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STUDY OF LOW PRESSURE APPLICATION OF THE ORBITRON

by Paul J. Bryant and Charles M. Gosselin

Prepared by
MIDWEST RESEARCH INSTITUTE
Kansas City, Mo.
for Langley Research Center

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ABSTRACT

Orbitron (refs. 1 and 2) vacuum gauge operation is reported with emphasis on the low pressure response characteristics. A linear ion current to pressure response was found for the ultrahigh vacuum range 10^{-8} to 10^{-12} torr. A sensitivity of 0.02 A/torr (dry air equivalent) was measured for a 1.0 μA emission current setting, and 0.125 A/torr for 10 μA emission. These values correspond to gauge factors of 2×10^4/torr and 1.25×10^4/torr, respectively. High sensitivity in relation to emission current results from the long orbiting path lengths which ionizing electrons travel. Still higher sensitivities and lower residual pressure equivalents can be obtained by employing longer path lengths. The moderate operation reported here gave very stable response. Residual readings were dependent upon gauge outgassing history indicating a contribution from electronic desorption as well as X-ray photocurrent. A residual of 9×10^{-12} torr (dry air equivalent) was recorded for 1.0 μA emission. Pressure response was determined by direct comparison to special modulated ion gauges and by a pressure ratio technique.

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I. INTRODUCTION

The field of vacuum technology may be divided into two major categories: (1) the evacuation of chambers, and (2) the measurement of gas pressure which exists therein. At the present state of the art it is possible to produce levels of evacuation below the operational limit of available gauges. However, a new direct reading gauge, the orbitron, has recently evolved (refs. 1 and 2) which offers a substantial promise of usefulness in the uhv range. Pressure response curves for this gauge have been determined and are presented in this report. A flow regulated pressure ratio technique was used to collect data at pressures less than 1×10^{-7} torr. Direct comparison with modulation type B-A gauges were also made.

The Orbitron gauge, which is shown schematically in Figure 1, may be described as an ionization gauge in which the ionizing electrons travel in long orbits within an electrostatic central force field. The orbitron design is unique in that electrons are trapped in an electrostatic field without the need of a crossed magnetic field.

Several advantages result from this design. The ionization efficiency per electron increases in proportion to the increased electron path lengths, therefore, a much higher gauge factor is obtained than is possible with a standard ionization gauge. Thus, an equivalent sensitivity may be obtained with a much lower electron emission current than with a standard ion gauge. The reduction of filament temperature, size and electron emission reduces such detrimental effects as: thermal and electronic desorption, chemical pumping and gas cracking, and X-ray photocurrent production.

The unique feature of electron trapping in an electrostatic field is achieved by inserting electrons into a concentric cylindrical field in such a way that their original orbit is close to the central anode. This is accomplished by simply distorting the field in the immediate vicinity of the filament so that most electrons from the filament gain the proper angular momentum component to carry them past the anode and into stable orbits as shown in the top view of Figure 1.

Electron path lengths in the orbitron are long compared to those of a standard ion gauge and the advantages listed above are obtained. However, if electron path lengths become too long, disadvantages will occur. An

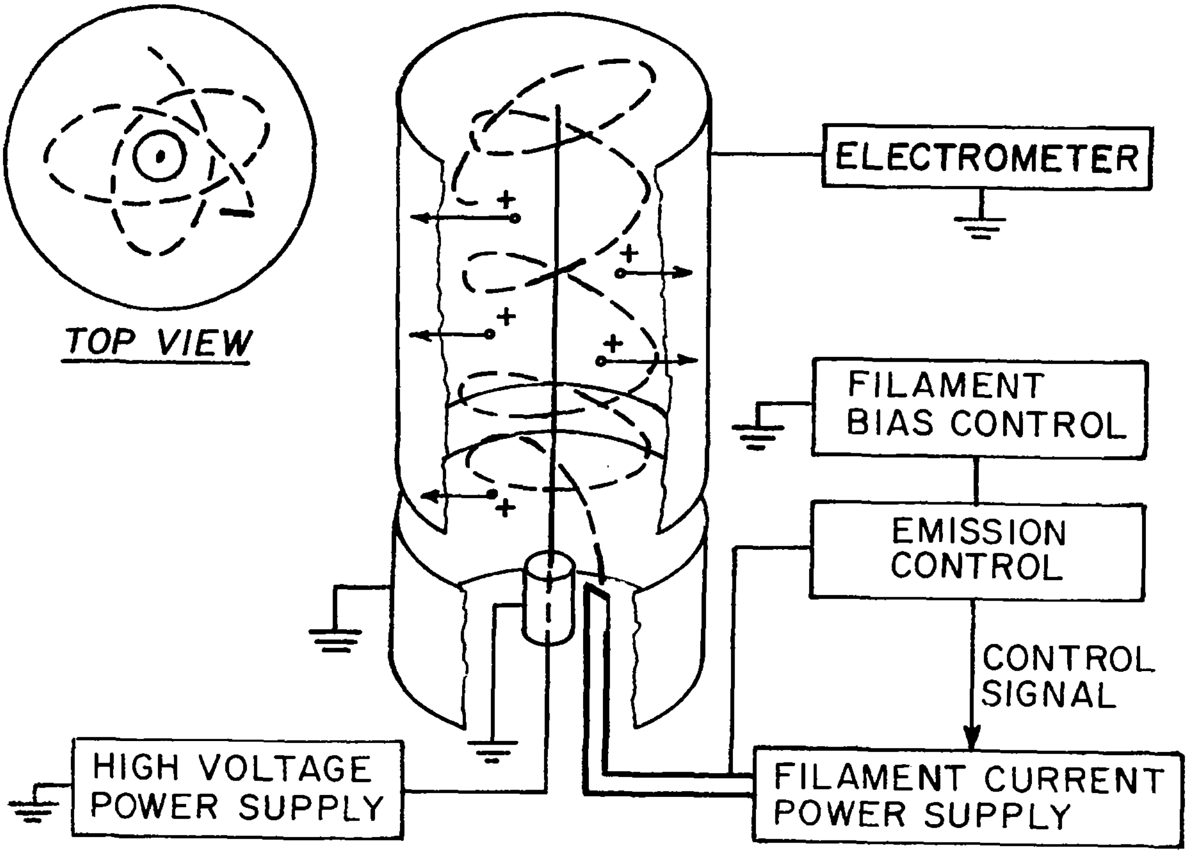

Figure 1. - Diagram of Orbitron and Major Electronic Components. Electrons emitted from the filament orbit the center electrode and generate ions by collisions with gas molecules. The ions are collected by the upper portion of the split cylindrical electrode.

uncontrolled gaseous discharge with strong electron trapping will become pressure dependent and yield a nonlinear ion current response. This condition may be avoided in the orbitron gauge by adjusting the electron path lengths to an optimum value.

