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LIQUID ROCKET PLANT

DESIGN OF A CRYOGENIC

TWO POINT LIQUID LEVEL CONTROLLER

Prepared by
C. A. Henson

Report 8771:2562

March 10 1964

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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I. INTRODUCTION

This report presents a design of a two-point liquid level controller for cryogenic liquids in the range of 7°R (liquid helium) to 160°R (liquid oxygen) that uses carbon composition resistors for the sensing elements.

II. SUMMARY

This cryogenic liquid level control system incorporates the high thermal sensitivity and resulting inverse change in resistance of commercial composition resistors at cryogenic temperatures to maintain (or monitor) the liquid level between an upper point ($\pm 1/8$ inch) and a lower point ($\pm 1/8$ inch).

In general, the system includes two bridge circuits that govern the action of a control circuit for the cryogenic liquid supply valve. One bridge, having a carbon resistor sensor as one leg, is used for the lower level control. A similar bridge, also having a carbon resistor sensor as one leg, is used for the upper level control. In operation, the bridges are unbalanced when their respective carbon resistor sensors are immersed in the cryogenic liquid. The control circuit is then energized in accordance with the set point controls of two meter relays, one being connected across each bridge.

Although the system depends upon the temperature of the resistor sensor, it does not depend solely upon the temperature difference between the liquid and the gas ullage. Considering the worst case, where the temperature of the gas is equal to or very near that of the liquid, the difference in self heating of the resistor sensor between gas and liquid immersion is sufficient to provide an operational signal to the control valve.

The resistor sensor probe may be made compatible with a nuclear irradiation environment by selecting the appropriate irradiation resistant tube material for holding the resistor sensors and the appropriate insulation for the conductors to the resistors.

III. RECOMMENDATIONS

It is recommended that carbon composition resistors be considered for use as sensors in point-to-point cryogenic liquid level control or liquid level monitoring systems. A prototype should be constructed to verify the sensitivity, repeatability and practicability of the system. Attached as Appendix A is a calibration, checkout, and operating procedure for a proposed liquid hydrogen-liquid nitrogen level control system.

IV. DESIGN DISCUSSION

Figure 1 is a simplified schematic of the liquid level control system showing the switching arrangement for selecting the desired resistor sensor for each bridge and the control circuit logic.

A. SENSOR RESISTOR

Preliminary testing was conducted in the Aerojet-General Corporation Liquid Rocket Plant Test Division Transducer Laboratory on different types of resistors. A 1000 ohm, 1/4-watt ohmite "Little Devil" carbon composition resistor was selected for the sensor because its small size makes it easy to mount in a probe, it has a high thermal sensitivity, and its power capacity is a "natural" for operation with a standard 28 volt power supply. A similar 1/10-watt resistor was considered since it was observed to have a faster switching time, but was not selected because of its miniature size and possible fragility.

B. BRIDGE RESISTORS (See Figure 2)

1. R1 and R2

A 1000 ohm resistor is used to match the sensor resistor (Rx) resistance at ambient temperature.

2. R3a and R3b

An 820 ohm fixed resistor with a 500 ohm, 10 turn pot is used for balancing the bridge with the sensor resistor at or near ambient temperature and to provide a balancing control for transmission line lengths from the control panel to the resistor sensor as field conditions dictate.

C. CALIBRATION RESISTORS

1. R4b

Use 2400 ohms (from the temperature vs carbon resistance curve in Figure 3) for calibration with liquid hydrogen.

2. R4c

Use 1280 ohms (from the temperature vs carbon resistance curve in Figure 3) for calibration with liquid nitrogen.

D. METER RELAY

An optical meter relay (Reference 1) is used which, by "fiber optics", provides a continuous indication below, above, and at the control set point by nature of a non-restricted meter movement.

