be used to check the operation of the cryostat itself and twelve test sensors will be calibrated. Two of the six checkout sensors will have resistance vs temperature characteristics similar to the test sensors, but will have NBS calibrations. The data from these two sensors will be used to verify, within the accuracy of the NBS

calibrated elements, that the established temperature is as expected in regards to both accuracy and reproducibility. After it has been established that the cryostat performs as expected, sixteen test sensors will be installed per calibration and two NBS calibrated sensors will normally remain in the cryostat.

B. INSTRUMENTATION

The instrumentation required to check out and support the cryostat operation has been designed and built and is ready for installation in the test complex. This instrumentation can be divided into two types: (1) those functions relating to data required for calibration of the RTT's and (2) those functions concerned with the operation of the cryostat.

Type (1) instrumentation consists of 18 channels for potentiometric RTT measurements with an accuracy of $\pm 0.0028^{\circ}\text{K}$ or 0.005°F , and one channel pressure with ± 0.002 psi accuracy.

Type (2) instrumentation includes one channel pressure with $\pm 1\%$ accuracy, two channels of continuous level sensing, two channels vacuum readout, three channels heater power, and one channel stirrer control.

The transducers to be calibrated will be verified at three points: the boiling point of liquid hydrogen (20.39°K or -422.97°F); the triple point of liquid neon (24.544°K or -415.49°F at 324.78 mm hg); and the boiling point of liquid neon (27.092°K or -410.90°F). The temperature transducers at the three calibration points normally exhibit resistance as follows:

Temperature	Transducer Resistance
-422.97°F	6.701 ohms
-415.49°F	12.413 ohms
-410.90°F	17.280 ohms

The change in resistance in these temperature regions for a change in temperature of 1°F slope is as shown below

-422.97°F	0.612 ohms/°F
-415.49°F	0.944 ohms/°F
-410.90°F	1.202 ohms/°F

Since a test stand instrumentation system accuracy of 0.028°K (0.050°F) or better is desired, the RTT should be calibrated to an accuracy 10 times better than this, or 0.005°F. Because the smallest slope occurs at the -422.97°F calibration point, the calculations will be based on a slope of 0.612 ohms/°F. A change in temperature will then equal a change in resistance (ΔR) of 0.003 ohms. The system with which these RTT's are designed to operate provides a constant excitation current of 2 ma. The calibration system will provide this same excitation.

A ΔR of 0.003 ohms at a current of 0.002 amperes will produce an output change (ΔE) of:

$$\Delta E = I \Delta R$$

$$\Delta E = (2 \times 10^{-3})(3 \times 10^{-3})$$

$$\Delta E = 6 \times 10^{-6} \text{ Volts}$$

The voltage from which this change must be detected will then equal

$$E = IR$$

$$E = (2 \times 10^{-3})(6.70)$$

$$E = 0.0134 \text{ Volts}$$

This type of resolution is easily obtainable with an electronic digital voltmeter which can provide data suitable for computer entry.

Establishing the temperature of the liquid in the cryostat may be accomplished in several ways:

(1) By the use of an I&N Platinum probe calibrated by NBS and read out on an NBS certified I&N Mueller G-2 Bridge.

(2) By the use of a Rosemount 134DJ element calibrated by NBS and read out in a potentiometric circuit on a digital electronic voltmeter or on an NBS certified I&N Mueller G-2 Bridge.

(3) By the use of a pressure transducer or manometer reading of the calibration fluid vapor pressure.

Methods (1) and (2) are limited by the accuracy to which they are calibrated by NBS. Method (3) is limited only by the definition of the calibration point itself, making it the most acceptable technique.

The normal boiling points of liquid hydrogen and liquid neon, and the triple point of neon, will be defined by the NBS and Grilly temperature values. The limit of error in the definition of these points will be the calibration accuracy of the pressure transducer with which the vapor pressure is measured (typically ± 0.002 psi).

The slope of the vapor pressure vs temperature curve of hydrogen at its normal boiling point is $2.3 \text{ psi}/^{\circ}\text{F}$. This means that the temperature of the hydrogen bath will be known to within $\pm 0.001^{\circ}\text{F}$. Neon has a slope of $2.9 \text{ psi}/^{\circ}\text{F}$ so that both neon bath temperatures will be known to the same order of magnitude.

The pressure transducer selected for monitoring and controlling the vapor pressure of the liquid in the cryostat is the Texas Instruments Fused Quartz precision pressure gage. This unit is a servo controlled fused Quartz Bourdon Tube device using an optical detector. It is capable of repeatability to 0.00010 psi in making measurements at atmospheric pressure. This unit contains both its own visual readout and an electrical output suitable for recording with the instrumentation system.