Pressure ratio technique. - The pressure ratio technique is outlined schematically in Figure 2. An equilibrium flow of a test gas is established from a gas inlet system through a restricted conductance into a uhv pumping station. The pressure (P_t) at the test gauge is determined by the equation:

$$P_t = \frac{Q}{S}$$

where: Q = the equilibrium quantity of test gas flowing in the pressure ratio system per second, and

S = pumping speed of the uhv system for the test gas. The pressure at the reference gauge (P_r) is

$$P_r = \frac{Q(C + S)}{SC} ,$$

where: C = conductance between test position and reference position. The pressure ratio between the test and reference gauge positions is given by

$$\frac{P_t}{P_r} = \frac{C}{C + S} = K .$$

If C and S are constant, then K is constant and

$$P_t = K\ P_r .$$

Therefore, the pressure at the test gauge position can be determined by measuring the pressure at the reference gauge position, if the following requirements are maintained: (1) an equilibrium flow of a test gas is established, (2) the conductance between the upstream (reference) position and downstream (test) position does not change, and (3) a constant pumping

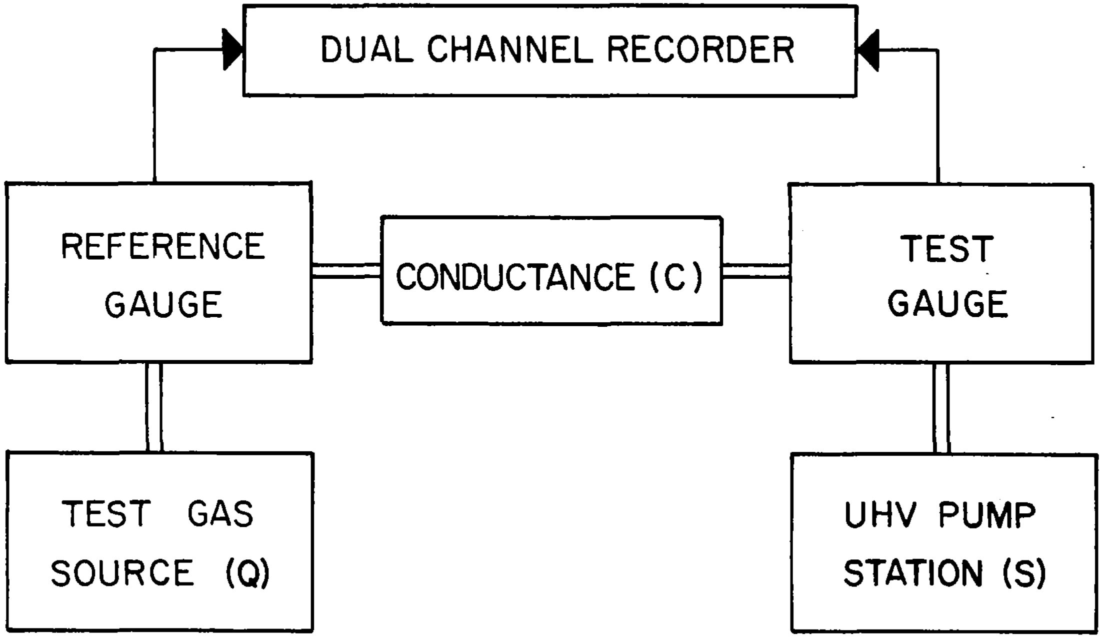

Figure 2. - Diagram of Pressure Ratio Technique. The flow (Q) of a test gas through the conductance (C) establishes a pressure ratio between the reference gauge and test gauge positions. This relationship can be used to determine the pressure in the test volume (P_t) by measurements of pressure in the reference volume (P_r) as long as; (1) P_t is contolled by equilibrium flow conditions; (2) C remains constant, and (3) the pumping speed for the test gas (S) remains constant.

speed for the test gas is maintained by the uhv system. Implied in this technique are the requirements that the background pressure is small compared with the flow regulated pressure P_t and that there are no other sources or sinks for the test gas.

The dynamic pressure-ratio method is described by Knudsen's equations (ref. 3). The application of this method to gauge calibration was discussed at the 1961 Washington meeting of the American Vacuum Society. Florescu (ref. 4) described the advantages of the two-calibrated conductance method and possible modifications to account for gauge desorption and pumping limitations. Roehrig and Simons (ref. 5) described a large system with orifice limited pumps which provided pressure calculation to 10^{-9} torr. Actually, the leak-up method of Dushman and Found (ref. 6) and the application of pressure-ratio techniques to mass spectrometer sampling (ref. 7) indicates that this basic technique has long been known and applied. This method has also been employed successfully to determine response characteristics for cold cathode gauges over their complete operating range (down to 2.5×10^{-12} torr)(refs. 8 and 9).

II. EQUIPMENT

The discussion of the equipment used in the evaluation of the orbitron is divided into two sections, (1) the ultrahigh vacuum test equipment and (2) the electronic systems. Included is a discussion of the operational procedures.

The primary design features of a uhv pressure-ratio system are twofold (1) the system must be capable of maintaining a sufficiently low background pressure so that known flow conditions will control the pressure value (P_t) at the test gauge position; (2) the system must be equipped with a suitable gas inlet subsystem including proper constant value conductances. A uhv pressure-ratio system based on these design features and on the experience gained through application (ref. 8) has been employed in evaluating the orbitron.

The uhv pressure-ratio system is shown schematically in Figure 3 and photographically in Figures 4 and 5. Special design criteria and operating techniques are employed to insure a low background pressure level. The methods employed are: (1) the entire pressure ratio system is bakeable to 400°C, (2) large area titanium sublimation pumps (TSP) are located in both the upstream (reference) and downstream (test) volumes, (3) the system can be cooled to liquid nitrogen temperature, thus reducing desorption and increasing the pumping speed of the TSPs, and (4) the reference gauges are carefully outgassed by long term filament operation and electron bombardment of metal gauge parts.