E. BRIDGE CALCULATIONS

1. Thevenin's Equivalent of Bridge (Figure 2 between terminals C and D)

a. Simplify Figure 2 by letting $R_3 = R_{3a} + R_{3b}$ and (Eq 1)

$R_t = R_{5a}$ or $R_{5b} + R_{5c} + R_{5d}$:

b. Short A to B (the power source) and omit R_t
the equivalent circuit between C and D is:

Sketch 1.

c. Considering terminals C and D:

$$R_{eq} = \frac{R_1 \cdot R_2}{R_1 + R_2} + \frac{R_3 \cdot R_x}{R_3 + R_x} \quad (\text{Eq 2})$$

$$= 500 + \frac{R_3 R_x}{R_3 + R_x} \quad (\text{since } R_1 = R_2 = 1K)$$

d. From equation 1, assuming I_{Rt} has negligible effect on bridge voltages

$$\begin{aligned} V_{eq} &= V \left(\frac{R_x}{R_x + R_3} \right) - V \left(\frac{R_2}{R_2 + R_1} \right) \\ &= \frac{28 R_x}{R_x + R_3} - 28 \left(\frac{1000}{1000 + 1000} \right) \\ &= \frac{28 R_x}{R_x + R_3} - 14 \end{aligned} \quad (\text{Eq 3})$$

e. By using R_{eq} and V_{eq} as determined, the bridge can be simplified to:

Sketch 2.

2. Unbalanced Bridge With Resistor Sensor Immersed in LH₂ (Reference Figure 2)

$$R_x = 2400 \text{ ohms}$$

$$R_3 = 1000 \text{ ohms (} R_{3a} \text{ fixed Res} + 180 \text{ ohms } R_{3b} \text{ for RUN condition - Bridge balanced at ambient temperature)}$$

a. By substituting these values in equation 2:

$$R_{eq} = 500 + \frac{R_3 R_x}{R_3 + R_x} = 500 \frac{(1000)(2400)}{1000 + 2400} = 1200 \text{ ohms} \quad (\text{Eq 4})$$

b. Using equation 3:

$$V_{eq} = \frac{28 R_x}{R_x + R_3} - 14 = \frac{(28)(2400)}{2400 + 1000} - 14 = 5.8 \text{ volts} \quad (\text{Eq 5})$$

3. Meter Relay Current Limited to 125 μ A with Range Pot Cut Out and Resistor Sensor Immersed in LH₂

a. From Sketch 2:

$$V_{eq} = I R_{eq} + I R_t$$

$$\text{or } R_T = \frac{V_{eq}}{I} - R_{eq} = \frac{5.8}{125 \times 10^{-6}} - 1200 = 45,300 \text{ ohms} \quad (\text{Eq 6})$$

b. From equation 1:

$$R_t = R_{5a} + R_{5c} + R_{5d}$$

$$\text{or } R_{5a} = R_t - R_{5c} - R_{5d} \quad (\text{Eq 7})$$

$$= 45,300 - 0 - 1080 \text{ (Range Pot } R_{5c} \text{ cut out)}$$

$$= 44,000 \text{ ohms approximately for current limiting resistor for LH}_2 \text{ operation}$$

4. Range Pot Setting for Meter Relay Current Reading of 85 μ A With Resistor Sensor Immersed in LH₂

a. From equation 6:

$$R_t = \frac{V_{eq}}{I} - R_{eq} = \frac{5.8}{85 \times 10^{-6}} - 1200 = 67,100 \text{ ohms} \quad (\text{Eq 8})$$

b. From equation 7:

$$R_t = R_{5a} + R_{5c} + R_{5d} \text{ or } R_{5c} = R_t - R_{5a} - R_{5d} \quad (\text{Eq 9})$$

$$R_{5c} = 67,000 - 44,000 - 1080 = 22,000 \text{ ohms approx.}$$

5. Unbalanced Bridge with Resistor Sensor Immersed in LN₂

$$R_x = 1280 \text{ ohms}$$

$$R_3 = 1000 \text{ ohms (820 ohms } R_{3a} + 180 \text{ ohms } R_{3b}, - \text{ Bridge balanced at ambient temperature)}$$

a. Using the same procedure as in equation 4:

$$\begin{aligned} R_{eq} &= 500 + \frac{R_3 R_x}{R_3 + R_x} \\ &= 500 + \frac{(1000)(1280)}{1000 + 1280} = 1060 \text{ ohms} \end{aligned} \quad (\text{Eq 10})$$

b. From equation 5:

$$V_{eq} = \frac{28 R_x}{R_x + R_3} - 14 = \frac{(28)(1280)}{1280 + 1000} - 14 = 1.7 \text{ volts} \quad (\text{Eq 11})$$

6. Meter Relay Current Limited to 125 μ A with Range Pot Cut Out and Resistor Sensor Immersed in LN₂

a. From equation 6:

$$R_t = \frac{V_{eq}}{I} - R_{eq} = \frac{1.7}{125 \times 10^{-6}} - 1060 = 12,540 \text{ ohms} \quad (\text{Eq 12})$$

b. From equation 7:

