NASA CR-72055

FACILITY FORM 602

N66 38106	
(ACCESSION NUMBER)	(THRU)
57	1
(PAGES)	(CODE)
CR-72055	14
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

NINTH QUARTERLY REPORT

PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES

Anthony J. Cassano

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 2.50

Microfiche (MF) .50

ff 653 July 65

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-4170

August 1, 1966

Consolidated Controls Corporation

Bethel, Connecticut

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NASA CR-72055
CCC - 564

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Technical Management
NASA - Lewis Research Center
Space Power Systems Division
J. P. Couch

Prepared by:
Anthony J Cassano
Anthony J. Cassano
Research Physicist

Approved:
R. E. Engdahl
R. E. Engdahl
Manager, Advanced
Research & Development

CONSOLIDATED CONTROLS CORPORATION
Bethel, Connecticut

FOREWARD

The major contributors to this development program are Mr. R. E. Engdahl, Mr. Anthony Cassano, Mr. George Garrity, Mr. David Mends and Mr. Philip Tubman.

ABSTRACT

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Continuing development of a thermionic diode pressure transducer for liquid metal applications is described. Final experimental results on the transducer test models using the electrical signal conditioning breadboard indicate an expected sensor operating life of more than 2500 hours. Successful operation of the heater control loop of the signal conditioning system was achieved by using a thermocouple input in place of the secondary reference collector current. Designs for the 80 psia and ± 5 psid transducers and the electrical signal conditioning system have been finalized and fabrication work is in progress. Implementation of a test program to demonstrate the operational characteristics of the transducers is underway. The test program has been detailed and construction of the necessary test facilities is well along. Study and evaluation of the metal-ceramic seal techniques developed for use in the transducers continued with the completion of a potassium compatibility test. AUTHOR

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1.0 Introduction

The objective of this program is to develop pressure transducers which can be used in advanced Rankine Cycle space power systems using liquid metals such as mercury, sodium, potassium and other alkali metals as working and heat transfer media at elevated temperatures. Accurate pressure measurements in the high temperature liquid, vapor, and two phase streams are required for research, design and control purposes. In addition, space flight requires lightweight systems capable of enduring long periods of unattended operation.

Liquid metal pressure measurements at elevated temperatures pose many design problems demanding the best from available materials. To establish a firm design base for the transducer equipment, four diaphragm materials and two transducer systems were chosen for evaluation. The selected transducer system using a thermionic diode sensor is being developed for use as either ground or flight hardware for measuring absolute and differential pressures. The absolute and differential pressure instruments are being developed for full scale ranges of 80 psia and ± 5 psid respectively.

2.0 Summary

Testing continued on transducer test units T-6 (FS-85 pressure capsule) and T-7 (C-129Y pressure capsule). Substantial improvement in expected operating life was indicated by the fact that T-6 and T-7 accumulated 2700 and 2000 hours of operation respectively.

The electrical signal conditioning breadboard was tested with both T-6 and T-7. Satisfactory emitter temperature control was demonstrated by stabilizing the emitter temperature at 2100°F, within 10°F, over an ambient temperature range of 1000 to 1800°F. Control was achieved by using the output of the W-5Re/W-26Re thermocouple mounted on the emitter housing as the input to the heater control loop.

Final designs for the 80 psia and ± 5 psid pressure transducers and the electrical signal conditioning system were completed. Fabrication work is underway with emphasis being placed on preparation and assembly of the pressure capsules and sensors.

A comprehensive test program to evaluate the performance of the pressure transducers has been developed. Two time tests are planned; 500 hours and 2000 hours. One absolute and one differential pressure transducer will be tested for 500 hours, after which they will be used for testing in an operational liquid metal loop. The second set of transducers will undergo the 2000 hour test and be used as back-up units for the loop testing. Additional test chambers and pressure cycling systems are needed for the testing and their preparation is well underway.

Potassium compatibility testing of the metal-ceramic seal assemblies was completed. There were no visible signs of failure. The test assemblies have been shipped for removal of the potassium prior to preparing the seals for metallographic inspection and evaluation.

3.0 Thermionic Diode Pressure Transducer Test Units

At the conclusion of the previous report period (Reference 1), transducer test units T-6 (FS-85 pressure capsule) and T-7 (C-129Y pressure capsule) had been in continuous operation at temperatures up to 1800°F for about 1375 and 1125 hours respectively. Testing performed during the report period increased the total hours of operation to 2700 (T-6) and 2000 (T-7).

The main objectives of the test program were to determine the effect of the secondary reference collector on operating life and to check the operation of the heater control loop of the electrical signal conditioning system. Test data did not indicate any definite effect of the secondary reference collector on operating life. However, tests performed with the signal conditioning breadboard showed that the secondary reference collector could not be used to accurately control the emitter temperature.

Originally it was intended to have the secondary reference collector current serve as an indication of the continuous operation of the thermionic diode sensor in the space-charge limited mode. Initial tests run on the signal conditioning breadboard with T-7 showed that the secondary reference collector current actually consisted of two components. The first component was the expected current flowing between the emitter and the secondary reference collector. The second component was a current flowing between the reference collector and the secondary reference collector due to the difference in the voltages applied to the two elements. While the voltage applied to the secondary reference collector was constant, the voltage applied to the reference collector varied. Its value was determined not by emitter temperature, but by the constant sum-of-the currents ($i_a + i_r$) condition. This second component therefore prevented accurate operation of the heater control loop with the secondary reference collector current as the input.

Rather than undertaking a re-design to eliminate the current between the reference collector and the secondary reference collector, the testing was continued using the output of the W-5Re/W-26Re thermocouple mounted on the emitter housing (Reference 1, page 6) as the heater control loop input. Use of this thermocouple to maintain a 2100°F emitter temperature also assured continuous space-charge limited operation since the thermionic sensor operated at supply voltages for which the onset of emission-limited conditions occurs at temperatures well below the 2100°F level.

Using test transducer T-7, operation of the heater control loop was checked with the W-5Re/W-26Re thermocouple as the input. The emitter temperature was programmed to 2100°F and held within 10°F over an ambient temperature range of 1000 to 1800°F.

Unfortunately, test transducer T-7 developed an open-circuit heater shortly after the emitter temperature tests. Examination of the T-7 sensor showed that the open circuit occurred inside the casting in the emitter housing, making repairs impossible. In all, T-7 had accumulated about 2000 hours of operation. The open-circuit appeared to result from an inadvertant heater current surge which took place while adjustments were being made on the signal conditioning breadboard.

The signal conditioning breadboard was then connected to test transducer T-6 and the emitter temperature tests repeated. The heater control loop achieved satisfactory emitter temperature control (at 2100°F within 10°F) over an ambient temperature range of 1000 to 1800°F. At that point, it was decided to suspend testing because the emission levels of the T-6 sensor had decreased from about 30 ma to less than 15 ma. This was not surprising since T-6 had been removed from its test chamber twice for adjustments. The resultant handling and exposure to atmosphere most certainly had a detrimental effect on the emission capabilities of the sensor. In all, T-6 accumulated about 2700 hours of operation.

4.0 Thermionic Diode Pressure Transducer Design

During the report period, the designs for the 80 psia and ± 5 psid transducers were completed and fabrication work was started on the pressure capsules, thermionic diode sensors and housing components. The designs for the pressure transducers were established around the use of a double housing concept; a main housing of Nb-1Zr surrounded by an outer shell of L-605 cobalt-based alloy. The thermionic sensor is installed in the low vapor pressure Nb-1Zr and the outer shell of L-605 allows the transducer to operate in air. The space between the Nb-1Zr and the L-605 will be evacuated to prevent oxidation damage to the Nb-1Zr.

Figure 1 presents a 2:1 scale sketch of the absolute pressure transducer design. Figures 2 and 3 are 2:1 scale sketches of the differential pressure transducer design. Two of the main design problems, the pressure capsule and the differential beam assembly, have been discussed in detail in previous reports. Reference 2 presents the design calculations and fabrication procedures for the absolute and differential pressure capsules. References 3 and 4 contain the design calculations and experimental results applicable to the differential beam assembly.

Referring to Figures 1 and 2, all points exposed to the liquid metal environment will be electron-beam welded. The main welds in this category are:

1. the pressure capsule assembly welds,
2. the pressure capsule/main housing weld,
3. the welds connecting the Nb-1Zr/L-605 transition piece to the main housing and the outer shell,
4. the main housing/housing cover weld and
5. the differential beam assembly and installation welds.

The final closure welds will not be exposed to the liquid potassium environment and may be either electron-beam or heliarc type. It is planned to use the heliarc weld since this type of weld can be done by this company. The main welds in this category are:

1. the sensor vacuum shell assembly welds,
2. the thermal expansion diaphragm assembly weld,
3. the swaged cable assembly and installation welds and
4. the L-605 outer shell assembly welds.

The use of a Nb-1Zr housing inside an L-605 outer shell required the use of a pressurization connection weldable to both Nb-1Zr and L-605 (Figures 1 and 2). The transition originally designed for this purpose used a tapered slug of L-605 forged into a tapered cavity in a piece of Nb-1Zr. Problems encountered with the temperature and pressure requirements of the forging process made a re-design necessary. While the transition piece dimensions were not changed, a vacuum diffusion joint will be used between the Nb-1Zr and L-605. Several test assemblies have been successfully fabricated and in all cases, the joint has been found to be sound.

A Nb-1Zr/Lucalox seal is used to seal the thermionic diode sensor chamber and preserve the high-vacuum environment. The sensor vacuum shell is made up of Nb-1Zr components, including a vacuum pinch-off tube. For the absolute pressure transducer, the pinch-off tube is inserted in the sensor vacuum shell (Figure 1). The differential pressure transducer has the pinch-off tube inserted into the main housing (not shown in Figure 2, but in Figure 3).

A Nb-1Zr thermal expansion diaphragm was incorporated into the design to absorb stresses set up by the difference in linear thermal expansion between the L-605 outer shell and the transducer Nb-1Zr inner structure.

The outer structure of the transducer, up to the swaged cable assembly, is L-605. All assembly welds will be heliarc type of similar metals, resulting in maximum reliability. The transition from the Nb-1Zr inner structure is made above the thermal expansion diaphragm with an L-605 tubular section. The Nb-1Zr/L-605 vacuum diffusion joint mentioned previously is used to accomplish the transition.