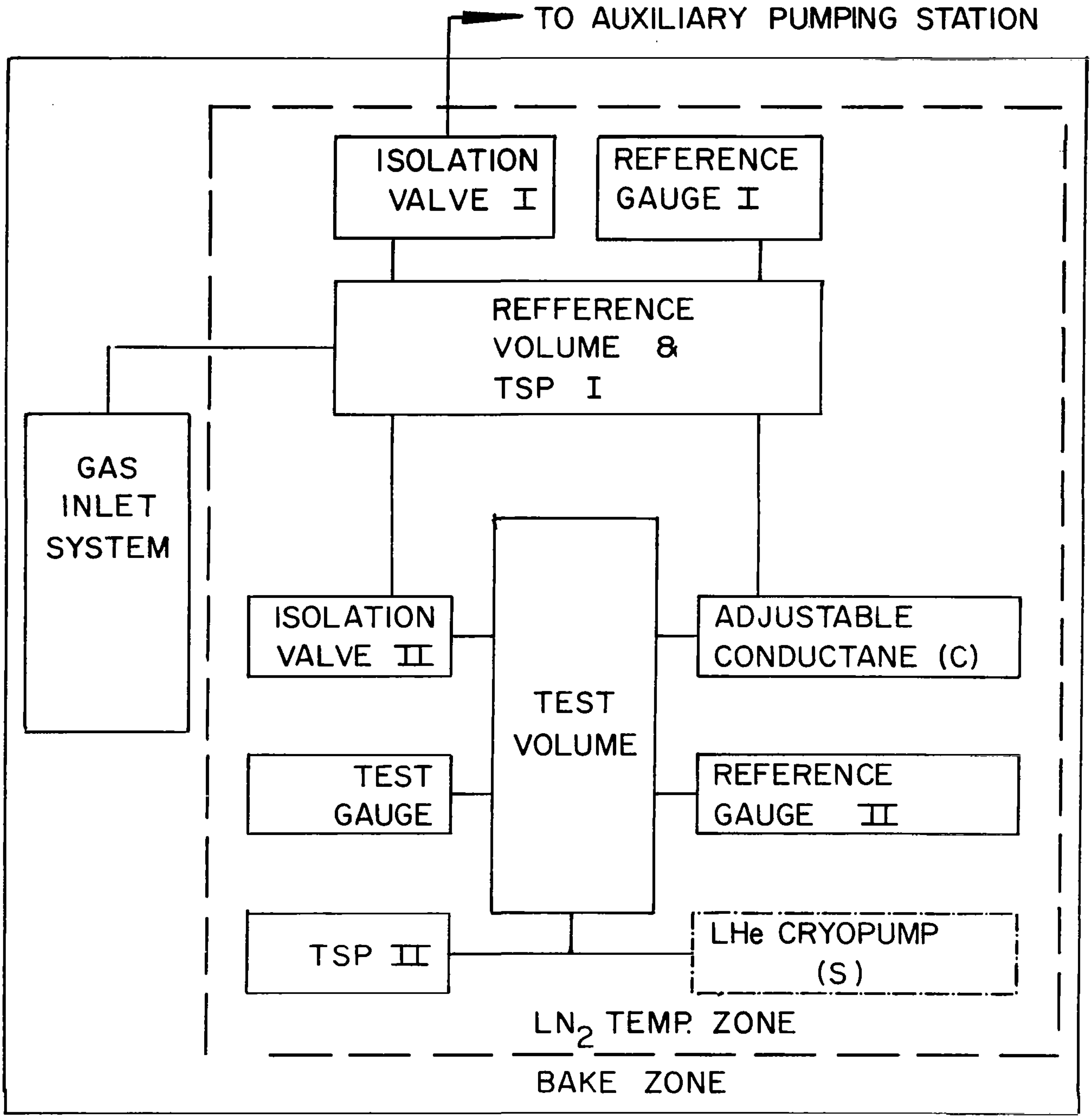

Figure 3. - Block Diagram of the UHV Pressure Ratio System. The background in the system is maintained at a low level by (1) reduced desorption resulting from cooling uhv surfaces to LN_2 temperature following 400°C bake, and (2) high pumping speed of titanium sublimation pumps (TSP) for active gases.

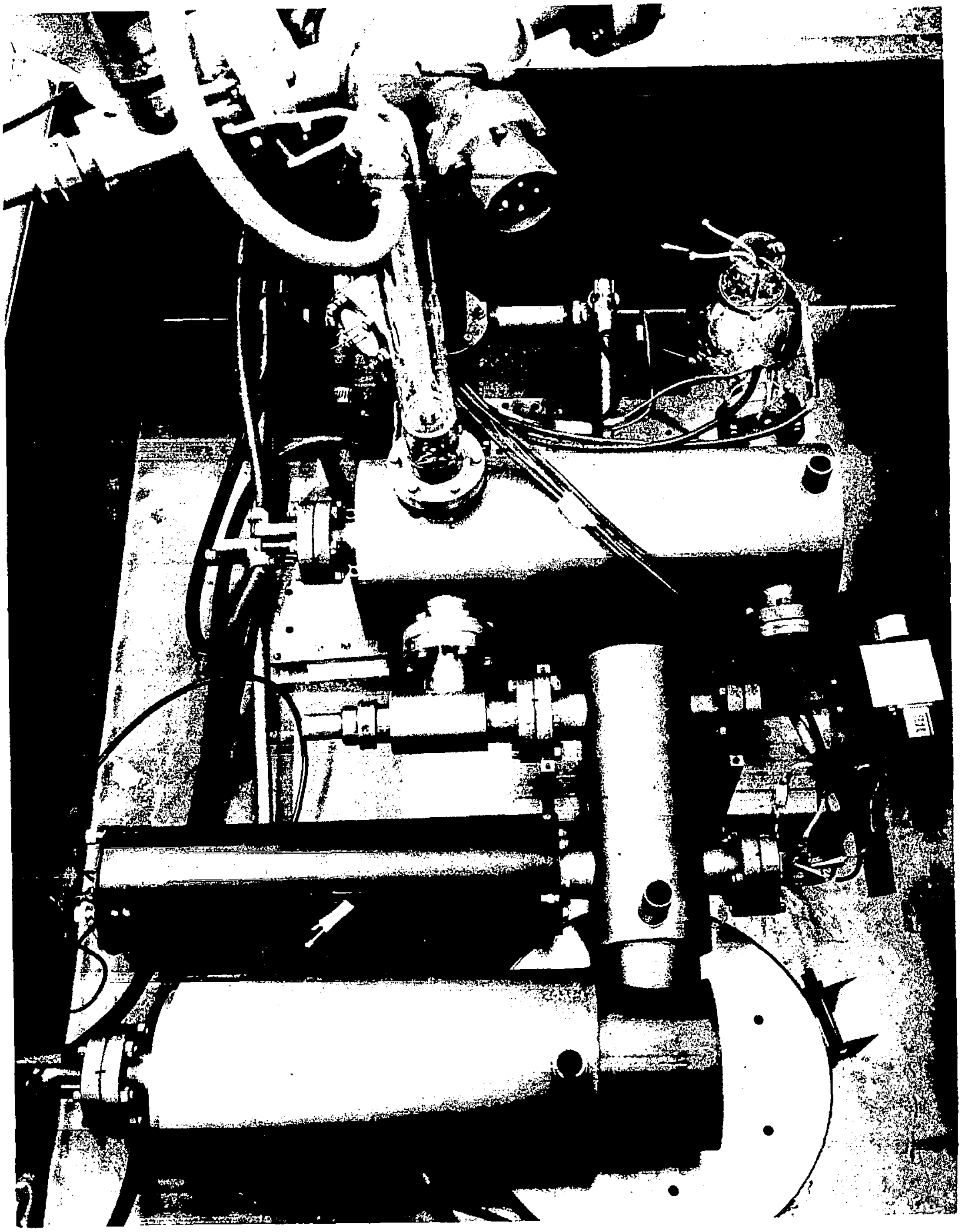

Figure 4. - Photograph of the UHV Pressure Ratio System. The entire system (except for the helium diffuser and LHe cryofinger) are mounted within an insulated stainless steel box.