(Eq 13)

$$R5b = R_t - R5c - R5d = 12,540 - 0 - 1080 = 11,460 \text{ ohms}$$

or 11,000 ohms = current limiting resistor for LN₂ operation

7. Range Pot Setting for Meter Relay Current Reading of 85 μ A with Resistor Sensor Immersed in LN₂

a. From equation 8:

$$\begin{aligned} R_t &= \frac{V_{eq}}{I} - R_{eq} \\ &= \frac{1.7}{85 \times 10^{-6}} - 1060 = 18,940 \text{ ohms} \end{aligned} \quad (\text{Eq 14})$$

b. From equation 9:

$$\begin{aligned} R5c &= R_t - R5b - R5d \\ &= 18,940 - 11,000 - 1080 = 8600 \text{ ohms approx.} \end{aligned} \quad (\text{Eq 15})$$

8. Meter Relay Movement for Worst Case of LH₂ Operation - LH₂ Temperature = GH₂ Temperature (37°R)

a. Power is dissipated by the sensor resistor while immersed in LH₂

$$P_{Rx} = \frac{V_{Rx}^2}{R_x} \quad (\text{Eq 16})$$

where P_{Rx} = Power dissipated in sensor resistor Rx

V_{Rx} = Voltage across sensor resistor Rx

R_x = Sensor resistor Rx

$$\text{However, } V_{Rx} = \frac{V}{2} + V_{eq}$$

where V_{eq} = Bridge unbalance

V = Voltage applied across bridge

$$\text{Therefore } P_{Rx} = \frac{\left(\frac{V}{2} + V_{eq}\right)^2}{R_x} = \frac{\left(\frac{28}{2} + 5.8\right)^2}{2400} + .16 \text{ watts}$$

b. A self-heating error of 1°F was observed when .16 watts was dissipated by an RTT in LH₂ (see page 6 of reference 2). The ratio of the area of this element to that of the resistor sensor is:

$$\frac{\text{Experiment element (RTT) area}}{\text{Resistor Sensor Area}} = \frac{\pi D' l'}{\pi D l} \quad (\text{Eq 17})$$

where D = Diameter

l = Length

Plain letter designates resistor

Prime mark designates RTT

$$\text{Therefore: } \frac{\pi D' l'}{\pi D l} = \frac{\pi (.25)(1)}{\pi (.08)(.25)} = 12.5$$

c. The anticipated error for dissipating .16 watts in the resistor sensor would be $1 \times 12.5 = 12.5^\circ\text{F}$ while immersed in LH₂.

d. From reference 3 we have the equation:

$$\frac{\Delta T}{\Delta T'} = \frac{C \mu K'}{K C' \mu'} \quad (\text{Eq 18})$$

where T = Temperature difference between fluid and element
 C = Specific heat, constant pressure
 μ = Viscosity of fluid
 K = Thermal conductivity of fluid
 A prime mark (K') indicates characteristic of gas

e. By substituting known values:

$$\frac{12.5^{\circ}\text{F}}{T'} = \frac{(1.44)(120 \times 10^{-6})(.0358 \times 10^{-3})}{(.287 \times 10^{-3})(2.8)(11 \times 10^{-6})} = .7 \quad (\text{Eq 19})$$

$$\text{or } T' = \frac{1.25^{\circ}\text{F}}{.7} = 17.9^{\circ}\text{F} = \text{Temperature difference between } \text{GH}_2 \text{ and resistor sensor}$$

f. Therefore, the change in temperature of the resistor upon passing from LH_2 to GH_2 would be $17.9^{\circ}\text{F} - 12.5^{\circ}\text{F} = 5.4^{\circ}\text{F}$.

g. In reference to Figure 3 the slope of the curve is:

$$\frac{\Delta R_x}{\Delta T} = 50 \text{ ohm}/^{\circ}\text{F} \text{ approx at the temperature of } \text{LH}_2. \quad (\text{Eq 20})$$

h. The ratio of $\frac{\Delta R_x}{\Delta I_m} = 20 \text{ ohm}/\mu\text{A}$ approx by solving for bridge voltages V_{eq} for various R_x near LH_2 temperatures and substituting in the equation I_m (Meter Relay Current) = $\frac{V_{eq}}{R_t + R_{eq}}$ (from equation 8). (Eq 21)

i. Therefore, from equations 20 and 21:

$$\frac{\Delta I_m}{\Delta T} = 2.5 \mu\text{A}/^{\circ}\text{F} \quad (\text{Eq 22})$$