A design was developed for the electrical cable and connector set-up used to deliver power to the transducer and connect it to the electrical signal conditioning system. The cable is of a swaged design about 2 feet long. The internal insulation is a two-piece crushable magnesia ceramic. One piece is tubular and the other is shaped like a sprocket. The wires are placed in the sprocket grooves and the tubular section is slipped over the sprocket assembly. The outer cable shell is stainless steel tubing to give the cable a certain amount of flexibility needed for loop installation. The cable is internally pressurized with argon and a metal-ceramic seal is used at both ends. Figure 4 is a pictorial section of the end of the swaged cable. A weld connection is made to the transducer while a minaturized multi-pin connector at the cold end of the cable allows the use of a standard design flexible cable to the signal conditioning equipment.

Prior to the start of fabrication of the transducers, tests performed on assemblies configured according to the actual transducer parts have demonstrated the feasibility of the various welds and metal-ceramic joints used in the design.

Fabrication was started on the four transducers. Figures 5 and 6 show two views of the first absolute and differential pressure transducer main housings. The pressure ports are noted along with the capsule installation port and the cavity into which the thermionic sensor is inserted.

Along with the main housings, work was concentrated on the pressure capsules (sensing element) and the thermionic diode sensors. At the conclusion of the report period, the first differential transducer was near completion and preparations were being made to install the unit into the test chamber for the pre-test adjustments (see Appendix A). Problems encountered in the grinding and electron-beam welding of the pressure capsules delayed work on the absolute pressure transducers. Work was done to improve the grinding procedures for the W-25Re capsule material and refine the electron-beam welding techniques.

5.0 Thermionic Diode Pressure Transducer Test Program

Of the four pressure transducer systems being built, two systems (one absolute and one differential) will be tested for 500 hours, after which they will be installed in an operating liquid metal loop for further evaluation. The other two transducers will be tested for 2000 hours, after which they will be used as back-up units for the loop test program. The time tests are designed to compare actual operating characteristics of the pressure transducers with the following optimum criteria.

1. The absolute pressure transducer will have a range from 0 to 80 psia. The differential pressure transducer shall have a range from -5 to +5 psid.
2. The transducers will operate at ambient and fluid temperatures up to 1800°F
3. The transducers will have an accuracy of at least 5% of full scale. The accuracy shall include the effects of linearity, hysteresis, sensitivity, change with temperature, zero shift (other than that caused by temperature), dynamic response characteristics up to 100 cps, and repeatability. The zero shift with temperature shall not exceed 0.001% of full scale per degree.

4. The transducers will have an operating life of 2000 hours at maximum fluid temperature with pressure cycling or 40,000 pressure cycles, whichever is reached first.

5. The transducers will have a frequency response of at least 100 cps to fluid pressures. The lower limit is preferably dc.

Appendix A contains the test schedule for the 500 and 2000 hour tests. To implement this program, additional facilities, aside from the existing Vacuum Test Facility, are necessary.

To accommodate one of the differential pressure transducers, the compatibility test chamber (Reference 4, figures 6 and 7) was modified following completion of the metal-ceramic seal compatibility testing (see Section 7.0). Electrical and thermocouple feedthroughs along with pressure and vacuum connections were added to the vacuum flange head. A second test chamber, similar in size and construction to the compatibility test chamber, was fabricated and installed on the Vacuum Test Facility. Initial pump-down and bake-out was started. The absolute pressure transducers will be tested in two of the original chambers of the Vacuum Test Facility.

A design was developed for the pressurization systems needed for testing the transducers. Four systems will be built, one for each transducer. All the systems have a pressure cycling capability of 20 cycles per hour. A timer-actuated solenoid valve is used to pressurize the pressure capsule for 1 1/2 minutes, followed by evacuation of the pressure capsule for 1 1/2 minutes (3 minute pressure cycle). The valving allows connection of a pressure gauge and a room-temperature transducing cell into the system to monitor the pressure and obtain an electrical signal for the X-Y recorder. In addition, the two systems for testing the differential pressure transducers are valved so that the pressure and vacuum ports can be switched, allowing pressurization of either side of the pressure capsule. Fabrication work was well under way at the conclusion of the report period. Completion of the additional test facilities is expected about the middle of July.

6.0 Transducer Signal Conditioning

During the report period, design work on the electrical signal conditioning system was completed. The system design is based on the block diagram presented in Reference 3. Fabrication and assembly work was started on the first of three systems planned for construction. A breadboard of the signal conditioning system shown in Figure 7 was assembled and tested with T-6 and T-7. Before discussing the breadboard test results, a brief description of the operation of the control system will be given.

Input power to the conditioning equipment is supplied via a transformer (T1), which in conjunction with the full wave bridge circuit produces an unregulated 30 VDC operating potential. The control system is comprised of four basic modules, part numbers TA 1913, TB 1913, TD 1913 and TE 1913.

Module TA 1913 contains a series [redacted] regulator (Q101 and Q102), a voltage reference (CR 101), difference amplifier (Q103), and a constant volt/second device (L101). Turn-on current for the series regulator is supplied by R101 and feedback from potentiometer (R103) sets the regulation point. In this manner a regulated 15 VDC potential is supplied to the volt/second device. If transistors Q104 and Q105 are considered as switches, the operation of this circuit is quite easily understood. If Q104 is saturated, the regulated potential will be impressed across one-half of the primary winding, i.e. (3 and 4).

Since the applied voltage is proportional to the time rate of change of flux in the core, a constant rate of flux change will induce a voltage into windings 5 and 6 causing a total primary voltage of twice the supply voltage. This potential is seen by the collector/emitter of Q105 which is cut off during this period. When the flux has changed from -ø max to +ø max, the core will saturate and the field across winding 3 and 4 will collapse. This action will reverse the process, turning on Q105, cutting off Q104, and causing a flux change from +ø max to -ø max. The period of oscillation obtained with this system is about 650 cps.

In this manner, six isolated, regulated power supplies are generated for the three additional modules in the signal conditioning system.

Module TB1913 contains a current regulator to maintain a constant sum-of-the-currents in the thermionic diode, and a computing amplifier to produce an output signal which is proportional to the transducer pressure. The current regulation functions are performed by Q201, Q202 and Q203 and the reference level is established by CR 213. The voltage drop across R206 and R207 due to load current, is compared to the voltage developed across the reference diode and the difference is applied to the base emitter loops of the regulation transistors. The current regulator is essentially a variable resistor inserted in series with a voltage source and load. Because the transconductance of the circuit is high, any change in load impedance will cause an almost equal and opposite change in the regulator resistance, thus maintaining an essentially constant output current. Two sensing resistors, R212 and R217, are inserted in series with the reference and active collectors of the thermionic diode and serve as signal sources to detect the $(i_a - i_r)$ current which is proportional to system pressure. The initial unbalance in the two collector currents of the thermionic diode is nulled by adjusting R217 under zero pressure conditions.

The computing amplifier (LA 201) is connected to operate in a differential mode where $e_1 = i_a(R217)$ and $e_2 = i_r(R212)$ are the signal voltages, e_f is the feedback voltage and e_o is the output voltage. The following expressions relate the e_1 and e_2 signal voltages to the circuit parameters.

$$i_{R215} = \frac{e_1 - e_f}{R215} = \frac{e_f - e_o}{R216}$$

$$e_o = e_f \left[\frac{1}{R216} + \frac{1}{R215} \right] - \frac{R216}{R215} e_1$$

$$e_f = \frac{R205}{R214 + R205} e_2$$

Substituting and rearranging yields the following expression for output voltage.

$$e_o = \frac{R205}{R214}\left[\frac{R215 + R216}{R214 + R205}\right] e_2 - \frac{R216}{R215} e_1$$

When R214 = R215 and R205 = R216, the output voltage becomes of the following form

$$e_o = \frac{Ro}{Ri}(e_1 - e_2)$$

The output voltage represents the current unbalance in the collectors of the thermionic diode sensor multiplied by the gain of the amplifier.

The above analysis neglects the effect of the input current from the modulus amplifier, which will be discussed when that amplifier is considered.

The TD1913 module consists of a single ended amplifier, isolation amplifier and control circuitry for the thermionic sensor heater. The input signal for the heater circuit is derived from the W-5Re/W-26Re thermocouple located on the emitter housing.

The thermocouple signal is a 1 to 22 mv signal which corresponds to 100°F to 2220°F emitter temperature. This signal is amplified by LA 301 ($A_v = 325$) and coupled to the isolation amplifier.

Using standard operational terminology, the output voltage may be determined as follows:

$$e_o = \frac{Ro}{Ri} \; e_i$$

$$e_o = \frac{220 \times 10^3}{6.80 \times 10^2} \; (21.0 \times 10^{-3})$$

$e_o \cong$ 6.5VDC @ 2100°F emitter temperature.

Isolation is required in the heater control circuit because the emitter thermocouple is at emitter potential which is programmed when pressure is applied to the system.

The output voltage of LA 301 is coupled to Q306, an emitter follower which performs an impedance matching function.

The secondary voltage of L301 is compared with a reference voltage supplied by CR 301 and the difference controls the base current of Q301.

As the emitter temperature increases above 2100°F, the transformer secondary voltage increases and shunts current from the base of Q1 which reduces the current in the heater. As the emitter temperature decreases, less voltage appears in the secondary winding and the control transistor supplies more current to the heater.

Current limiting of the heater is accomplished by connecting the collector of Q303 to a low-voltage regulated potential which clamps the heater at 12VDC when over-program conditions exist. This feature is intended to limit the current surge through the heater when the system is energized at room temperature.

The initial efforts during breadboard testing were devoted to analyzing the individual control functions and determining the interaction between them. As a result of these efforts, the probe current approach to detecting the emitter temperature was found to be inadequate. When pressure was applied to the active collector, the net probe current was found to be inversely proportional to the diode potential and directly proportional to the probe potential. This characteristic prevented the use of the probe for steady state and perturbed pressure measurements (see Section 3.0). The problem was resolved by using the W-5Re/W-26Re thermocouple on the emitter housing to sense the emitter temperature.

Some early emitter temperature data, taken on test units T-6 and T-7, are shown in Figure 8. The reason for the shape to the T-7 curve is not known and T-7 reached its end of life before it could be determined. The T-6 curve is characteristic of approximately twenty plots which were run on this unit and modifications to the breadboard during the time accounted for minor variations in the curve. Figure 9 shows the control characteristic of the heater loop with the first differential transducer (completed and installed after the conclusion of the report period) and indicates a ± 10°F emitter temperature change when the chamber varies over a 800°F range. While Figure 9 presents data obtained after the report period, it is presented here as preliminary data so that correlation with Figure 8 may be obtained.