The potentiometric method of measurement was chosen for readout of temperature transducers due to its advantages over bridge networks. Because of the low level signal required to achieve the desired resolution, the Dymec 2401 Integrating Digital Voltmeter was chosen as the readout device. Previous experience with these units in other applications has proven good long-term stability and repeatability. The current loop of the potentiometric system is driven by a New Jersey Electronics constant current power supply which regulates to 0.005%. (See block diagram Figure 2). The potential leads from each transducer gain access to the digital voltmeter through a step switch scanner. To eliminate thermal errors the constant current excitation to the transducers is reversed between two readings made of each data point. Comparison of the normal and the reverse readings will indicate the magnitude and polarity of the thermal emf. The stability of the measurement system, will be monitored by scanning a pair of standard cells for voltage reference, a standard resistor for current reference, and the pressure transducer for vapor pressure indication. All data from the data channels will be printed and punched on IBM cards by a 526 summary card punch in a format for computer entry. The estimated system error will be ± 3 microvolts which will be equivalent to 0.001 ohm or 0.002°F error for the RTT. This is well within the required measurement accuracy of 0.005°F.

The control functions of the instrumentation console have been designed with visual indication capabilities for the benefit of the cryostat operator. Following are the control functions:

- (1) 1 channel pressure - 1% accuracy:

This channel is used to monitor the vapor pressure of the liquid hydrogen between vessels 2 and 3. It serves to establish the temperature of the fluid within this region and to provide warning in case of excess pressure build-up.

(2) 2 channels continuous level sensing:

These units will indicate the depth of liquid to assure that the RTT's being calibrated are submerged in the liquid in vessel 1 and that vessel 2 is completely surrounded by liquid hydrogen.

(3) 2 channels vacuum readout:

Alphatron nuclear ionization vacuum gages were chosen for monitoring the vacuums between vessels 1 and 2 and between vessels 3 and 4, which will be maintained at a level of 10 microns or less during cryostat operation. This type of gage was selected to prevent the possibility of igniting an explosive mixture of hydrogen gas should it leak into the vacuum chambers.

(4) 3 channels heater power:

Variable AC voltages at 10 amperes of current are provided for electric heaters mounted within the cryostat. These are used for a more rapid return to ambient temperatures before disassembly and to prevent ice build-up in vent lines.

(5) 1 channel stirrer control:

In order to minimize temperature gradients within vessel 1 a solenoid stirring device will be placed within the calibration bath.

C. ESTABLISHMENT OF CALIBRATION TEMPERATURES

When the cryostat is not in use, it will be stored in an assembled state. Dismantling brackets will be kept with the cryostat. To prepare the cryostat for operation, it will be disassembled as follows.

The flange sealing the top of the cryostat to the lower portion of vessel 4 will be disassembled by removing the bolts. The rest of the cryostat will be lifted so that the flange joining the two parts of vessel 3 can be attached to the rim of the lower portion of vessel 4, using the extended bolts on the vessel 3

flange and the dismantling brackets. After vessels 3 and 4 are attached in the raised position, the top part of the vessel 3 flange can be separated from the bottom part, leaving the lower portions of vessels 3 and 4 connected, and the rest of the cryostat loose from vessel 3. This part of the cryostat will now be raised and the same sequence of operations can be performed between vessels 2 and 3 and the remaining portion of the cryostat. The remainder of the cryostat and all of vessel 1 can then be raised and attached in the raised position to the bottom portion of vessel 2. Figure 3 illustrates the steps necessary to dismantle the cryostat.

At this point, the RTT's may be removed and reinstalled in vessel 1 without breaking the seal established at the flange connecting the bottom and top portions of vessel 1. Each time the cryostat is dismantled all gaskets will be replaced with new ones. The studs will be torqued to a specified value to insure equal gasket loading upon reassembly. After the RTT's have been installed, vessel 1 will be leak checked with a mass spectrometer helium leak detector. After each vessel is reassembled into the unit, a leak check will be performed.