The expected meter movement, when the resistor sensor passes from LH_2 to GH_2 (same temperatures) will be:

$$5.4 \times 2.5 \mu\text{A} = 13 \mu\text{A} \text{ approx.}$$

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REFERENCES

1. Assembly Products, Inc., Optical Meter Relay, described in Bulletin 33-A, dated April 1963.
2. Technical Report No. 8771:2103, A Study of Self Heating and Energy Transfer Between an Rtt Sensing Element and Single Phase Liquid Hydrogen, by A. E. Lehmborg, dated 28 October 1963.
3. Memorandum 8771:2007, A. E. Lehmborg to C. A. Henson, Calculation of Reaction of Resistance Probe to Alternate Immersion in LH₂ and GH₂ of Same Approximate Temperatures, dated 28 September 1963.

SIMPLIFIED SCHEMATIC, LH₂/LN₂ LIQUID LEVEL CONTROL SYSTEM

S1'' MECHANICALLY CONNECTED
TO S1 FIG 1

R5a - CURRENT LIMITING

RESISTOR FOR LH₂ OPERATION

R5b - CURRENT LIMITING RESISTOR FOR LN₂ OPERATION

R5c - RANGE POT

R5d - METER RELAY

CONTROL
PANEL

TRANSMISSION
LINES

RESISTOR
SENSOR

LH₂ / LN₂ LIQUID LEVEL CONTROL
TYPICAL BRIDGE SCHEMATIC

CURVE PLOTTED FROM NASA
TECHNICAL NOTE DATA
REPORT D264 FEB. 1961
FIG 3

LH₂/LN₂ LIQUID LEVEL CONTROL CIRCUIT

PROPOSED LAYOUT

LH₂/LN₂ LIQUID LEVEL CONTROL PANEL

FIG 5

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APPENDIX A

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PROPOSED
LIQUID HYDROGEN - LIQUID NITROGEN
LEVEL CONTROL SYSTEM

CALIBRATION, FILL, AND OPERATING PROCEDURE

Prepared by
C. A. Henson

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APPENDIX A

I GENERAL DISCUSSION

The Liquid Hydrogen - Liquid Nitrogen Level Control System incorporates the high thermal sensitivity and resulting inverse change in resistance of commercial carbon composition resistors at cryogenic temperatures in its operation.

In general, the system includes two bridge circuits (see Figure 1) which govern the action of a control circuit for the LH₂ (or LN₂) supply valve. One bridge, having a carbon resistor sensor as one leg, is used for the lower level control. A similar bridge, also having a carbon resistor sensor as one leg, is used for the upper level control. In operation, the bridges are thrown out of balance when their respective carbon resistor sensors are immersed in LH₂ (or LN₂). The control circuit, incorporating the relay logic shown in Figure 1, is then energized in accordance with the set point controls of two meter relays, one being connected across each bridge.

The level control system can be set for either automatic or manual control. In the event of a malfunction of either bridge or of either level sensor, the system can be operated in the manual mode (by appropriate switching) whereby the liquid level can be maintained (approximately) at the upper or lower level sensor.

It will be noted that the level controller described herein may be used for either LH₂ or LN₂. However, this system can be used for any noncorrosive (to carbon composition resistors) cryogenic liquid by changing the calibration resistor R4 and the current limiting resistor R5 (Figure 2).

II CALIBRATION AND CHECKOUT PROCEDURE

A. GENERAL

The switches, lights, potentiometers, and alarms referred to in the following procedures are shown on the Control Panel, Figure 5, while their corresponding numbers, called out in parenthesis, are shown in figures 1, 2, or 4 as applicable.

B. CONDITIONS

1. The sensor resistors are to be at ambient temperature.
2. Turn all power switches, alarm switches, and the voltmeter switch (bottom row of toggle switches) to the Off position.
3. Place the CAL-RUN switch (S20, Figure 4) in the Cal position.
4. Place the LN₂ - LH₂ SELECT switch (S21, Figure 2) in the LH₂ (or LN₂) position.