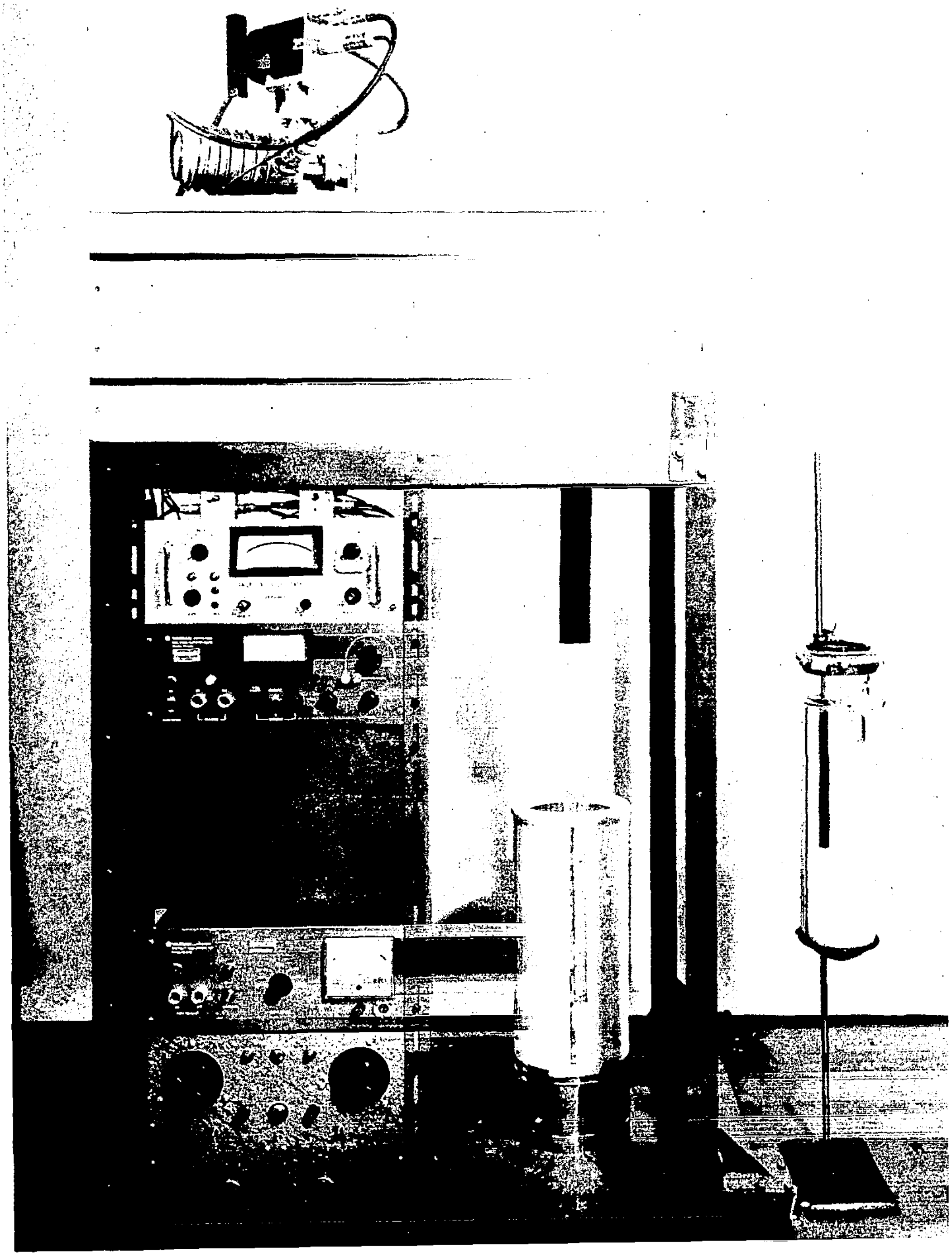

Figure 5. - Photograph of the Pressure Ratio Test Stand. The LHe cryofinger protrudes from the floor of the insulated box into a dewar assembly containing LHe. The system is evacuated during the 400°C bake by a getter-ion and TSP auxiliary pumping unit mounted above the insulated box.

The test gas used for operation of the pressure ratio system is helium. This gas is chosen since it can be easily admitted into a uhv system via a vycor diffuser. The He gas is further purified of active gas species such as H_2 and CO as it passes through TSP-I. The TSPs have no effect on He gas even when operated at liquid nitrogen temperature.

The adjustable conductance between the reference and test volumes is a Granville-Phillips variable leak valve. When the valve is full open, a pressure ratio $\frac{P_r}{P_t} = 3.4 \times 10^3$ can be maintained when the liquid helium cryopump is activated. This value for the pressure ratio is used to collect data during the study. To insure that the ratio does not change during a run the conductance (c) is held constant by establishing a constant equilibrium system temperature before a test is begun and by maintaining this condition throughout the test period. The pumping speed for the test gas is maintained constant by the use of a conductance limited LHe cryopump. Also the amount of gas which is required for one monolayer coverage of the pumping surface has been determined and the pressure ratio technique is terminated before this saturation point is reached.

The pressure ratio is verified for each run by direct B-A gauge reading at the reference gauge positions. These measurements are made at pressure levels well above the residual current limitation of the B-A gauges.

The orbitron is mounted at the test gauge position and is surrounded by a μ metal magnetic shield. It has been determined that this shield is highly desirable due to variations introduced into the ion current of the orbitron resulting from environmental changes.

The reference volume, TSP-I, test volume, and TSP-II are double walled, such that liquid nitrogen can be circulated in the enclosed space. After passing through the double walled region the LN_2 is exhausted into a liquid tight insulated box which surrounds the pressure ratio system as shown schematically in Figure 3 and photographically in Figure 4. Evaporation of the puddling LN_2 on the floor of the box provides a cold N_2 gas environment in which to conduct the pressure ratio study. The insulated box also provides a furnace environment for bakeouts up to 400°C.

The electronic equipment used to operate the orbitron is shown schematically in Figures 1 and 6. Also a photograph of the control panel is shown in Figure 7. The following list of major components were used to assemble the control unit:

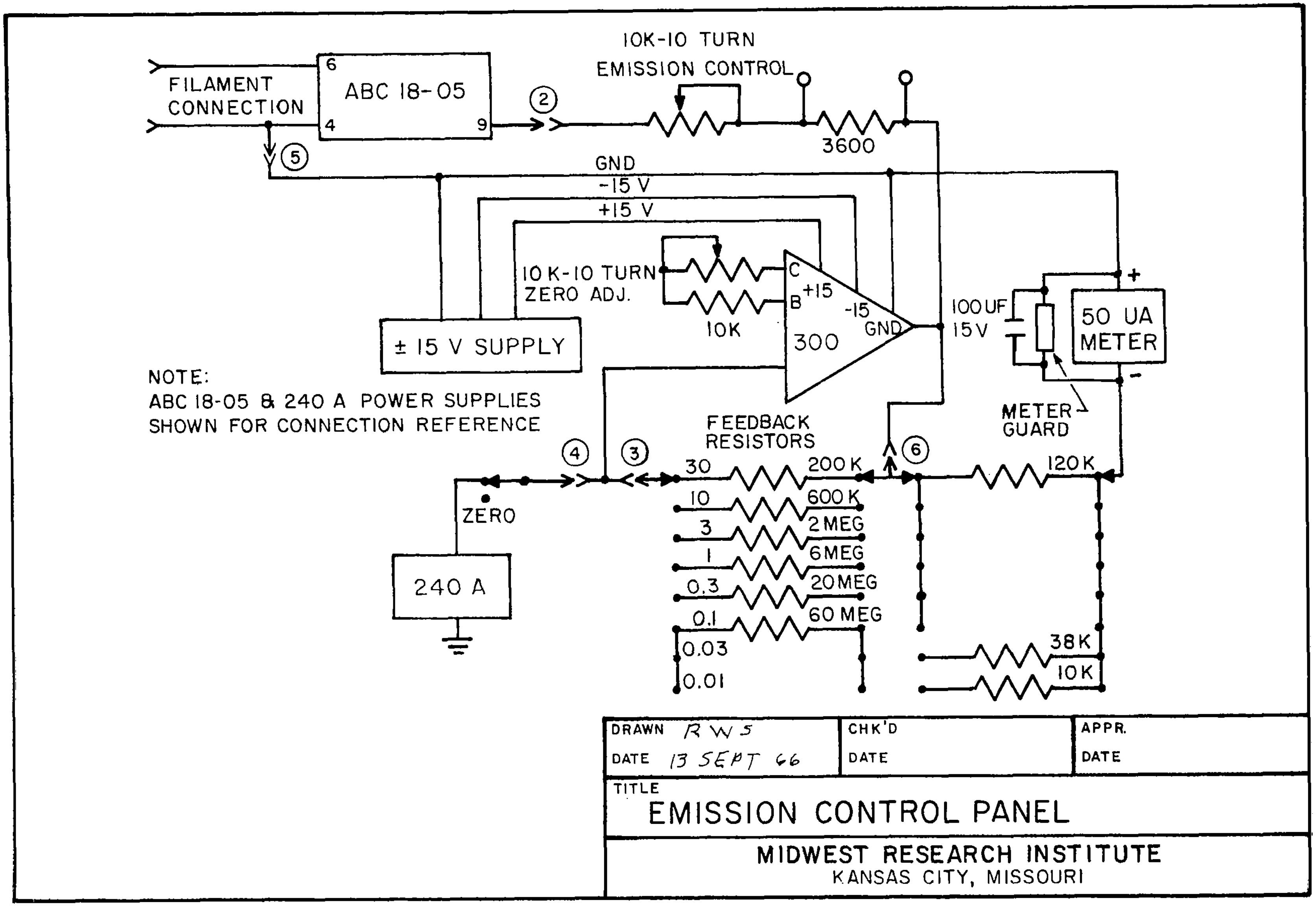

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Figure 6. - Emission Control Circuit

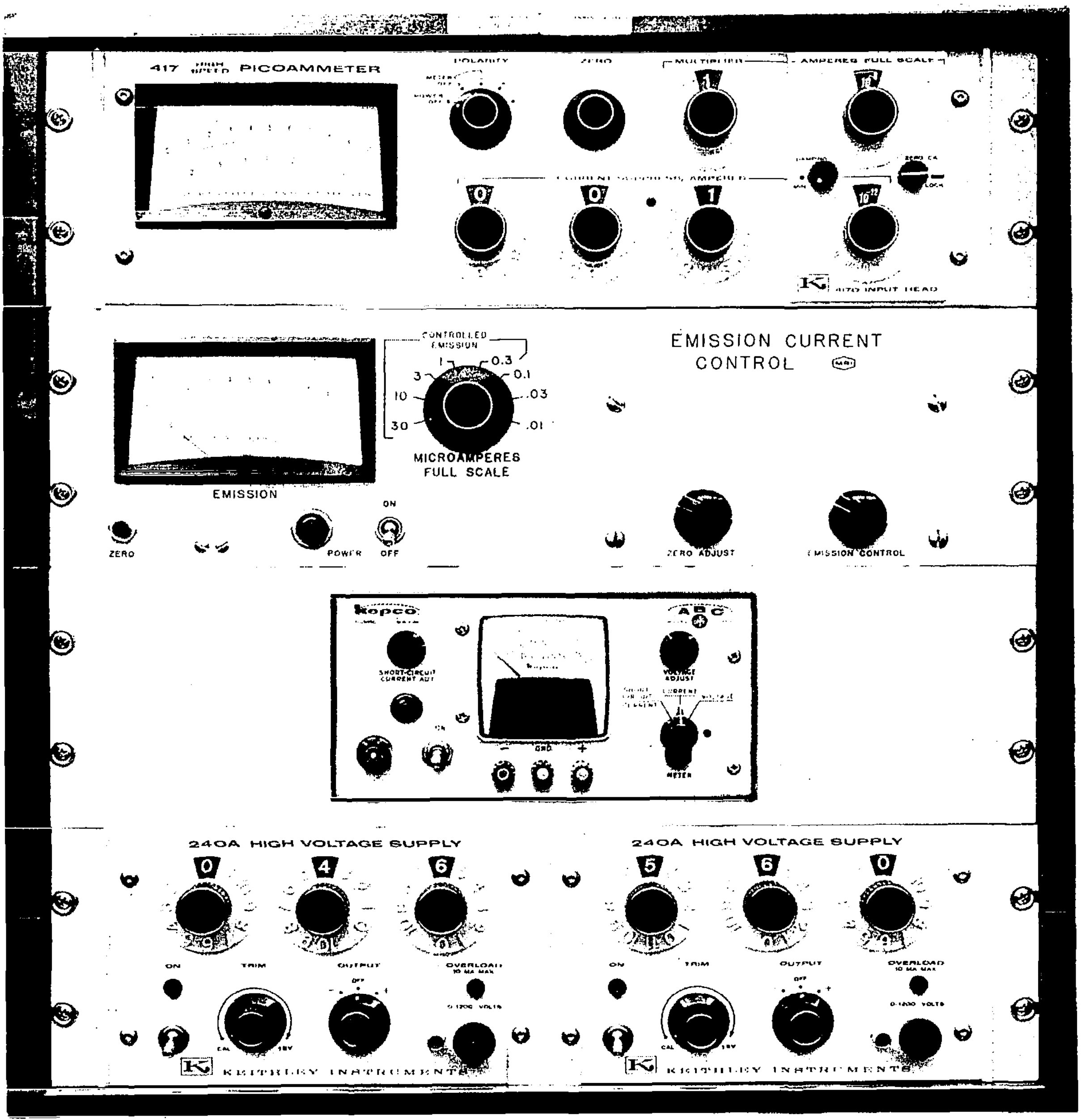

Figure 7. - Photograph of the Laboratory Control Unit for the Orbitron Gauge. This electronic package is equipped with modules which can vary the operational parameters over a wide range.

Electrometer - Keithley Model 417
Filament current - Kepco Model ABC 18-05 Power Supply
Emission Control - See Figure 6
Filament Bias - Keithley Model 240A Control
H.V. Power Supply - Keithley Model 240A

These modules were chosen so as to provide a control unit with a wide operational range thus permitting exploration of the operational parameters.

The filament current power supply and emission control are held at a potential above ground as determined by the filament bias control. The emission current is supplied from ground through the bias control to the filament. This current is monitored by the emission control unit which supplies a control signal to the filament current power supply. Regulated electron emission can be maintained at any level between 0.01 μA and 30 μA. The filament bias control is variable in one volt steps from 0-1200 volts.

The anode voltage is supplied by a high voltage power supply (0 - 1200 V).

The ion current is measured via a picoampmeter equipped with zero suppression and signal damping. Therefore, fixed background currents can be eliminated from total current response. The procedure to determine the zero suppression level is as follows: the emission current is reduced to less than 0.001 μA; the electrometer sensitivity is increased to its most sensitive range as the zero suppression control is adjusted to maintain a zero signal level; finally, the electrometer is returned to the operational range and the emission current is brought up to the desired operating level.

