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CONSTRUCTION AND EVALUATION OF A NUDE FAST-RESPONSE COLD-CATHODE IONIZATION GAGE

by Alphonsa Smith and Leonard T. Melfi, Jr.

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

A nude cold-cathode gage has been employed as a means of measuring a sudden pressure increase from 10^{-6} torr to 10^{-3} torr $\left(1.33 \times 10^{-4}\ \mathrm{N/m^2}\right.$ to $\left.1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$. This report discusses the construction and evaluation of such a gage. An experimental gage was constructed to allow variation in the electrode material, gage geometry, and the electric and magnetic fields. These parameters were varied to determine a suitable combination which would give linearity, sensitivity, and other operational characteristics.

Response-time tests for an optimized experimental gage were made. These studies indicated a gage response time of less than 100 microseconds for a pressure increase from 10^{-6} torr to 10^{-3} torr $\left(1.33 \times 10^{-4}\ \mathrm{N/m^2}\right.$ to $\left.1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$. It is shown that the location of the gage in the vacuum chamber is important in effectively determining the response time histories. This gage can be employed in vacuum facilities where measurements of rapidly increasing pressures are to be obtained.

INTRODUCTION

Vacuum measurements in the range from 10^{-6} torr to 10^{-3} torr $\left(1.33 \times 10^{-4}\ \mathrm{N/m^2}\right.$ to $\left.1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$, which had previously been limited to static-pressure measurements, have been extended recently to include dynamic-pressure measurements. Measurements of the variation of pressure with time in the millisecond time range were necessitated by the firing of full-scale rockets under vacuum conditions. In order to obtain dynamic-pressure measurements required for these studies a gage was needed which had no time lag due to tubulation and was sufficiently rugged to survive subjection to high pressures and extreme operating conditions. Most commercial gages are housed in either metal or glass envelopes and are attached to the vacuum system with connecting tubing. An inherent time lag is associated with the enclosed volume and tubing and, consequently, these gages were not applicable for rapid-response-time studies.

A gage was constructed to meet the requirements for dynamic-pressure measurements in the range from 10^{-6} torr to 10^{-3} torr $(1.33 \times 10^{-4}$ N/m^2 to 1.33×10^{-1} N/m$^2)$. For laboratory testing, this gage was constructed to allow variation of the operational parameters. With the use of data obtained with this gage, a model was constructed which incorporated a suitable combination of operating parameters and included a perforated shroud to attain a more suitable operation.

Response-time studies were made by using an electrically driven microvalve to inject the calibration gas into the system at a very rapid rate. All laboratory tests were performed with nitrogen as the test medium. Since ionization gages are gas composition sensitive, additional tests in other environments would be necessary for comparison.

This report describes the construction and testing of a gage designed to make pressure measurements in the range from 10^{-6} torr to 10^{-3} torr $(1.33 \times 10^{-4}$ N/m^2 to 1.33×10^{-1} N/m$^2)$ in less than 100 microseconds. Pertinent design information is also provided. The physical quantities of this paper have been expressed in terms of both the U.S. Customary Units and the International System of Units (SI). The relationship between these two systems for the quantities used herein is presented in the appendix.

DESCRIPTION OF APPARATUS

In order to test the experimental gage, a high-vacuum system was needed. (See fig. 1.) This system contained a vacuum chamber, a 2-inch (5.08 cm) diffusion pump, and a mechanical pump. A hot-filament ionization gage was used to determine the approximate pressure in the system. The ultimate pressure of this system was approximately 5×10^{-7} torr $(6.67 \times 10^{-5}$ N/m$^2)$. The calibration gas was admitted through a variable-leak valve, and the pressure was stabilized by balancing the leak rate against the system pumping speed for gage calibrations.

A McLeod gage similar to the one used in reference 1 was used for gage calibrations. This gage, which included a cold trap to protect the vacuum system from mercury vapor, has a double range from 1×10^{-6} to 4×10^{-2} torr $(1.33 \times 10^{-4}$ to 5.33 N/m$^2)$ and from 1×10^{-5} to 4×10^{-1} torr $(1.33 \times 10^{-3}$ to 53.33 N/m$^2)$.

In order to make response-time measurements, an oscilloscope was used to permit measurement of the gage output with reference to a given pressure. Response-time records were obtained with the use of an oscilloscopic camera which photographed the instantaneous change in the gage output as a function of time. The change in the gage output caused the preset trigger of the oscilloscope to initiate the sweep and allow the gage-output wave function to be displayed on the oscilloscope screen.

The high d-c voltage required for the gage operation was supplied by a variable 300 to 3500 volt, highly regulated, power supply with a maximum load current of

25 milliamperes. The gage-output current was measured with the use of a linear microammeter with 17 ranges in overlapping one and three sequence, from 10^4 to 10^{-4} microamperes.

A fast-acting electrically driven microvalve employing the same principles as the one discussed in reference 2 was used for rapid injection of small pulses (micrograms) of the calibration gas (N_2) into the vacuum system. The microvalve has a capacity of 1 to 400 micrograms of gas at a single opening and an opening duration of from 40 to 100 microseconds.