C. CALIBRATION AND CHECKOUT OF BRIDGE NO. 1

1. Turn BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) to Sensor No. 1 position.
2. Turn the UPPER SENSOR, LOWER SENSOR, SENSOR NO. 2, and SENSOR NO. 1 toggle switches (S10, S9, S8 and S7, Figure 1) to Bridge No. 1 (to the left) position.
3. Turn the VOLTMETER toggle switch to Bridge No. 1 position.
4. Turn BRIDGE NO. 1 POWER toggle switch to the On position. The BRIDGE NO. 1 POWER light will come ON.
5. Check the voltage applied to Bridge No. 1 on the voltmeter. The reading should be 28 ± 1 volts (the power supply requirement).

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6. Adjust Bridge No. 1 Balance Pot (R3b, Figure 2) to read zero microamperes on Bridge No. 1 Nullmeter (M1, Figure 1). Bridge No. 1 is now balanced using resistor sensor No. 1 as one element of the bridge.

7. While watching Bridge No. 1 Nullmeter (M1, Figure 1), turn BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) to Sensor No. 2, then to Lower Sensor and then to Upper Sensor. The μ amp reading for each of these positions should not vary more than $\pm 2 \mu$ amps. (Disregard the momentary unbalance of the bridge during the switching action.)

8. Turn BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) to the Cal Res position. Adjust the Nullmeter Range Pot (R5c, Figure 2) for an 85μ amp reading. This simulates a resistor sensor immersed in LH_2 (or LN_2).

9. Turn the Bridge No. 1 Nullmeter (M1, Figure 1) set points to the following positions:

a. Lower Set Point to 80μ amps; this is the lower liquid level control point.

b. Upper Set Point to 95μ amps; this is the malfunction control point.

10. Return the BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) to position 1.

11. This completes the calibration and checkout of Bridge No. 1. Leave all controls as positioned.

D. CALIBRATION AND CHECKOUT OF BRIDGE NO. 2

1. Turn BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to Sensor No. 1 position.

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2. Turn UPPER SENSOR, LOWER SENSOR, SENSOR NO. 2 and SENSOR NO. 1 toggle switches (S10, S9, S8 and S7, Figure 1) to Bridge No. 2 (to the right) position.

3. Turn the VOLTMETER toggle switch to Bridge No. 2 Position.

4. Turn BRIDGE NO. 2 POWER toggle switch to the On position.

The BRIDGE NO 2 POWER light will come ON.

5. Check the voltage applied to Bridge No. 2 on the voltmeter.

The reading should be 28 ± 1 volts (the power supply requirement)..

6. Adjust Bridge No. 2 Balance Pot (R3b, Figure 2) to read zero microamperes on Bridge No. 2 Nullmeter (M2, Figure 1). Bridge No. 2 is now balanced using resistor sensor No. 1 as one element of the bridge.

7. While watching Bridge No. 2 Nullmeter (M2, Figure 1) switch the BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to Sensor No. 2, then to Lower Sensor and then to Upper Sensor. The μ amp reading for each of these positions should not vary more than $\pm 2 \mu$ amps. (Disregard the momentary unbalance of the bridge during the switching action).

8. Turn BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to the Cal-Res position. Adjust the Nullmeter Range Pot (R5c, Figure 2) for an 85μ amp reading. This simulates a resistor sensor immersed in LH_2 (or LN_2).

9. Turn the Bridge No. 2 Nullmeter (M2, Figure 1) set points to the following positions:

a. Lower Set Point to 80μ amps; this is the upper liquid level control point.

b. Upper Set Point to 95μ amps; this is the malfunction control point.

10. Return the BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to position 1.

11. This completes the calibration and checkout of Bridge No. 2. Leave all controls as positioned.

E. CONTROL CIRCUIT CHECKOUT WITH BRIDGE NO. 1

1. All controls are set as at the completion of the calibration and checkout of Bridges No. 1 and No. 2.

2. Check that the CAL-RUN switch (S20, Figure 2) is in the Cal position.

3. Check that the LN_2 - LH_2 SELECT switch (S21, Figure 2) is in the LH_2 (or LN_2) position.

4. Check that the BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) is in the No. 1 position.

5. Turn SENSOR SELECT switches No. 1 and NO. 2, LOWER SENSOR and UPPER SENSOR (S7, S8, S9 and S10, Figure 1) to Bridge No. 1 position (to the left).

6. Turn CONTROL POWER toggle switch (S13A, Figure 4) to the On position. The CONTROL POWER LIGHT (DS13, Figure 4) will come ON.