Figure 10 is typical of the input/output characteristic of both the T-6 and T-7 test units when subjected to input pressure. In this case, the input pressure was limited to 50 psia in order to produce a 0.001 inch travel of the active collector.

The breadboard control circuit did not have a potentiometer in the (i_a-i_r) amplifier and as a result the null voltage could not be eliminated. (An approximate null was achieved by using fixed resistors).

The stability of the emitter temperature with line voltage variation is shown in Figure 11 and is fairly representative of all the test transducers which have been tested to date.

Investigation into the drift characteristics of the transducer is continuing to determine if a cold junction is required in the control system. The present test configuration has a continuous tungsten/rhenium thermocouple system which is terminated at the top of the test stand and is not representative of the final configuration.

In the final units, two metal-ceramic seals will introduce a change in the materials of the thermocouple system and may introduce some contact potentials in series with the emitter readout thermocouple. This problem is now under investigation. At the present time, the drift characteristic of the emitter temperature does not introduce deleterious effects to the system. Figure 12 shows typical magnitudes of drift which are about 10°F over a 30 hour period. The system remained within this envelope for a 7 to 8 day period before the program was changed manually.

The dynamic control characteristic of the emitter temperature with change in chamber temperature is shown in Figure 13. The dashed line of the chamber temperature-time curve does not represent the actual chamber temperature with time, but represents a change in the chamber power level. The change in power level took place in approximately 10 to 15 seconds. At point A on Figure 13, the chamber heater was drawing 100 amperes and the chamber temperature was stabilized at 1400°F. Then the current in the heater was reduced to 65 amperes and the emitter temperature was monitored until a stable emitter temperature was achieved. At point B in Figure 13 the chamber heater current was increased from 65 amperes to 145 amperes and the emitter temperature monitored until a stable emitter temperature was again achieved. In Figure 13, the dotted lines show the assumed chamber temperature with time.

At steady state the following data was determined:

Chamber Current	Chamber Temperature
65 amperes	986°F
100 amperes	1404°F
145 amperes	1820°F

Work began on the fabrication of three signal conditioning systems. The system will be housed in a relatively small, portable, slant-front cabinet of standard design. The signal conditioning breadboard will be used to test one of the transducers, bringing the total number of signal conditioning systems to four.

7.0 Metal-Ceramic Seal Compatibility Program

During the report period, five compatibility test assemblies, each containing four metal-ceramic test seals, were charged with potassium and installed in the compatibility test chamber. Potassium compatibility testing was completed; and the test assemblies shipped for removal of the potassium.

No potassium leakage was observed during the test. Examination of the test assemblies after completion of the test showed no visible signs of failure.

Detailed sketches and information on the test seals and compatibility test assemblies were presented in Reference 2 (table 3 and figures 11 through 19). The procedure that was followed for the compatibility testing of the metal-ceramic seals was the same as that used for the compatibility testing of the four candidate pressure capsule materials (Reference 4, page 18).