III. RESULTS AND CONCLUSIONS

The orbitron gauge design tested here is found to provide a linear ion current to pressure response from 2 x 10^{-7} torr down to the approach to a residual reading of 9 x 10^{-12} torr. Above 2 x 10^{-7} torr the sensitivity begins a slow increase with pressure. Sensitivity values obtained for various operating conditions ranged from 0.02 A/torr (dry air equivalent) with 1.0 μA emission current, up to 0.125 A/torr for 10 μA emission current. The gauge factor values in dry air equivalent were 1.25 x 10^4/torr for 10 μA emission and 2.0 x 10^4/torr for 1.0 μA emission.

Figure 8 presents response curves for the orbitron gauge operating at 1.0 and 10 μA emission current, labeled Ie = 1.0 μA and Ie = 10 μA. The anode voltage (V_A) was held at 560 V, and the filament bias (V_f) was set at

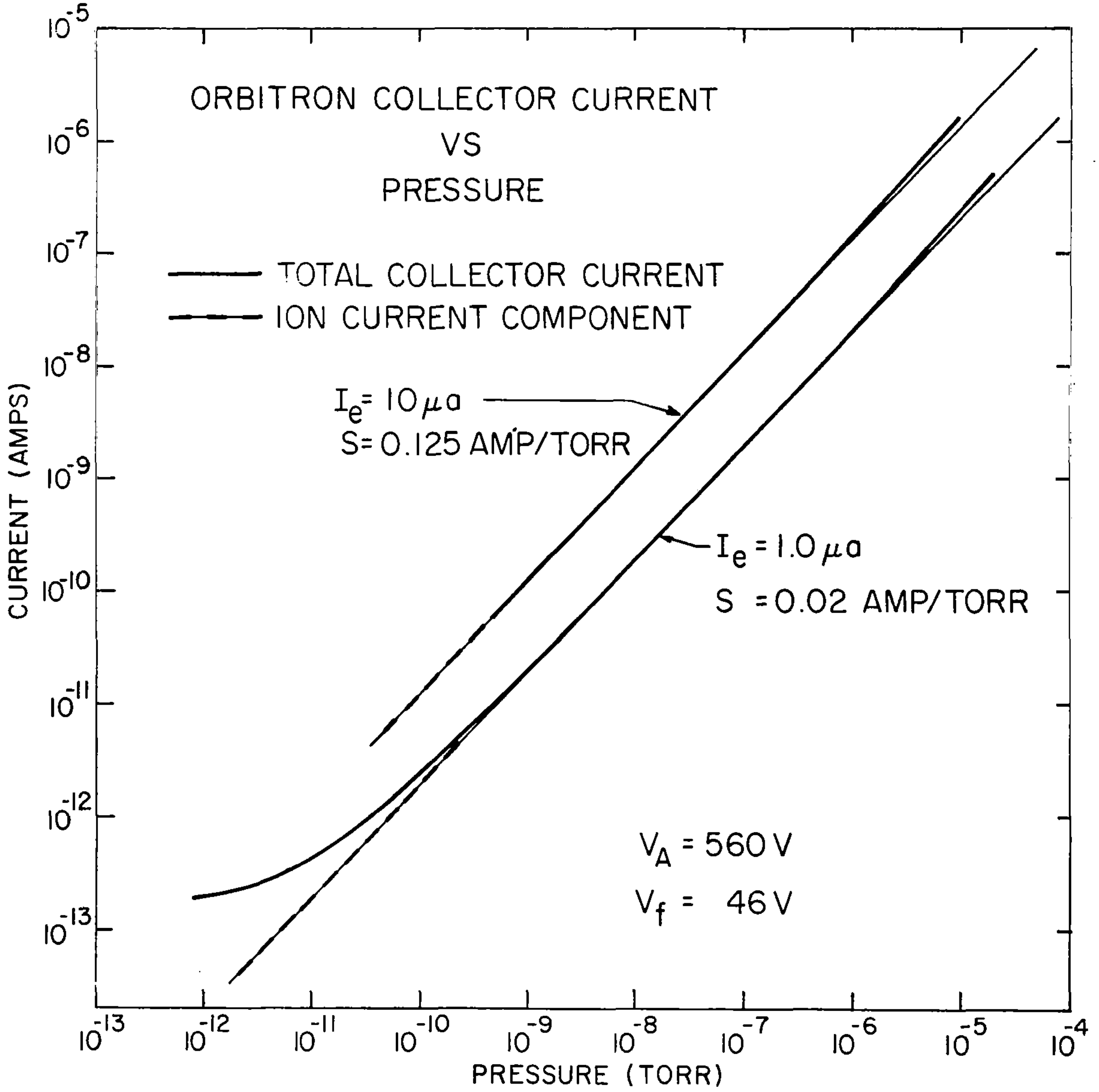

Figure 8. - Orbitron Gauge Response Curves for 1.0 and 10.0 μA Emission Settings. Residual current values may vary with gauge outgassing history; the ion current component varies linearly with pressure as determined by direct comparison to a special modulated ion gauge.

46 V above ground. These parameters gave stable operation and high sensitivity. The plots show a linear ion current to pressure response from the residual background level up to 2 x 10^{-7} torr.

The high sensitivity of the orbitron gauge is attributable to the long path lengths which the ionizing electrons execute. This high sensitivity is desirable for low pressure measurements, however, as stated in the Introduction, excessive path lengths will generate a pressure dependent discharge which is undesirable. The small sensitivity rise recorded above 2 x 10^{-7} torr (see Figure 8) is believed to be attributable to this pressure dependent phenomenon. This effect is only noticeable above 2 x 10^{-7} torr for the gauge parameters employed here and could possibly be eliminated by an adjustment of parameters for higher pressure measurements.

The response curve for a 1.0 μA emission current setting, with V_A = 560 and V_f = 46 V, is of primary interest (see Figures 8 and 9) since it presents the best overall operation for low pressure measurements. The gauge sensitivity for this setting is relatively high (0.02 A/torr, K = 2 x 10^4/torr) and the low emission value (1.0 μA) is of course, desirable for several reasons listed in the Introduction. Note that the 10 μA emission gives only a 6.25 increase in sensitivity. The sensitivities listed in this report are low compared to the values obtained by the authors of (refs. 1 and 2). Although the sensitivity of the gauge tested here is relatively low, its operation is characteristic for the orbitron gauge design. Quantitative values for the sensitivity would establish the residual value. For example, the 9 x 10^{-12} torr residual would be 2.1 x 10^{-12} torr if the sensitivity were as high as that reported in (ref. 2).

Figure 8 gives the response for 1.0 μA operation from 8 x 10^{-13} torr to 2 x 10^{-5} torr by direct comparison with a special modulated ion gauge. Figure 9 gives the low pressure response from 10^{-9} to 10^{-12} torr, also for 1.0 μA operation as determined by the pressure ratio technique. The two response curves determined by direct comparison and by the pressure ratio method show good correlation.

The approach to a residual reading of 9 x 10^{-12} torr nitrogen equivalent as seen in Figures 8 and 9 does not necessarily represent the typical operation of an orbitron. As with other ion gauges the history, outgassing conditions, and even the low pressure environment may alter the residual reading.