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7. Turn the AUTO-MAN CONTROL switch (S14, Figure 4) to the Auto position. The AUTO light (DS8, Figure 4) will come ON. (The lights and alarm indicated in section 8a will also come on.)

8. The following conditions will exist when the BRIDGE NO. 1 SENSOR SELECT rotary switch (S1, Figure 1) is positioned as follows:

a. Position 1:

- (1) LOWER SENSOR NOT IMMersed light (DS1, Figure 4) is ON.
- (2) FILLING light (DS15, Figure 4) is ON.
- (3) Bridge No. 1 Nullmeter (M1, Figure 1) has a reading of $0 \pm 2 \mu\text{amps}$.

(4) The Lower Level Alarm buzzer (DS16, Figure 1) is ON.
(This switch (S16, Figure 4) may be turned off at this time if desired).

b. Position 2 - Same as Position 1.

c. Lower Sensor Position - Same as Position 1.

d. Upper Sensor Position - Same as Position 1. (However, this position is not used in Auto Control.)

e. Cal-Res Position (this simulates the Lower Level Sensor Resistor Immersed)

- (1) The LOWER SENSOR NOT IMMersed light (DS1, Figure 4) is OFF.
- (2) The LOWER SENSOR IMMersed light (DS2, Figure 4) is ON.
- (3) The FILLING light (DS15, Figure 4) is ON.

(4) The Lower Level Alarm Buzzer (DS16, Figure 4) is not ON (when the ALARM ON-OFF switch (S16, Figure 4) is in the On position).

(5) Bridge No. 1 Nullmeter has a reading of $85 \pm 2 \mu$ amps.

9. Turn BRIDGE NO. 1 SENSOR SELECT rotary switch (DS16, Figure 1) to the Lower Sensor position (this is the normal position at the start of the filling operation).

a. Disconnect the lower level sensor resistor leads from the SENSOR SELECT SWITCH (S9, Figure 1). This will simulate an open circuit in the lower liquid level resistor sensor circuit and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) buzzer will come ON.
- (2) The MALFUNCTION light (DS5, Figure 4) will come ON.
- (3) The NOT FILLING light (DS14, Figure 4) will come ON.
- (4) The Bridge No. 1 Nullmeter will indicate over 100μ amps (over full scale).

b. Short the leads from the SENSOR SELECT SWITCH (S9, Figure 1) to the lower level sensor resistor to simulate a short in the lower level sensor circuit and the following will occur.

- (1) The malfunction alarm (DS17, Figure 4) buzzer will come ON.
- (2) The MALFUNCTION light (DS5, Figure 4) will come ON.
- (3) The NOT FILLING light (DS14, Figure 4) will come ON.
- (4) The Bridge No. 1 Nullmeter will indicate over 100μ amps (over full scale).

c. Remove the short in the lower level sensor circuit

(paragraph 9. b) and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) will remain ON.
- (2) The MALFUNCTION LIGHT (DS5, Figure 4) will remain ON.
- (3) The NOT FILLING light (DS14, Figure 4) will remain ON.
- (4) The reading on Bridge No. 1 Nullmeter will drop

back to $0 \pm 2 \mu$ amps.

d. Depress the RESET switch (S4, Figure 4) to release the Latch-Up action and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) will go OFF.
- (2) The MALFUNCTION light (DS5, Figure 4) will go OFF.
- (3) The NOT FILLING light (DS14, Figure 4) will go OFF.
- (4) The FILLING light (DS15, Figure 4) will go ON.
- (5) The reading on the Bridge No. 1 Nullmeter will remain

at $0 \pm 2 \mu$ amps.

e. This completes the control circuit checkout with Bridge No. 1. Leave all switches as positioned.

F. CONTROL CIRCUIT CHECKOUT WITH BRIDGE NO. 2

1. All controls are set as at the completion of the Control Circuit checkout with Bridge No. 1.

2. Turn BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to the Upper Sensor position (operating position for Auto control).

3. Turn the SENSOR SELECT switch (S10, Figure 1) to Bridge No. 2 position (to the right). (Operating position for Auto control.)

4. Turn BRIDGE NO. 1 SENSOR SELECTOR rotary switch (S1, Figure 1) to the Cal-Res position (simulating immersion of lower level sensor).

5. Check that the AUTO-MAN CONTROL switch (S14, Figure 4) is in the Auto position. The following conditions will now exist (simulating the liquid level between the lower and upper liquid level sensors).

a. Bridge No. 1 Nullmeter will have a reading of $85 \pm 2 \mu\text{amps}$.

b. Bridge No. 2 Nullmeter will have a reading of $0 \mu\text{amps}$.