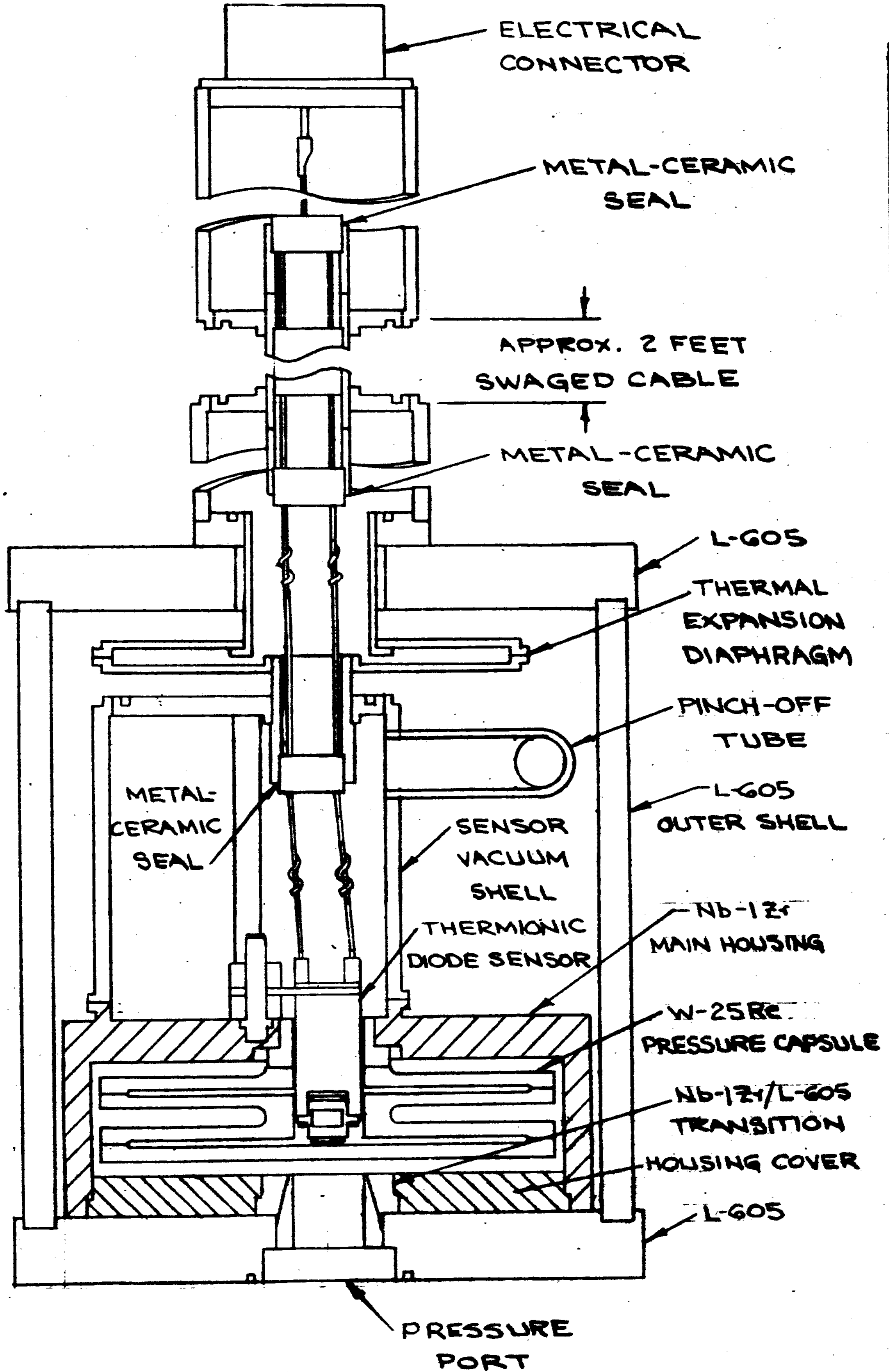


FIGURE 1

ABSOLUTE PRESSURE TRANSDUCER

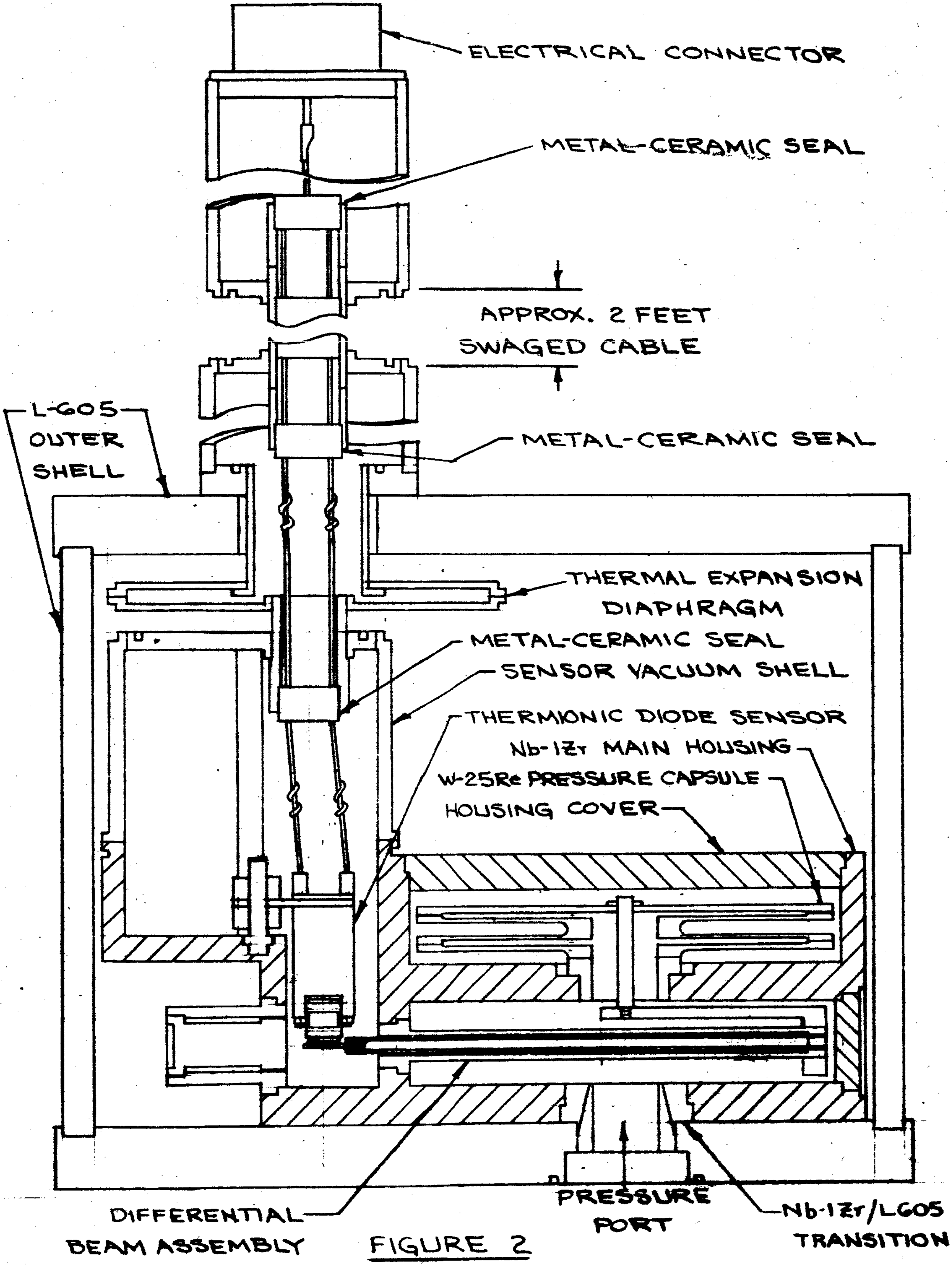


FIGURE 2

DIFFERENTIAL PRESSURE TRANSDUCER

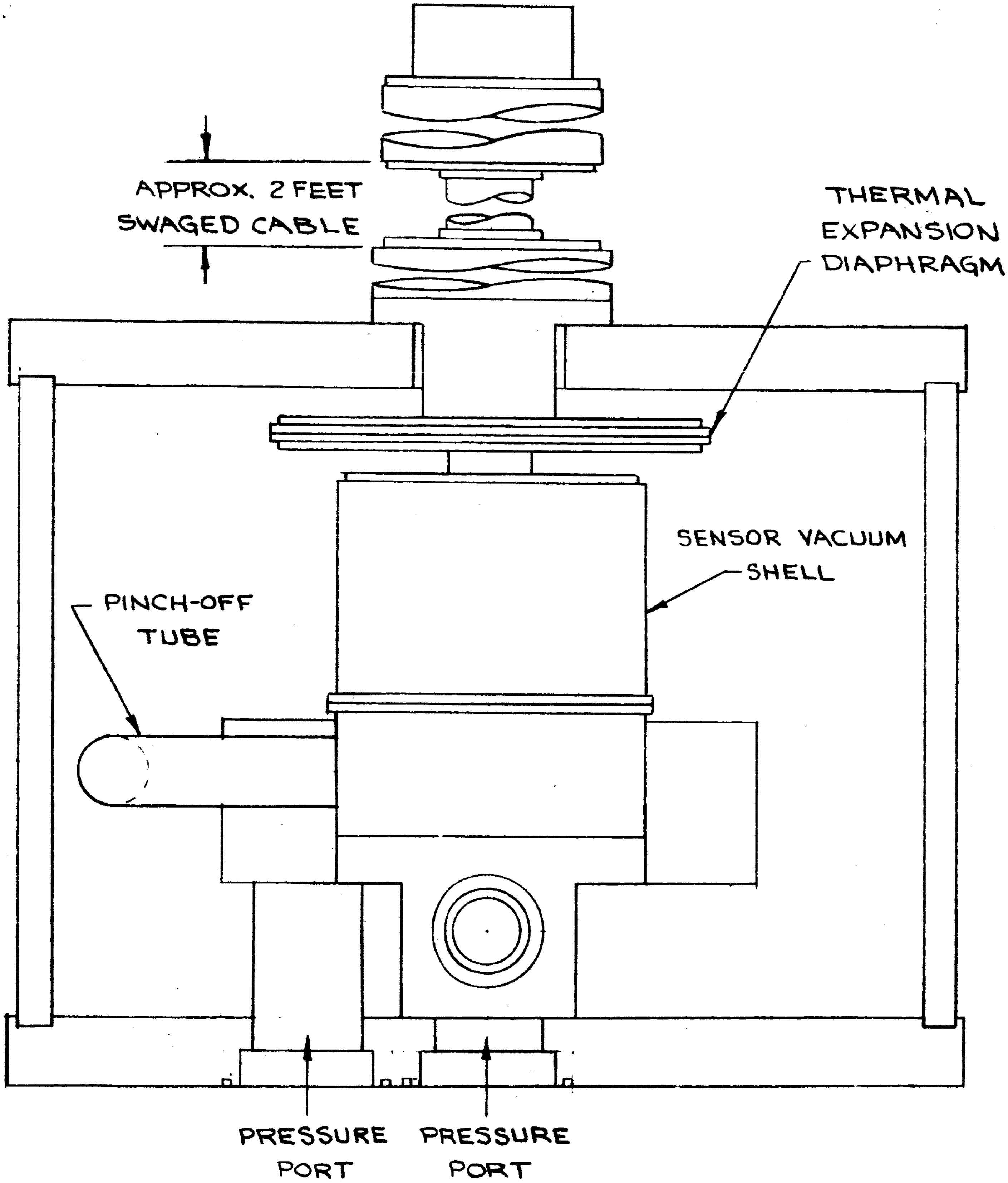


FIGURE 3

DIFFERENTIAL PRESSURE TRANSDUCER