Residual readings were measured for the orbitron gauge at very low pressures with a negligible ion current component. The residuals showed a dependence upon gauge parameters and gauge history. Residual readings varied with emission current (see Table I), e.g., the emission current values of 1.0 and 10.0 μA gave residual currents of 5.4 x 10^{-13} and

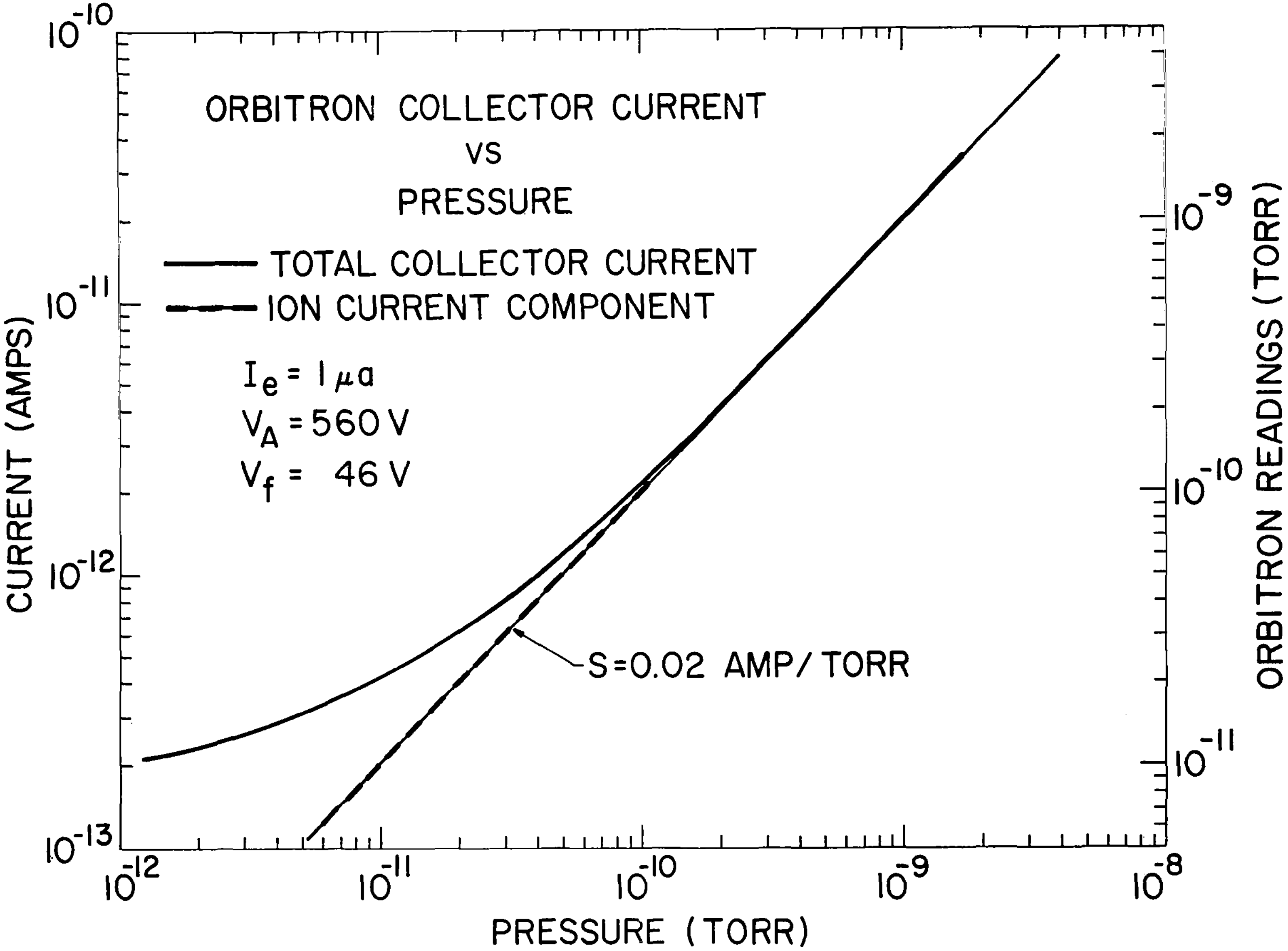

Figure 9. - Orbitron Gauge Response Curve for 1.0-μA Emission. Pressure values plotted on the abscissa were determined by the pressure ratio technique.

TABLE I

ORBITRON RESIDUAL CURRENT VS OPERATING PERAMETERS*

Emission (I_e)	Anode Voltage (V_A)	Filament Voltage (V_f)	Collector Current (I_p)
0.01 µA	560 V	46 V	- A
0.3	560	46	1.4×10^{-13}
0.6	560	46	4.2×10^{-13}
1.0	560	46	5.4×10^{-13}
2.0	560	46	1.1×10^{-12}
3.0	560	46	2.1×10^{-12}
4.0	560	46	2.6×10^{-12}
5.0	560	46	3.0×10^{-12}
6.0	560	46	3.5×10^{-12}
7.0	560	46	3.7×10^{-12}
8.0	560	46	5.4×10^{-12}
9.0	560	46	5.4×10^{-12}
10.0	560	46	5.4×10^{-12}
1.0	370	30	0.5×10^{-13}
10.0	560	46	4.8×10^{-11}
10.0	544	45	4.6×10^{-12}
10.0	517	42	4.2×10^{-12}
10.0	490	40	3.8×10^{-12}
10.0	462	38	3.2×10^{-12}
10.0	435	36	-
10.0	408	32	1.7×10^{-12}
10.0	381	31	1.1×10^{-12}
10.0	370	30	0.8×10^{-12}

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* Reflector Potential = 0 ; Pressure $< 1.0 \times 10^{-12}$ torr.

5.4×10^{-12} A respectively, at one time. Additional residual data recorded at time intervals indicated a time reduction related to outgassing of the gauge. Thus, electronic desorption of adsorbed gas species may contribute to the residual readings along with X-ray photocurrent. Note that the orbitron gauge design has a dual cylindrical collector arrangement (ref. 2) (see Figure 1) which partially nulls the X-ray photocurrent effect.

Several tables list data recorded for various operating parameters. Table I lists the residual readings obtained for various emission currents, and applied voltage values. Table II presents the ion current values recorded at a fixed pressure for various reflector tube potentials.

Data were recorded for orbitron gauge sensitivity at a fixed pressure as the filament bias to anode voltage ratio was continuously varied. A series of these plots for a set of emission current values from 1.0 to 10.0 μA is shown in Figure 10. A few resonance values are recorded, for which sensitivity is sharply reduced. Otherwise, the plots show a wide range of operating parameters for which the orbitron gauge is stable and gives a constant sensitivity.

The orbitron gauge design (ref. 2) tested here has a simple construction, gives high sensitivity and stable operation. Due to the very low emission current values employed this gauge design should be particularly useful for low pressure measurements in the presence of CO, O_2, or H_2 which have shown anomalous effects proportional to emission current.