(Under actual run conditions this meter will read somewhere between 0 and $85 \pm 2 \mu\text{amps}$, depending upon the liquid level position.)

c. LOWER SENSOR IMMersed light (DS2, Figure 4) is ON.

d. FILLING light (DS15, Figure 4) is ON.

6. Turn BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to Cal-Res position (simulating the immersion of the upper liquid level sensor) and the following conditions will occur:

a. The reading on Bridge No. 1 Nullmeter (M1, Figure 1) will remain $85 \pm 2 \mu\text{amps}$.

b. The reading on Bridge No. 2 Nullmeter (M2, Figure 1) will be $85 \pm 2 \mu\text{amps}$.

c. LOWER SENSOR IMMersed light (DS2, Figure 4) remains ON.

d. FILLING light (DS15, Figure 4) will go OFF.

e. NOT FILLING light (DS14, Figure 4) will come ON.

7. Turn BRIDGE NO. 2 SENSOR SELECT rotary switch (S2, Figure 1) to the upper Sensor position (this is the normal position at the start of the filling operation and also during a run).

a. Disconnect the upper level sensor resistor leads from the SENSOR SELECT SWITCH (S10, Figure 1). This will simulate an open circuit in the upper liquid level resistor sensor circuit and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) buzzer will come ON.
- (2) The MALFUNCTION light (DS5, Figure 4) will come ON.
- (3) The NOT FILLING light (DS14, Figure 4) will come ON.
- (4) The Bridge No. 2 Nullmeter will indicate over 100 μ amps (over full scale).

b. Short out the leads from the SENSOR SELECT SWITCH (S10, Figure 1) to the upper level sensor resistor to simulate a short in the upper level sensor circuit and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) buzzer will come ON.
- (2) The MALFUNCTION light (DS5, Figure 4) will come ON.
- (3) The NOT FILLING light (DS14, Figure 4) will come ON.
- (4) The Bridge No. 2 Nullmeter will indicate over 100 μ amps (over full scale).

c. Remove the short in the upper level sensor (paragraph 7.b) and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) will remain ON.
- (2) The MALFUNCTION LIGHT (DS5, Figure 4) will remain ON.
- (3) The NOT FILLING light (DS14, Figure 4) will remain ON.
- (4) The reading on Bridge 2 Nullmeter will drop back to

$0 \pm 2 \mu\text{amps.}$

d. Depress the RESET switch (S4, Figure 4) to release the Latch-Up action and the following will occur:

- (1) The malfunction alarm (DS17, Figure 4) will go OFF.
- (2) The MALFUNCTION light (DS5, Figure 4) will go OFF.
- (3) The NOT FILLING light (DS14, Figure 4) will go OFF.
- (4) The FILLING light (DS15, Figure 4) will go ON.
- (5) The reading on the Bridge No. 2 Nullmeter will remain

at $0 \pm 2 \mu\text{amps.}$

e. This completes the control circuit checkout with Bridge No. 2. Leave all switches as positioned.

III FILL AND LEVEL CONTROL OPERATING PROCEDURE

A. AUTO CONTROL

1. All controls are set as at the completion of the calibration and checkout procedure (Section II).

2. Recheck the following steps before setting the CAL-RUN switch to Run:

a. Bridge No. 1 Nullmeter set points should be as follows:

(1) Lower Set Point at $80 \mu\text{amps.}$ This is the lower liquid level control point.

(2) Upper Set Point at 95μ amps. This is the malfunction control point for Bridge No. 1.

b. Bridge No. 2 Nullmeter set points should be as follows:

(1) Lower Set Point at 80μ amps. This is the upper liquid level control point.

(2) Upper Set Point at 95μ amps. This is the malfunction control point for Bridge No. 2.

c. All power and alarm switches should be ON.

d. BRIDGE NO. 1 SENSOR SELECT rotary switch should be on position "1".

e. BRIDGE NO. 2 SENSOR SELECT rotary switch should be on the Upper Sensor position.

f. There should be 28 ± 1 volts on each bridge.

g. The SELECT switch should be on LH_2 (or LN_2).

h. Bridge No. 1 and No. 2 Nullmeters should each have a reading of $0 \pm 2 \mu$ amps.

i. The AUTO-MAN CONTROL switch should be on Auto.