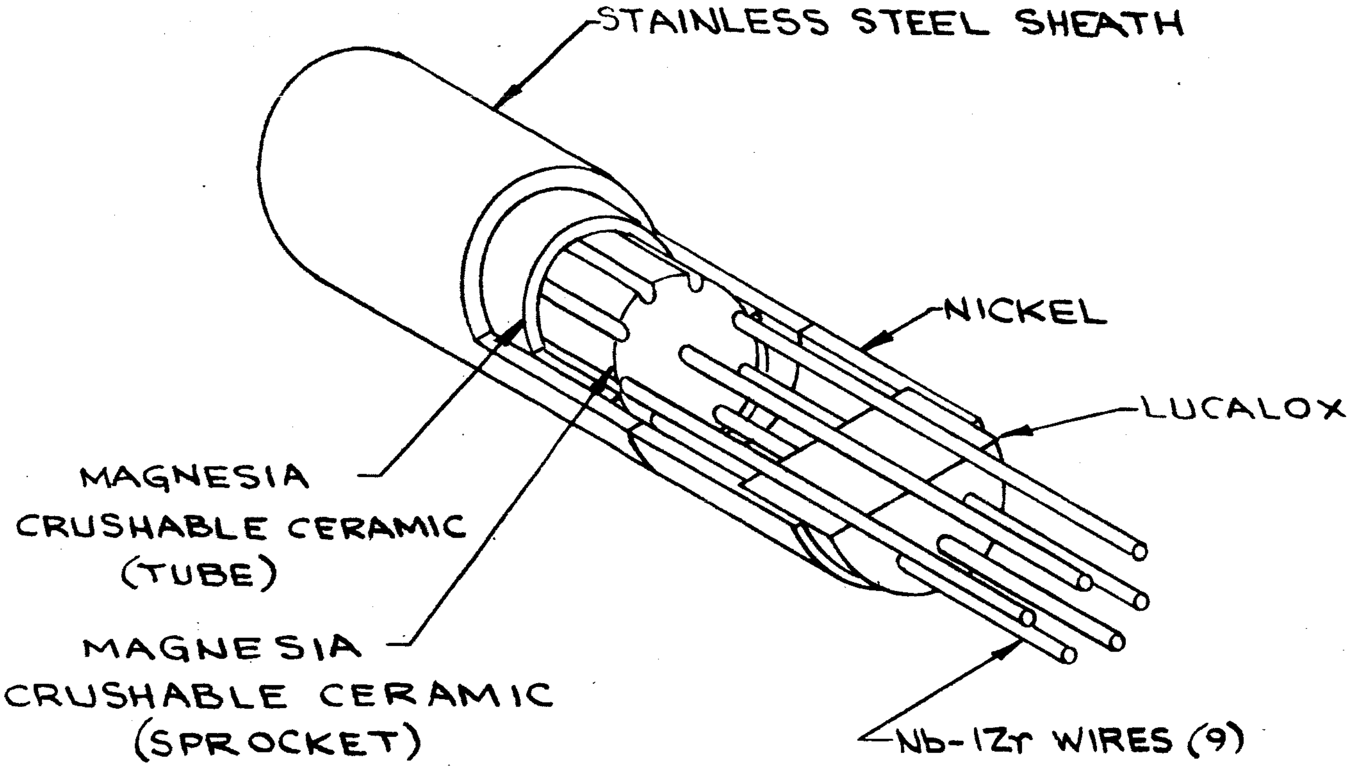


FIGURE 4

ELECTRICAL CABLE PICTORIAL SECTION

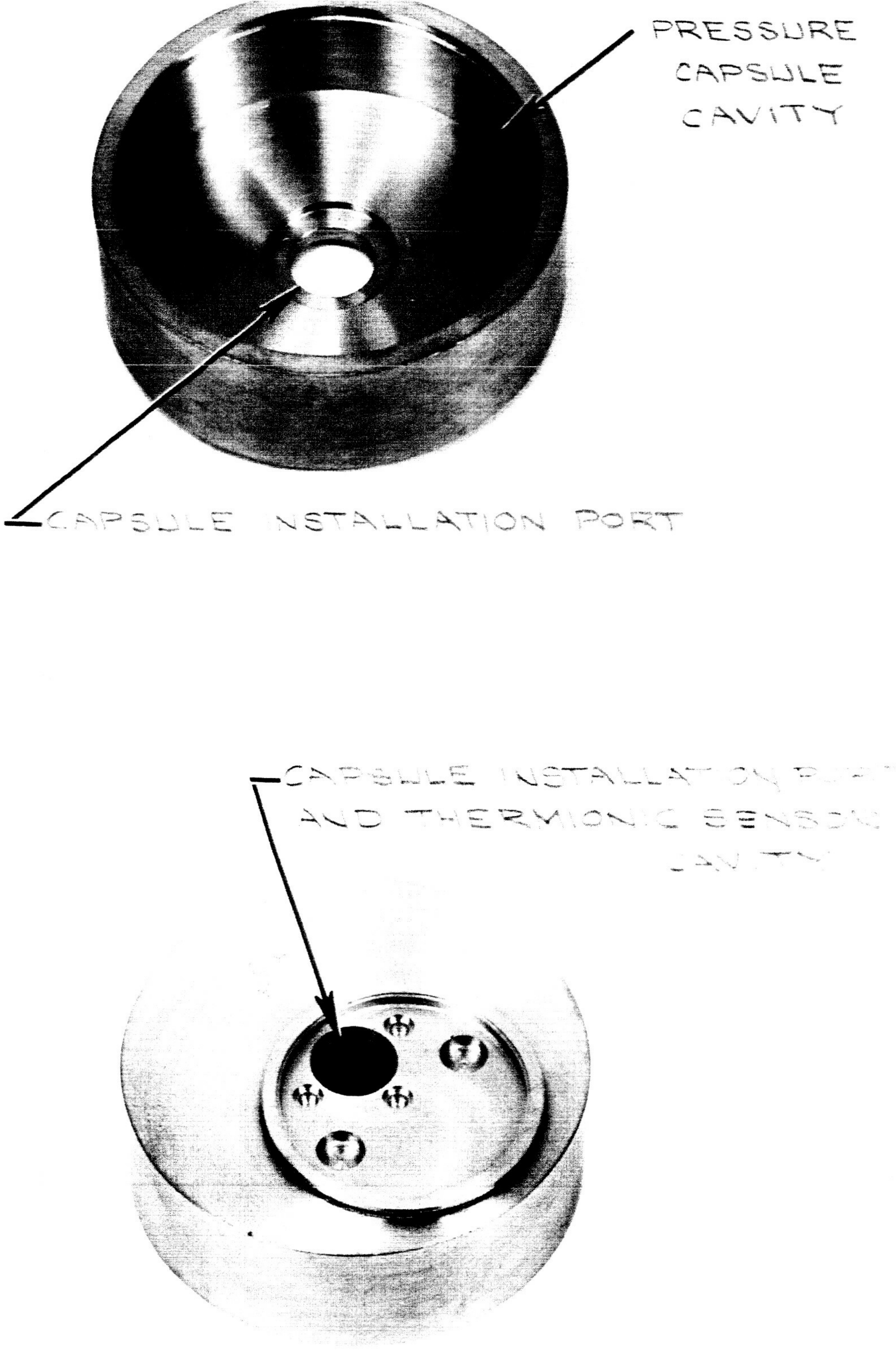


FIGURE 5

ABSOLUTE PRESSURE TRANSDUCER MAIN HOUSING

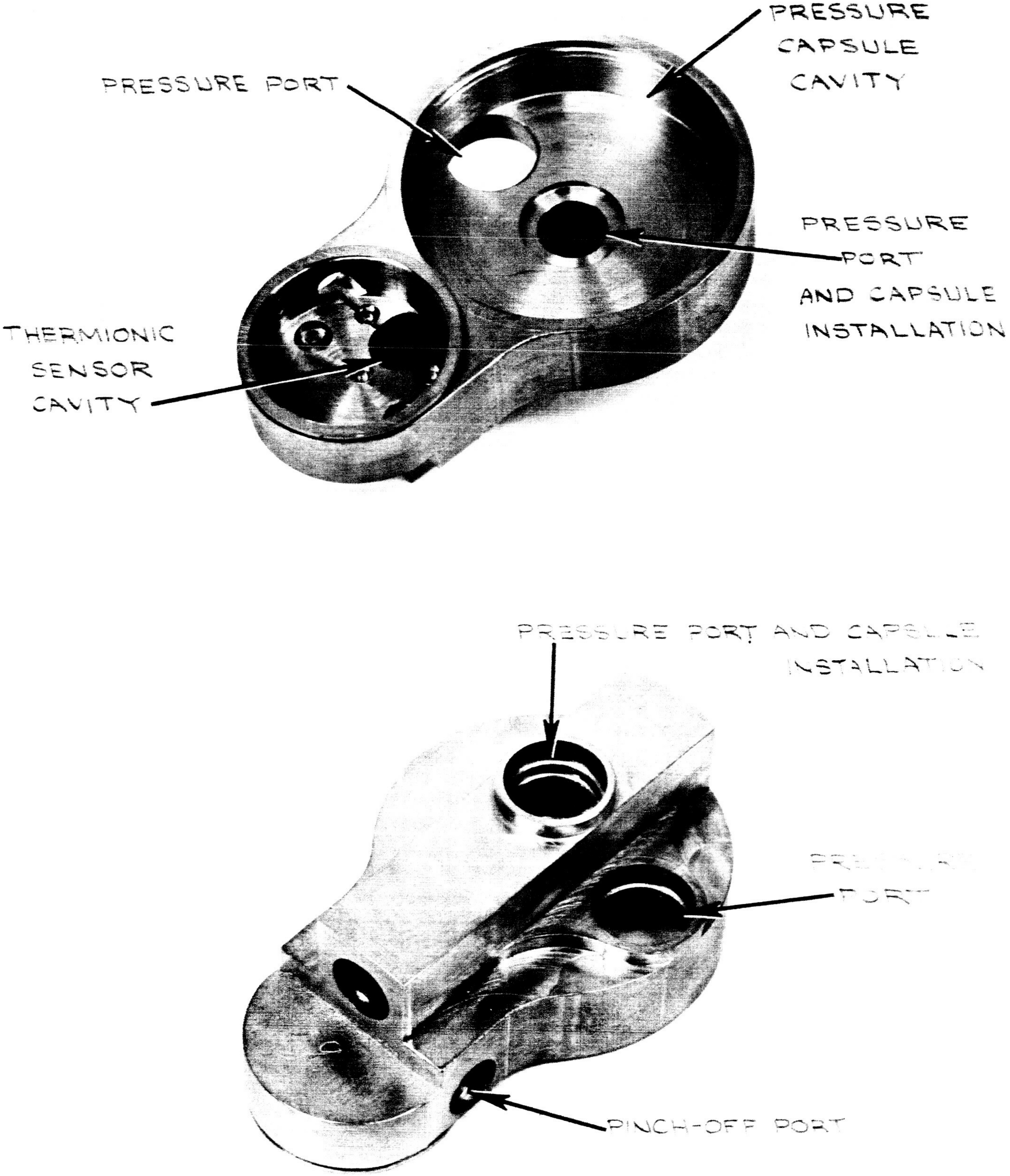


FIGURE 6