The essential components of the experimental gage (fig. 2) are three electrodes: two circular cathodes and a cylindrical anode positioned symmetrically between the two cathodes. The operational characteristics of the gage are dependent upon the anode voltage, gage geometry, electrode material, and magnetic field. These parameters were varied or interchanged for laboratory evaluations. A permanent magnet was used to create the axial magnetic field perpendicular to the cathodes.

LABORATORY PROCEDURE

The laboratory testing of the gage was divided into two parts: gage construction, and response-time studies.

Gage Construction

From a study of cold-cathode-gage principles, it was determined that the operational characteristics of the gage are dependent upon the electrode material, gage geometry, magnetic field, and applied voltage. Experimental tests using different parameter variations were performed to obtain suitable operating characteristics. The variations of these parameters are shown in table I.

A preliminary gage was constructed and mounted into a vacuum system containing a McLeod gage. The electrode geometry for the gage and supporting equipment is shown in figure 3. For the initial investigation, four types of electrode materials were tested: copper, molybdenum, stainless steel, and aluminum. It is feasible to construct cold-cathode gages from any combination of these materials. However, it is known that the sputtering rate and work function of each material would have some effect on the gage operation. Copper was chosen as the cathode material because of the ease of fabrication. The anode was constructed of molybdenum. Visual observation of the electrometer indicated a more stable gage output with this combination. The choice of this material for the gage electrodes is supported in references 3 and 4. Cold-cathode gages have been constructed with a wire loop or a cylinder for the anode, and with circular cathodes of a larger diameter. Previous published literature (ref. 5) has stated that wire-loop anode gages are unstable. Since the anode diameter has no effect on the sensitivity of the gage (ref. 6), a 1-inch (2.54 cm) diameter was chosen as a convenient size. Several tests using different anode lengths were made. It was shown in figure 4 that the sensitivity of the gage was approximately proportional to the anode length. This figure is typical of a number of curves plotted for tests made at different pressures. The cathodes were $1\frac{1}{2}$ inches (3.81 cm) in diameter, and were placed 1/8 inch (0.32 cm) from the anode.

From a combination of tests using different anode lengths and cathode spacings, it was determined that an anode length of 1/4 inch (0.64 cm) and a cathode spacing of 1/2 inch (1.27 cm) would be used. This combination gave sufficient sensitivity for use at the desired pressure ranges. The magnetic-field strength was supplied by a permanent magnet and could be adjusted from 400 gauss to 1000 gauss $\left(\text{from } 4 \times 10^{-2} \text{ tesla to } 1 \times 10^{-1} \text{ tesla}\right)$ by inserting metal spacers in the gap between the pole faces. Figure 5 shows the dependence of the gage on the magnetic field.

Increasing the magnetic field from 400 gauss to 1000 gauss $\left(\text{from } 4 \times 10^{-2} \text{ tesla to } 1 \times 10^{-1} \text{ tesla}\right)$ caused a small change in the gage sensitivity. For this gage it was decided that a magnetic-field strength of 800 gauss $\left(8 \times 10^{-2} \text{ tesla}\right)$ would be used. In order to determine an operating voltage, tests were performed with the gage in dry nitrogen gas to obtain the voltage-current characteristics curves (fig. 6). This figure shows the ordinary diode characteristics of the gage for a fixed magnetic field of 800 gauss $\left(8 \times 10^{-2} \text{ tesla}\right)$ and a cathode spacing of 1/2 inch (1.27 cm) with pressure as a variable. A calibration of the variation of the ionization current with pressure was made for different voltage settings starting at a high voltage and decreasing until the discharge was extinguished. It can be observed from this figure that as the pressure approached 10^{-3} torr $\left(1.33 \times 10^{-1} \text{ N/m}^2\right)$, the gage appeared to reach a saturation point. This saturation effect presents a limitation for the use of the gage above this pressure.

A calibration curve of current against pressure (fig. 7) showed the calibration curves for a number of anode voltages. From these curves it was determined that an applied voltage of 1750 V would be used. At this voltage, the gage-calibration curve appeared to be more linear than that for the other voltages. A suitable combination of gage parameters, as determined from preceding experimental study, is shown in table II. In order to determine the repeatability of the data measured by the gage, several calibrations were made within a period of 3 days. (See fig. 8.) These tests indicate that there is no noticeable scatter and that the data measured by this gage is repeatable within the accuracy of the instrument used in the test.

No combination of the parameters would allow the gage to be operated above 10^{-3} torr $\left(1.33 \times 10^{-1} \text{ N/m}^2\right)$ without an erratic change in the calibration curve. It has been shown (ref. 7) that this limitation is caused by the net space charge changing from negative to positive. This increase would account for the change in the slope of the voltage-current characteristic curves. This slope change occurs at a pressure where the theory indicates that the space charge changes from negative to positive. An increase in the positive space charge can occur when there is a considerable loss of electrons from the plasma region.