Prior to filling the space between vessels 2 and 3 with liquid hydrogen the spaces between vessels 1 and 2, and between 3 and 4 will be evacuated to 10 microns or less pressure. After the spaces have been evacuated, vessel 1 and the space between vessels 2 and 3 will be evacuated to 1.5 psia or less. Next, both of these spaces will be brought up to atmospheric pressure by the introduction of helium into the system. This cycle will be repeated to purge the vessels and system. After purging, both the calibration and shield spaces will be filled with liquid hydrogen until the temperature of each vessel has stabilized at $-423.0 \pm 1^\circ\text{F}$. When the temperature has stabilized, a pressure of 760 mm Hg will be established in vessel 1 with the Texas Instruments precision pressure gage and a pressure controller and control valve. The voltage drop across one of the reference RTT's will be

monitored to determine when stability has been attained. At this time the test RTT's will be calibrated semi-automatically by the Data System at the boiling point of liquid hydrogen, -422.97°F . Following the calibration of the test RTT's at the normal boiling point of hydrogen, vessel 1 will be purged of all liquid hydrogen with helium. The vessel will then be run through two vacuum and gaseous neon pressure cycles. The heaters in vessel 3 will be turned on until the hydrogen temperature has stabilized at $-410.9 \pm 1^{\circ}\text{F}$ with a corresponding vessel pressure of 73 psia. Liquid neon will then be introduced into vessel 1 until the temperature has stabilized at -410.9°F . Then using the Texas Instruments precision pressure gage and a pressure controller and control valve, a pressure of 760 mm Hg will be established in vessel 1. When stability has been attained, the test sensors will be calibrated semi-automatically by the data system at the established normal boiling point of neon, -410.904°F .

To establish the triple point of neon, the shield space will be vented and refilled as required. The heaters in vessel 3 will then be turned on until the temperature has stabilized at $415.5 \pm 1^{\circ}\text{F}$ and the pressure is at 43 psia. At this time the pressure in vessel 1 will be reduced to 6.2819 psia (324.78 mm Hg). The three phases of neon (liquid, solid, and gas) will attain equilibrium at 6.2819 psia and -415.49°F . The RTT's will then be calibrated semi-automatically with the data system.

After the calibration of the RTT's has been completed the liquid neon remaining in the cryostat will be transferred back to storage. The vacuum spaces (between vessels 1 and 2 and between vessels 3 and 4) will be brought up to atmospheric pressure and vessel 1 and the space between 2 and 3 will be purged with N_2 . During purging the heaters will be turned on to expedite the warming of the vessels so that they may be readily disassembled.

The flow diagram is shown in figure 4.

IV. CONCLUSIONS

The equipment described in this report will be capable of calibrating eighteen RTT's to an accuracy of $\pm 0.050^{\circ}\text{F}$ in the temperature range of liquid hydrogen. The three-point calibration described above will take approximately two eight-hour shifts from beginning of assembly of the cryostat to final disassembly of the cryostat after completion of the calibration. With eighteen units in calibration, the time per unit is estimated at eight hours compared with twelve hours per unit with existing equipment. The new system will have a higher reliability and greater accuracy in addition to its time-saving features.

- ① CONTINUOUS LIQUID LEVEL SENSOR -
VESSEL NO. 3 - LIQUID HYDROGEN
- ② INSTRUMENTATION JUMPER CABLE
- ③ CONNECTING CABLE TO INSTRUMENTATION
CONSOLE
- ④ HERMETICALLY SEALED FEEDTHRU
CONNECTORS FOR INSTRUMENTATION
AND CONTROLS
- ⑤ CHROMALOX HEATING ELEMENT -
LIQUID HYDROGEN - VESSEL NO. 3
- ⑥ CHROMALOX HEATING ELEMENT -
LIQUID NEON - VESSEL NO. 1
- ⑦ CONTINUOUS LIQUID LEVEL SENSOR -
LIQUID NEON - VESSEL NO. 1
- ⑧ STIRRING SOLENOID AND IMPELLER -
LIQUID NEON - VESSEL NO. 1
- ⑨ STIRRER AND HEATER CONTROL CABLE
CONNECTOR
- ⑩ PROBE UNDER TEST
- ⑪ TRANSDUCER JUMPER CABLE

LEGEND	
	VACUUM
	LH ₂
	LN ₂

LIQUID NEON CRYOSTAT
SECTION VIEW
FIGURE 1

LIQUID NEON CRYO STAT
DATA SYSTEM
FIGURE 2

DISMANTLING BRACKET
INSTALLATION SEQUENCE

STEP 1

STEP 2

STEP 3

STEP 4

NOTE: TO ASSEMBLE REVERSE SEQUENCE.

CRYOSTAT ASSY/DISASSY
SEQUENCE

FIGURE NO.3

CRYOSTAT PIPING
FLOW DIAGRAM
FIGURE NO. 4