DIFFERENTIAL PRESSURE TRANSDUCER MAIN HOUSING

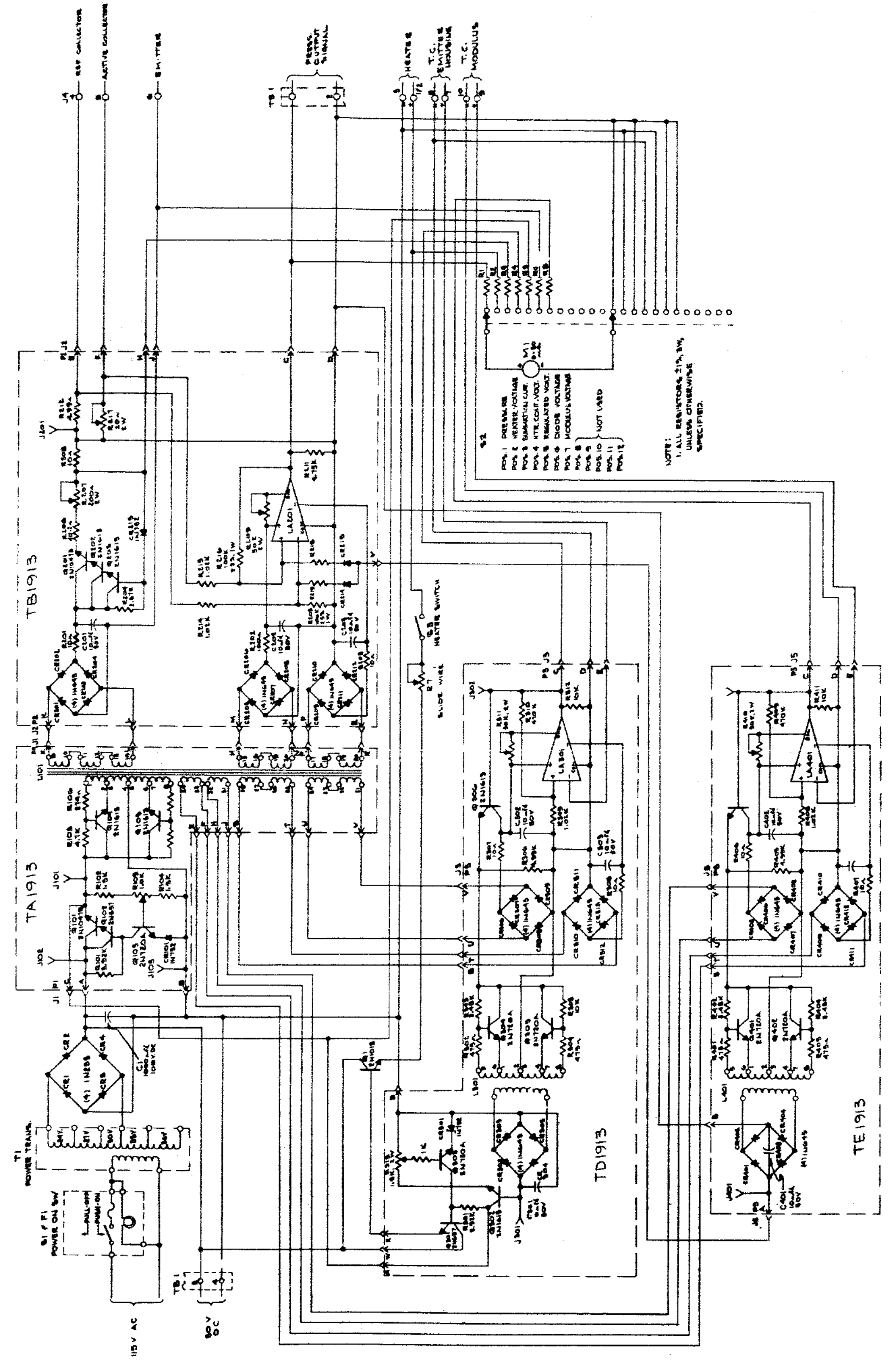


FIGURE 7

SIGNAL CONDITIONING SYSTEM SCHEMATIC

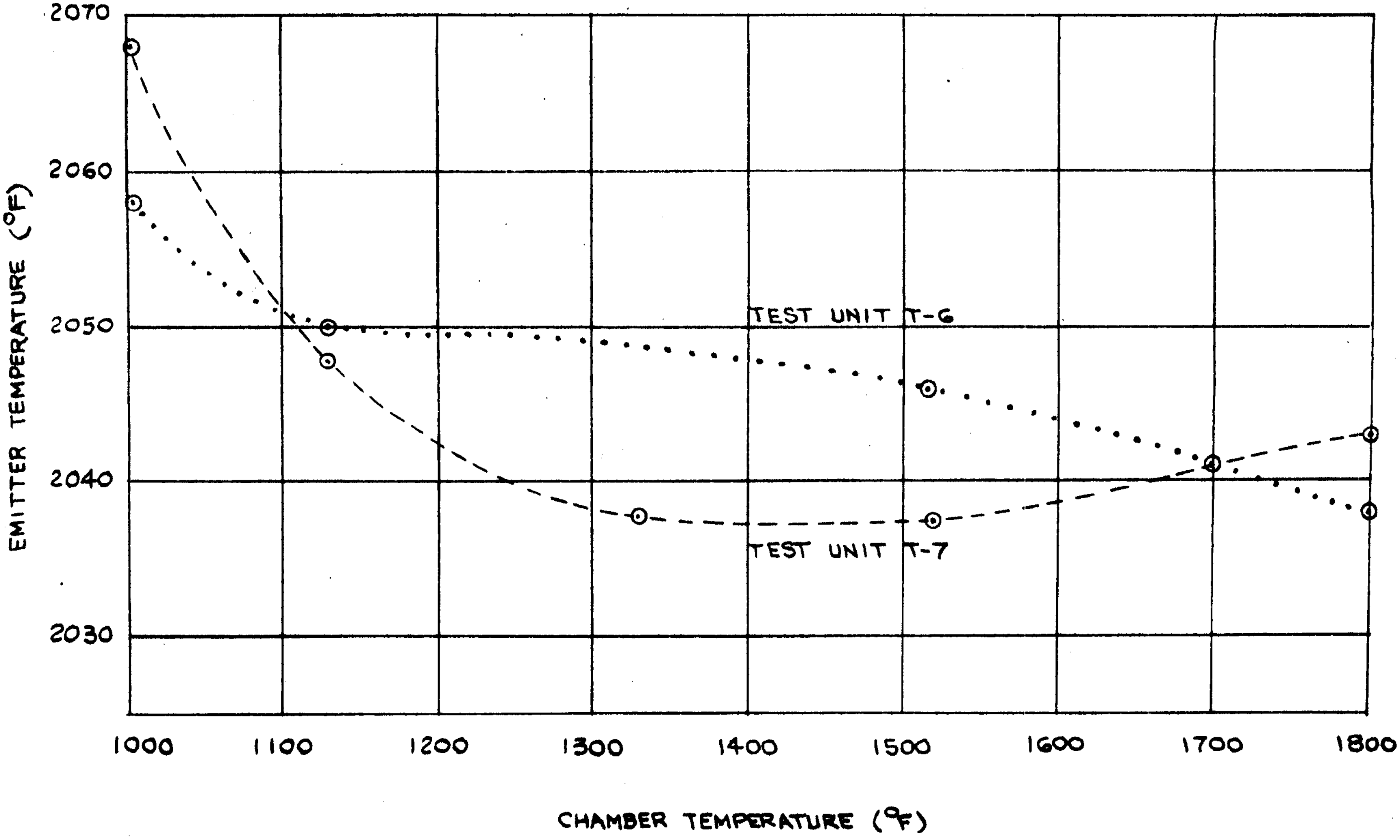


FIGURE 8

EMITTER TEMPERATURE - CHAMBER TEMPERATURE