TABLE II

COLLECTOR CURRENT VS REFLECTOR TUBE POTENTIAL*

Reflector Tube Potential	Emission 1 µA			Emission 10 µA	
	P_t = 1 x 10^{-12} Torr	P_t = 1.2 x 10^{-8} Torr	P_t = 1.9 x 10^{-9} Torr	P_t = 1.2 x 10^{-8} Torr	P_t = 1.4 x 10^{-9} Torr
0 V	0.51 x 10^{-12} A	0.9 x 10^{-10} A	3.5 x 10^{-11} A	1.5 x 10^{-9} A	1.7 x 10^{-10} A
-10	0.50	1.3	3.2	1.4	1.6
-20	0.57	1.2	3.1	1.3	1.6
-30	0.51	1.4	3.2	1.3	1.4
-40	0.55	1.6	3.1	1.2	1.4
-50	0.57	1.7	3.0	1.2	1.3
-60	-	1.7	-	1.2	-
-70	-	1.7	-	1.1	-
-80	-	1.6	-	1.1	-
-90	-	1.5	-	1.1	-

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* Operating Voltages: V_A = 560 V, V_f = 46 V, Collector = 0 V.

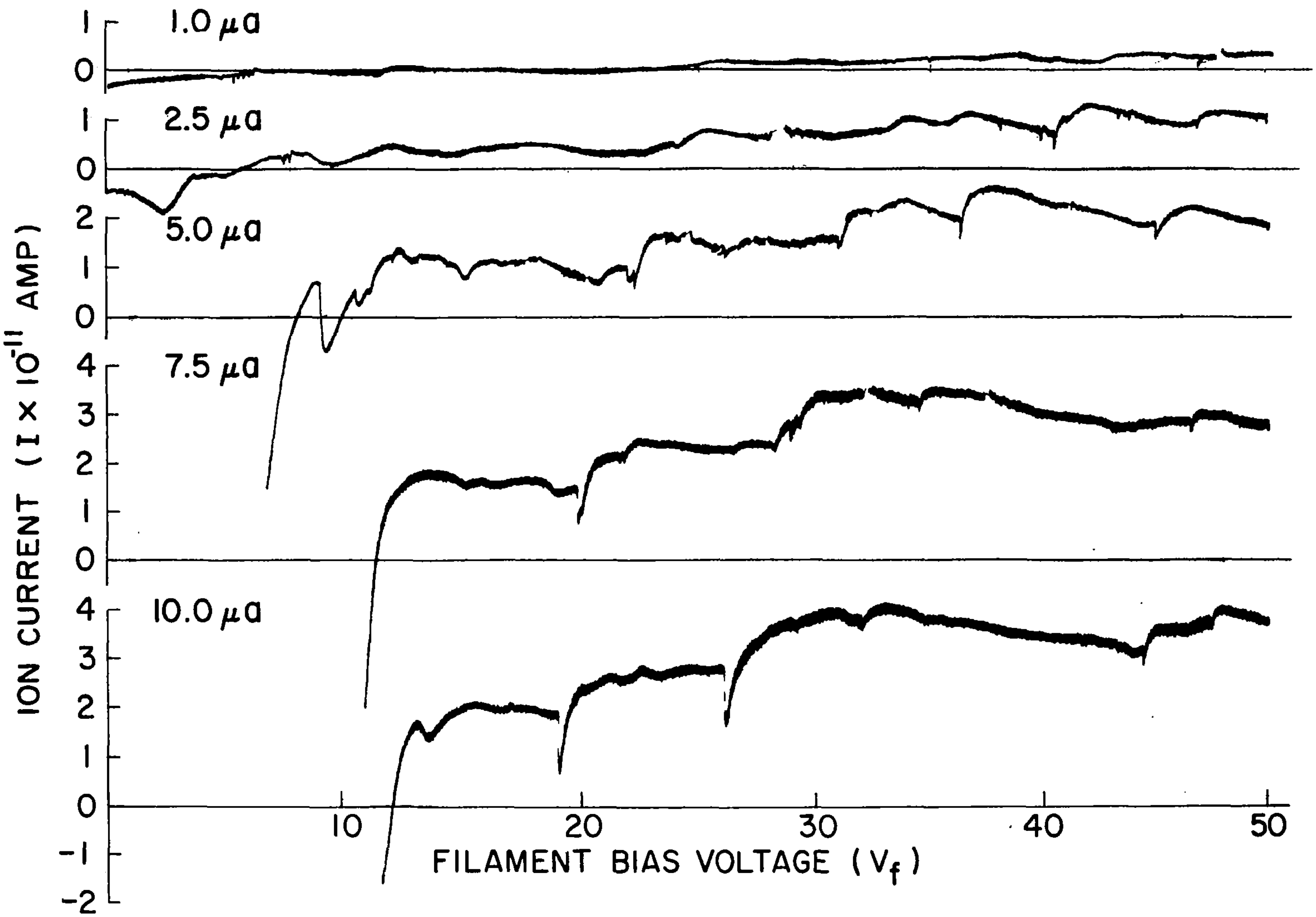

Figure 10. - Plot of Orbitron Ion Current Vs. Filament Bias Voltage. This plot displays the effect on the ion current due to slowly changing the filament bias (V_f), with V_A = 560 V and reflector tube grounded. Note that, except for a few bias values, stable operation and constant sensitivity can be maintained for a wide range of emission currents.

REFERENCES

1. Mourad, W. G.; Pauly, T.; and Herb, R. G.: Orbitron Ionization Gauge. Rev. Sci. Instr., vol. 35, 1964, p. 661.

2. Meyer, E. A.; and Herb, R. G.: Performance Study of the Orbitron Ionization Gauge. J. Vac. Sci. & Tech., vol. 4, No. 2, March-April 1967.

3. Knudsen, M.: The Law of Molecular Flow and Viscosity of Gases Moving Through Tubes. Ann. Physik, vol. 28, 1909, p. 76; Effusion and the Molecular Flow of Gases Through Openings. vol. 28, 1909, p. 999; Experimental Determination of the Vapor Pressure of Mercury at 0° and at Higher Temperatures. vol. 29, 1909, p. 179; Thermal Molecular Flow of Gases Through Tubes and Porous Bodies. vol. 31, 1910, p. 633; and Method of Determining the Molecular Weight With Very Small Amounts of Gas or Vapor. vol. 44, 1914, p. 525.

4. Florescu, N. A.: Reproducible Low Pressures and Their Application to Gauge Calibration. Trans. Natl. Vac. Symp., 1961, 1962, p. 504.

5. Roehrig, J. R.; and Simons, J. C., Jr.: Accurate Calibration of Vacuum Gauges to 10^{-9} Torr. Trans. Natl. Vac. Symp., 1961, p. 511.

6. Dushman, S.; and Found, C. G.: Studies With the Ionization Gauge. Phys. Rev., vol. 17, 1921, p. 7.

7. Honig, R. E.: Gas Flow in the Mass Spectrometer. J. Appl. Phys., vol. 16, 1945, p. 646.

8. Bryant, P. J.; Gosselin, C. M.; and Longley, W. W., Jr.: Cold Cathode Magnetron Gauge Characteristics. Jour. Vac. Sci. and Tech., vol. 3, March-April 1966, pp. 62-67; and Extreme Vacuum Technology Developments. NASA Contractor Report, Contract NASr 63(06), NASA CR-324, November 1965.

9. Bryant, P. J.; and Gosselin, C. M.: Response of the Trigger Discharge Gauge. Jour. Vac. Sci. and Tech., vol. 3, November-December 1966.

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