3. Turn the CAL-RUN switch to Run. The cryostat will start filling. Positive indication will be shown by an increase in the Bridge No. 1 Nullmeter reading (as Bridge No. 1 becomes unbalanced). The filling action is manually monitored by the use of two resistor sensors (Figure 1). The lower level alarm buzzer and the LOWER SENSOR NOT IMMERSHD light will come ON during this filling action and remain ON until the liquid level reaches the level sensor resistor, at which point they will turn OFF.

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4. Upon immersion of SENSOR NO. 1, turn the BRIDGE NO. 1 SENSOR SELECT rotary switch to position 2. Immersion of No. 1 sensor will be evident by the LOWER SENSOR IMMERSSED light coming ON and the Bridge No. 1 Nullmeter will read $85 \pm 2 \mu\text{amps}$.

5. Upon immersion of Sensor No. 2, turn the BRIDGE NO. 1 SENSOR SELECT rotary switch to Lower Sensor position. From this point on the liquid level is automatically controlled (providing the AUTO-MAN CONTROL switch is set to Auto).

6. While on Auto control, the position of the liquid level between the Upper and Lower Level Sensors may be monitored by observing the reading on the Bridge No. 2 Nullmeter.

B. MANUAL CONTROL

1. All controls are set as at the completion of the calibration and checkout procedure (Section II).

2. Recheck the following steps:

a. Bridge No. 1 Nullmeter set points should be as follows:

(1) Lower Set Point at $80 \mu\text{amps}$. This is the lower liquid level control point.

(2) Upper Set Point at $95 \mu\text{amps}$. This is the malfunction control point for Bridge No. 1

b. Bridge No. 2 Nullmeter set points should be as follows:

(1) Lower Set Point at $80 \mu\text{amps}$. This is the upper liquid level control point.

(2) Upper Set Point at 95μ amps. This is the malfunction control point for Bridge No. 2.

- c. All power and alarm switches should be ON.
- d. BRIDGE NO. 1 SENSOR SELECT rotary switch should be on position "1".
- e. BRIDGE NO 2 SENSOR SELECT rotary switch should be on the Upper Sensor position.
- f. There should be 28 ± 1 volts on each bridge.
- g. The SELECT switch should be on LH_2 (or LN_2).
- h. Bridge No. 1 and No. 2 Nullmeters should each have a reading of $0 \pm 2 \mu$ amps.

3. Turn the AUTO-MAN CONTROL switch to MAN. It should be noted that on manual control, only the following lights and alarms are energized as appropriate:

- a. AUTO CONTROL light (DS8, Figure 4)
- b. MAN CONTROL light (DS7, Figure 4)
- c. MALFUNCTION light (DS5, Figure 4)
- d. Malfunction alarm (DS17, Figure 4)

4. Turn the CAL-RUN switch to the Run position; the cryostat will start filling. Positive indication will be shown by an increase in the Bridge No. 1 Nullmeter reading (as Bridge No. 1 becomes unbalanced). The filling action is manually monitored by the use of two resistor sensors (Figure 1).

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5. Upon immersion of Sensor No. 1, turn the BRIDGE NO. 1 SENSOR SELECT rotary switch to position 2. Immersion of No. 1 Sensor will be evident by the Bridge No. 1 Nullmeter reading $85 \pm 2 \mu\text{amps}$.

6. Upon immersion of Sensor No. 2, turn the BRIDGE NO. 1 SENSOR SELECT rotary switch to Lower Sensor position. From this point on the liquid level is maintained manually by observing the readings on the Bridge No. 1 Nullmeter (Lower Level Control) and the Bridge No. 2 Nullmeter (Upper Level Control) in accordance with the following conditions:

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CONDITION	BRIDGE NO. 1 NULLMETER (LOWER LIQUID LEVEL)	BRIDGE NO. 2 NULLMETER (UPPER LIQUID LEVEL)	LIQUID LEVEL
1	Under $85 \pm 2 \mu$ Amps	Under $85 \pm 2 \mu$ Amps	Below Lower Level
2	$85 \pm 2 \mu$ Amps	Under $85 \pm 2 \mu$ Amps	Between Upper and Lower Levels
3	$85 \pm 2 \mu$ Amps	$85 \pm 2 \mu$ Amps	Over Upper Level
4	95μ Amps or over		Malfunction in Lower Bridge Circuit
5		95μ Amps or over	Malfunction in Upper Bridge Circuit