CHARACTERISTICS, T-6 AND T-7

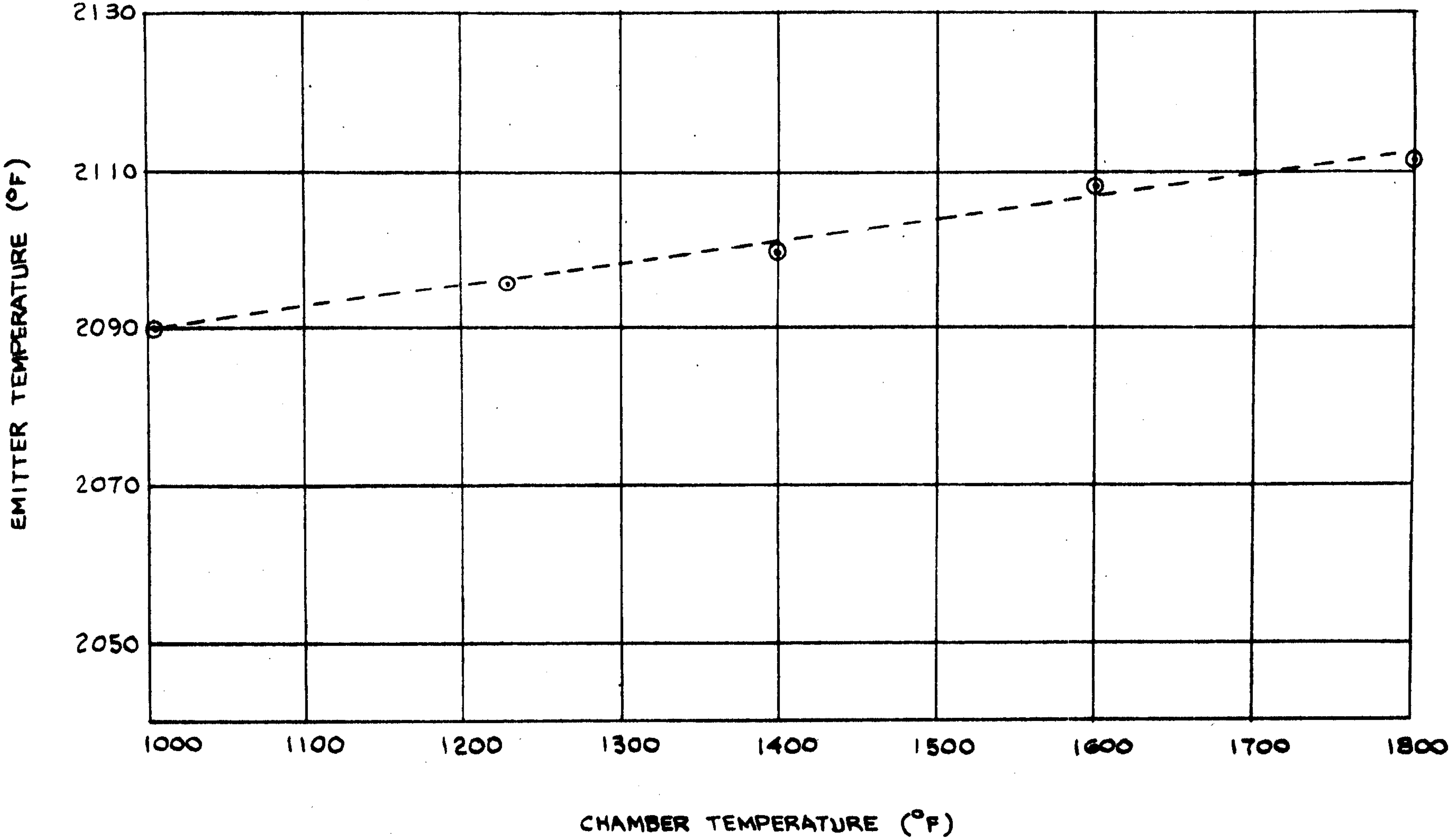


FIGURE 9

EMITTER TEMPERATURE - CHAMBER TEMPERATURE CHARACTERISTIC, FIRST DIFFERENTIAL TRANSDUCER

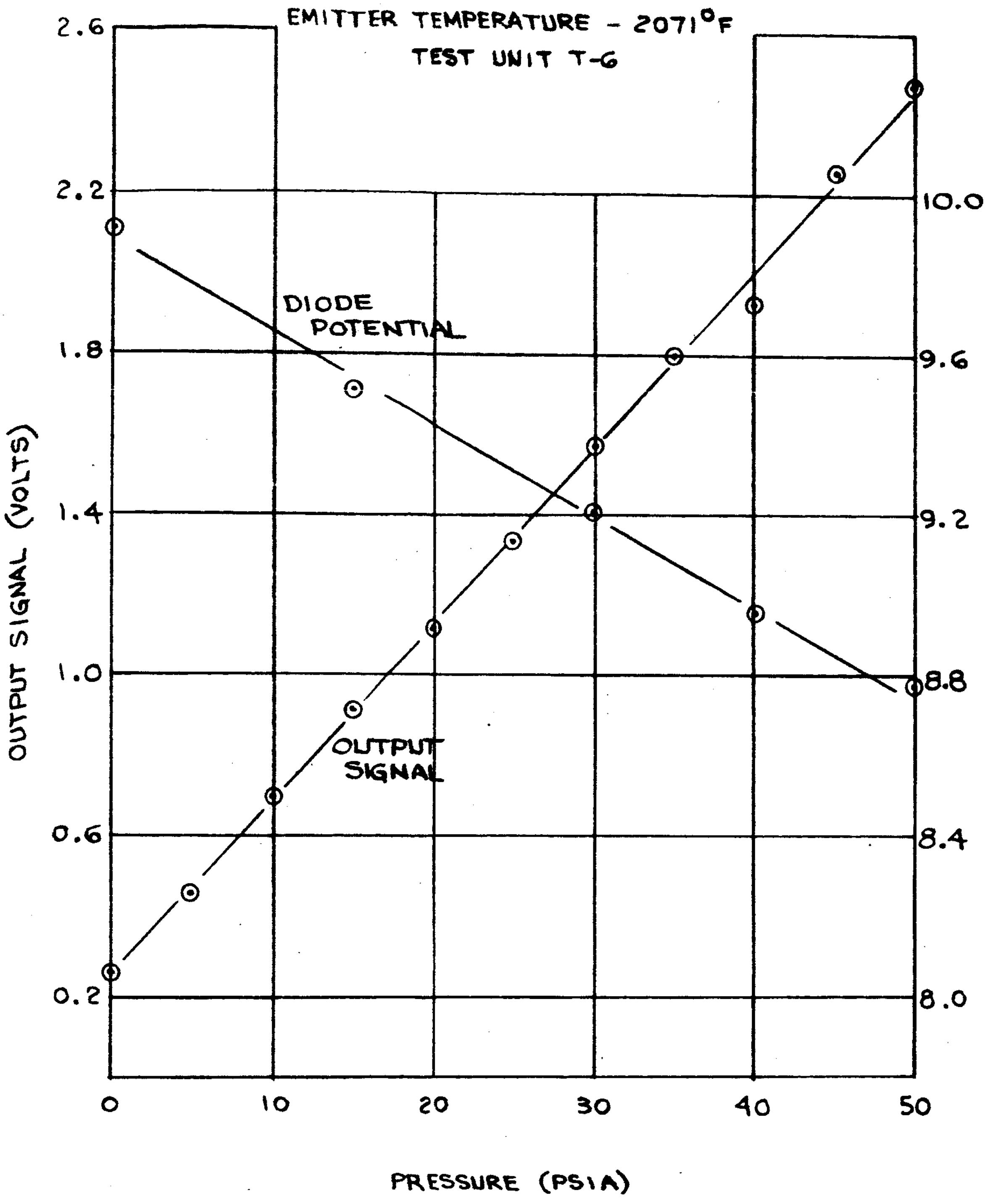
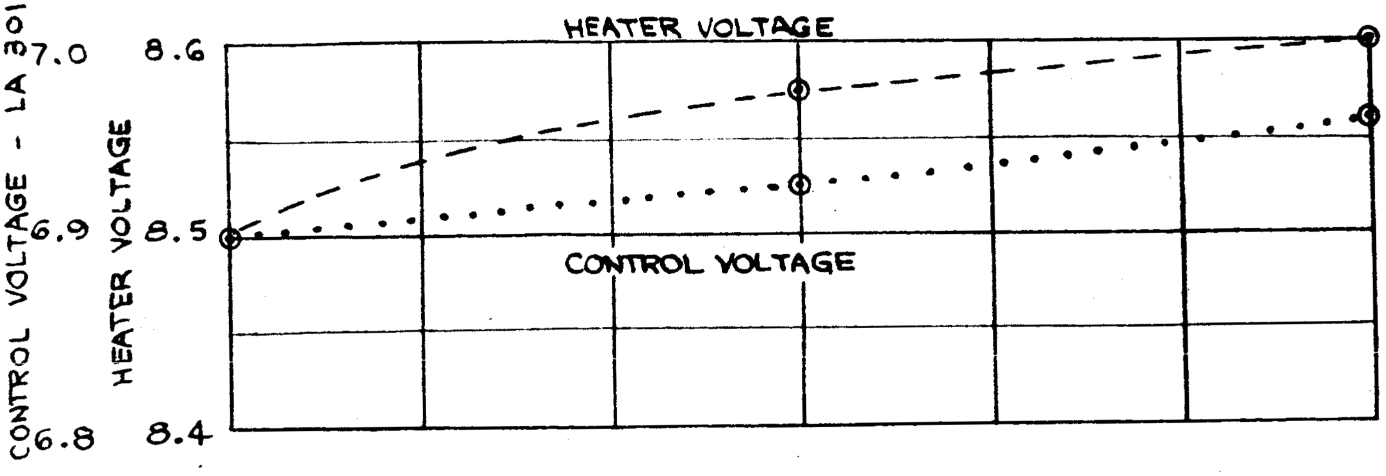


FIGURE 10

PRESSURE - OUTPUT AND DIODE POTENTIAL CHARACTERISTICS, T-6



TEST UNIT T-6

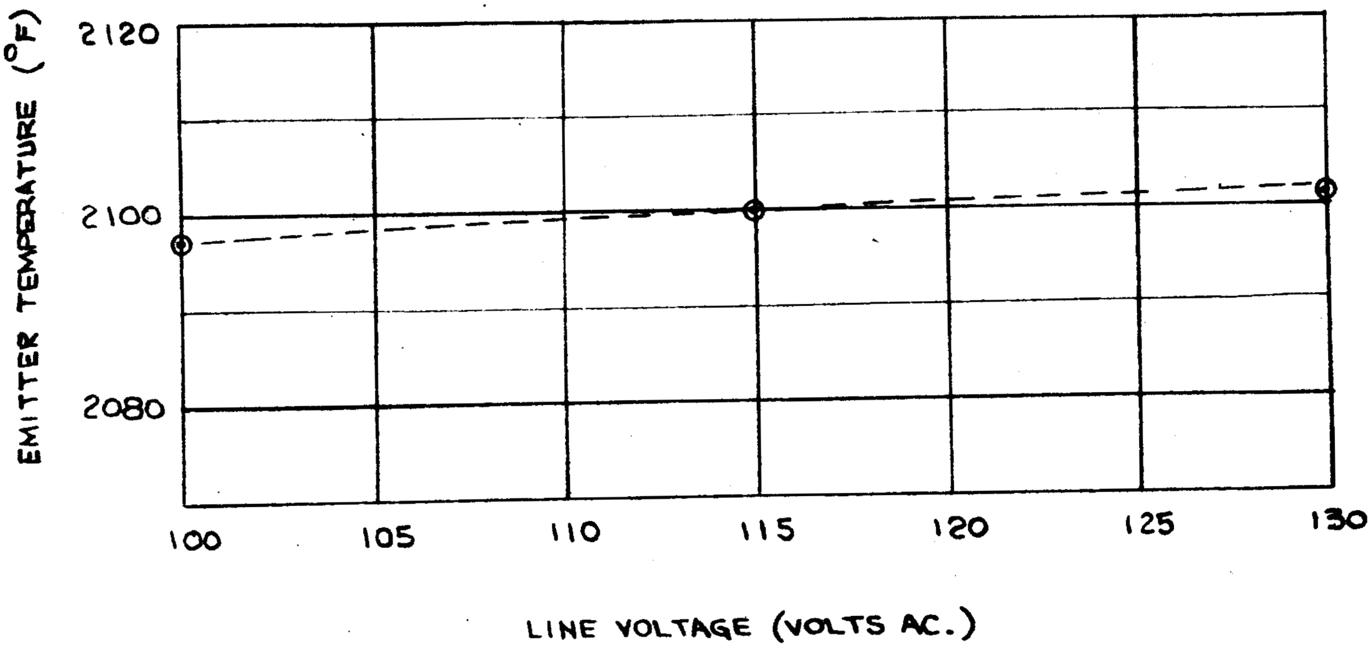


FIGURE 11

EMITTER TEMPERATURE AND HEATER PARAMETERS AS FUNCTIONS OF LINE VOLTAGE, T-6

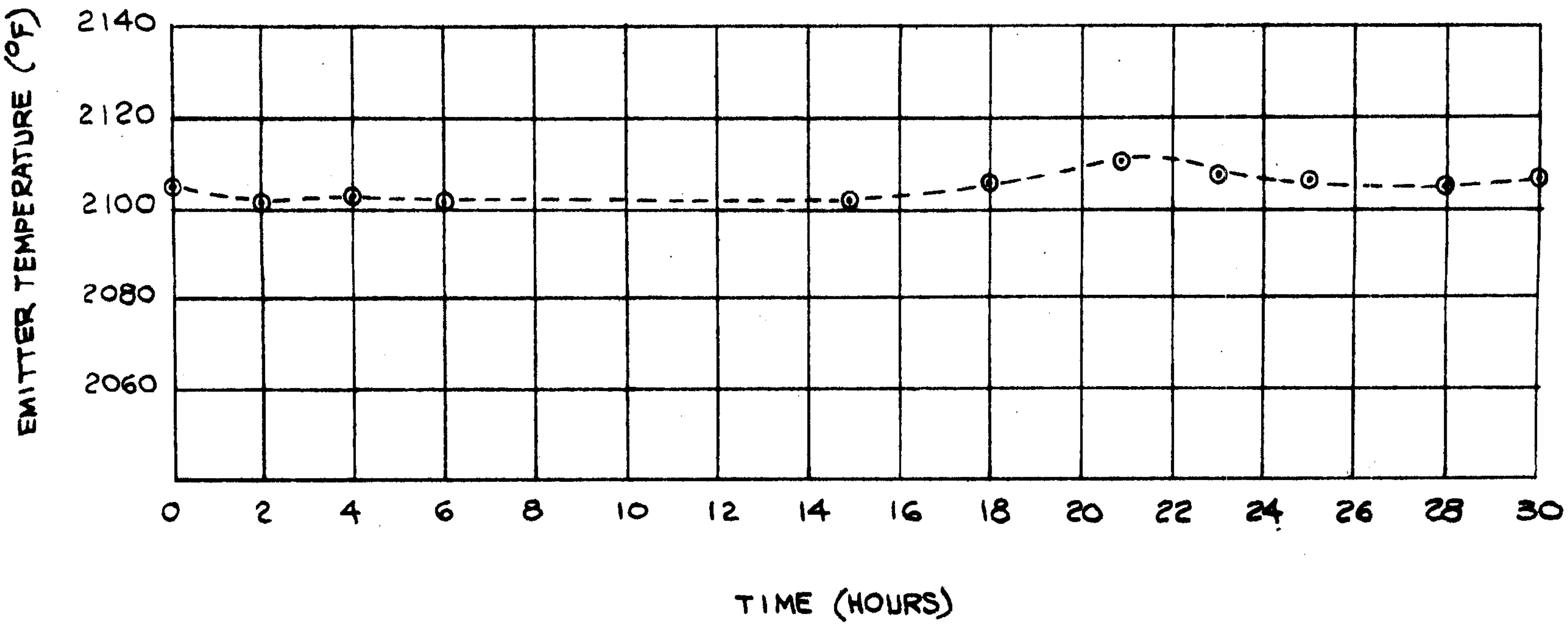


FIGURE 12

EMITTER TEMPERATURE AS FUNCTION OF TIME, T-6

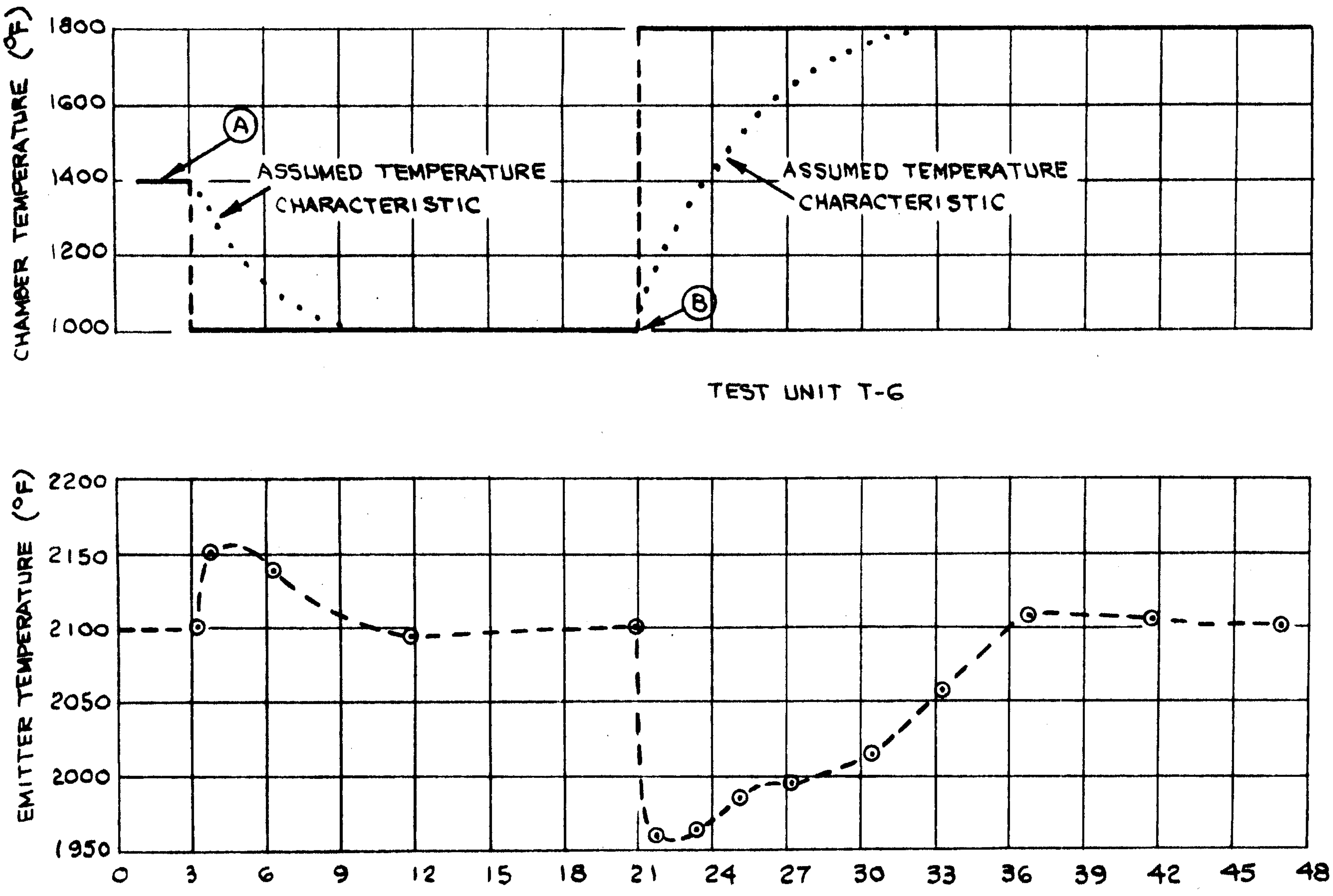


FIGURE 13

CHAMBER AND EMITTER TEMPERATURES
AS FUNCTIONS OF TIME, T-G

LIST OF REFERENCES

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APPENDIX A

PRESSURE TRANSDUCER TEST PROGRAM

OBJECT

The test program will establish the operating characteristics of the 80 psia and ± 5 psid pressure transducers developed under contract NAS 3-4170. The transducer ambient temperature range will be 1000-1800°F.

GENERAL

The transducers will be pressurized with high-purity argon. Transducer test pressures will be monitored by a room temperature transducing cell using interchangeable pressure diaphragms (output of 16 millivolts per volt excitation, accuracy better than 0.2% of full scale). The transducer output signal (0-5 volts) will be obtained from the transducer electrical signal conditioning system. Test pressure and transducer output data will be correlated by an X-Y recorder (accuracy of 0.2% of full scale with maximum sensitivity of 100 microvolts/inch). The transducer ambient temperature will be monitored by a thermocouple inserted in the argon pressurization line and placed adjacent to the pressure capsule.

PRE-TEST PROCEDURES:

The pre-test procedures are intended to establish the proper operating conditions for the thermionic diode sensor.

1. Pre-activate the emitters, after installation in the molybdenum emitter housing, in vacuum (about 10^{-6} torr) at 2280°F for 25 minutes before assembling the thermionic diode sensor.

2. Assemble the thermionic diode sensor. Install the sensor in the transducer and adjust the active collector distance to about 0.006 inch.

3. Install the transducer in a vacuum test chamber. Raise the test chamber temperature until the thermocouple indicates a transducer ambient temperature of 1800°F. The chamber pressure should not be allowed to exceed 5×10^{-8} torr.

4. Energize the sensor heater and raise the emitter temperature to 2280°F as measured by the W-5 Re/W-26 Re thermocouple installed on the emitter housing. Apply 15 volts to the diode to draw active and reference collector currents. For an emitter-collector distance of about 0.006 inch, the current level is 45 milliamperes minimum. Maintain sensor operation at 2280°F emitter temperature and 15 volts for 20 minutes, after which lower the emitter temperature to its operating level of 2100°F.

5. Determine the diode space-charge characteristics by measuring the active and reference collector currents as a function of increased voltage. Vary the voltage from 5 to 20 volts in 1 volt increments. Plot the results on log-log coordinates with emitter-collector distance as a parameter related through theoretical space-charge formulae. Using the space-charge plots, determine the active collector and reference collector distances. Also determine whether any emission limiting effects (poisoning) occur at applied voltages up to about 20 volts. Since the thermionic sensor must operate in the space-charge limited region, any emission-limited condition will introduce error into the output signal and must be avoided.

6. If the 1800°F space-charge characteristics indicate that the active and reference collector distances are not equal, so that $i_a \neq i_r$, remove the transducer from the test chamber and re-adjust the active collector distance so that it is equal to the reference collector distance as determined by the space-charge data. Install the transducer in the test chamber and perform the space-charge tests of (5) above to determine the active collector and reference distances. Repeat the procedure until the active collector and reference collector distances are shown to be equal ($i_a = i_r$) by the space-charge data.

7. When the 1800°F space-charge characteristics indicate that the active and reference distances are equal, so that $i_a = i_r$, connect the transducer signal conditioning system and obtain a set of pressure-output data by varying the transducer pressurization from zero to full scale and back to zero. Full scale pressure for the absolute unit is 80 psia. For the differential unit, full scale pressure is ± 5 psid. Simulate positive and negative pressure operation by performing the pressurization cycle twice; pressurize one port to 5 psia while the other is evacuated, then exchange the ports and repeat the pressure cycle. The pressure-output data will be used to correlate the data obtained during the main part of the test program.

8. Remove the transducer from the test chamber. Install the protective cover and electrical header connections on the sensor chamber. Evacuate the sensor chamber through the pinch-off tube to a pressure below 10^{-8} torr. Perform the pinch-off operation. The transducer is now ready for the main part of the test program.

TEST PROGRAM

1. Following emitter activation, adjustment of the active collector distance and sealing of the sensor section of the

transducer, install the transducer in a vacuum test chamber. During testing, the pressure should not be allowed to exceed 10^{-7} torr.

2. Raise the test chamber temperature until the thermocouple indicates a transducer ambient temperature of 1800°F. Perform a space-charge run to verify proper operation of the thermionic sensor (see Step 5 of the Pre-Test Procedures).

3. Vary the transducer pressurization from zero to full scale and back to zero. Perform three pressurization cycles. Full scale pressure for the absolute unit is 80 psia. For the differential unit, full scale pressure is ± 5 psid. Simulate positive and negative pressure operation by performing the three pressurization cycles twice; pressurize one port and evacuate the other for three pressure cycles, then exchange the ports and repeat the three pressure cycles. Monitor the pressure and transducer output with the X-Y recorder. From the test results, determine the transducer accuracy. The accuracy shall include the effects of linearity, hysteresis, sensivitity, zero shift and repeatability.

4. Repeat (3) above at capsule temperatures of 1600, 1400, 1200, 1000, 1200, 1400, 1600, and 1800°F. In addition to transducer accuracy, evaluate the zero shift due to capsule temperature change.

5. Using a solenoid operated valve to switch the transducer from the argon pressurization line to the vacuum line, pressure cycle (vacuum-full scale pressure-vacuum) the transducer once every three minutes. For the 500 hour life test program, continue the pressure cycling for 100 hours. For the 2000 hour life test program, continue the pressure cycling for 400 hours. The absolute unit is cycled between 0-80 psia. The differential unit is cycled by applying 0-5 psia to one port and vacuum to the other for half the cycling test time (50 or 200 hours); the ports then are switched for the second half of the test. Perform pressure-output spot checks during the test using the X-Y recorder. Evaluate the transducer accuracy as a function of test time.

6. Repeat steps 2, 3, 4, and 5 above five times for the 500 hour life test program and five times for the 2000 hour life test program. After the first 1000 hours of the 2000 hour life test, apply continuous full-scale pressure to the transducer for 200 hours to evaluate creep characteristics with time. For the differential unit, apply 5 psia to one port and vacuum to the other for 100 hours; the ports then are switched for a second 100 hours. Following the 200 hour full scale pressure test, continue the pressure cycling test.

7. After completion of the life test program, remove the transducer from the test chamber. Remove the test pressurization fittings in the transducer and install the loop test fittings and associated piping. Calibrate the frequency response test assembly by installing the transducing cell and monitoring the cell output on an oscilloscope using a triggered calibrated sweep. The frequency response test assembly is used to first pressurize the transducing cell and then vent the cell to ambient atmosphere. The scope is triggered by initiation of the venting operation and the time needed to vent from full scale pressurization to ambient is set at 10 milliseconds as measured by the calibrated oscilloscope sweep. A set of springs is used to vary the venting speed of the frequency response test assembly. A 10 millisecond ramp pressure change corresponds to a pressure perturbation of 100 cycles per second. After calibrating the frequency response test assembly, remove the transducing cell and install the test transducer. Using the signal conditioning system, monitor the output of the transducer on the oscilloscope and evaluate the transducer capability to follow the 100 cps pressure perturbation created by venting the transducer from full pressure to ambient in 10 milliseconds. A full scale calibration pressure of 80 psia will be used for the absolute transducer test. For the differential transducer, a full scale calibration pressure of 5 psia will be used and the test will be

performed twice; first pressurize one port and vent the other to room atmosphere, then reverse the ports and repeat the test. The frequency response tests will be performed under room ambient conditions.

8. Install the transducer on a vibration table and perform vibration tests, along three axes, in accordance with the following schedule:

0 to 10	cps, 0.20 inch double amplitude
10 to 20	cps, ± 1.0 g
20 to 90	cps, 0.05 inch double amplitude
90 to 2000	cps, ± 20 g

During the vibration testing, apply full scale pressurization to the transducer and monitor the output using the signal conditioning system and the X-Y recorder. A time sweep will be used on one axis of the recorder and the transducer output will be monitored on the other axis. Various check-frequencies will be noted on the recorder chart to help evaluate the test results. A full scale pressure of 80 psia will be used for the absolute transducer test. For the differential transducer, a full scale pressure of 5 psia will be used and the test will be performed twice; first pressurize one port and vent the other to room atmosphere, then reverse the ports and repeat the test. The vibration tests will be performed under room ambient conditions. Note any resonant peaks exhibited by the transducer during the course of the vibration tests. It must be remembered that in operation, the transducer will be subject to greatly increased damping conditions due to the presence of liquid metal in the transducer interior.

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