In an effort to improve the gage operation at 10^{-3} torr $\left(1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$, a perforated shroud (fig. 9) was attached to the cathode as an essential part of the gage. This addition was made to retard electron loss from the gage discharge. Laboratory tests were repeated with this change in the cell geometry; it was determined from figure 10 that an applied voltage of 2000 V would be used as the operating voltage. This voltage was chosen because at 10^{-3} torr $\left(1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$ the gage appeared to be more stable at this voltage. Use of an applied voltage of 2000 V gave a gage sensitivity which was approximately the same as that of the previous gage of figure 2. The erratic change that occurred at 10^{-3} torr $\left(1.33 \times 10^{-1}\ \mathrm{N/m^2}\right)$ in the previous gage-calibration curve did not appear for the gage with the shroud (fig. 10).

Because of these improved operating characteristics, it was decided that this gage would be used. All subsequent data are referenced to this gage.

Response-Time Studies

Rapid-response tests were made by using an electrically triggered fast-acting microvalve to insert small reproducible pulses of the calibration gas $\left(N_2\right)$ into the vacuum system. The back side of the microvalve was pressurized at 4 atmospheres $\left(14.053 \times 10^{5}\ \mathrm{N/m^2}\right)$ with dry nitrogen. The test setup for rapid-response measurements is shown in figure 11. In order to record the gage response to rapid pressure increases, the system was pumped down to its ultimate pressure, 5×10^{-7} torr $\left(6.67 \times 10^{-5}\ \mathrm{N/m^2}\right)$, and nitrogen was admitted into the system to maintain a pressure equilibrium of 10^{-6} torr $\left(1.33 \times 10^{-4}\ \mathrm{N/m^2}\right)$. The oscilloscope was connected across a resistor in the gage circuit and was set to trigger simultaneously with an incoming signal. This incoming signal was caused by the change in the gage output due to the pressure increase which occurred when the microvalve was triggered. The oscilloscope centimeter scale was calibrated against a McLeod gage to correspond to a given pressure for each centimeter of deflection.

The positions of the gage with respect to the gas-inlet port are shown for position 1 in figure 12(a) and for position 2 in figure 12(b). The initial gage response is shown in figures 13 and 17 for positions 1 and 2, respectively. In order to determine the source of the transient signal shown at the beginning of the trace in these figures, additional tests were made with the gages off. The transient signal shown in figure 14 was found to be caused by the electrical triggering of the microvalve. A delayed sweep operation was used to obtain response-time records of the gage only (figs. 15 and 18). These records are combined in figure 16 and 19 to give the overall response time.

DISCUSSION OF RESULTS

Observation of figure 13 shows that the microvalve transient signal caused a damped sinusoidal wave to form at the beginning of the trace. This damped sinusoidal wave represents the operating time of the valve after being energized. The duration of this transient signal is approximately 65 microseconds. Also, there exists a delay time of 180 microseconds required for the initial gas molecules to traverse from their original position at the exit of the microvalve to the gage-discharge region. Since the gage discharge is established and the time required for the initial molecules to become ionized is less than 10^{-8} seconds (ref. 8), this delay time was attributed to the relative position of the gage and gas inlet. Figure 14 displays the microvalve transient signal only. This figure indicates that the signal was caused by electrical pickup from the microvalve trigger. (See ref. 2.) Figure 15 shows the response time of the gage over three decades of pressure, with the transient signal and the time required for the molecules to reach the gage discharge region removed by the delay sweep in the oscilloscope. From these data it can be seen that the time of response increases with each decade of pressure change. This increase can be accounted for by the fact that more molecules are required to increase the pressure from 10^{-5} torr to 10^{-4} torr $\left(\text{from } 1.33 \times 10^{-3}\ \text{N/m}^2 \text{ to } 1.33 \times 10^{-2}\ \text{N/m}^2\right)$ than from 10^{-6} torr to 10^{-5} torr $\left(\text{from } 1.33 \times 10^{-4}\ \text{N/m}^2 \text{ to } 1.33 \times 10^{-3}\ \text{N/m}^2\right)$. The same phenomena apply to other decades of pressure change. The total response time for the three decades of pressure change is shown in figure 16. This response time can be seen to be less than 100 microseconds. Response-time measurements were also made for position 2 of the gage (shown in fig. 12(b)). The time delay (fig. 17) for this position was found to be approximately 800 microseconds. This time delay is much greater than that for the gage shown in position 1. This increase was assumed to be caused by the gage being a greater distance from the gas-inlet port and the obstructed path required for the molecules to travel to the gage. Each decade of response-time measurement is shown in figure 18. With the gage in this position the overall response time (fig. 19) from 10^{-6} torr to 10^{-3} torr $\left(\text{from } 1.33 \times 10^{-4}\ \text{N/m}^2 \text{ to } 1.33 \times 10^{-1}\ \text{N/m}^2\right)$ was found to be approximately 335 microseconds. This type of distortion in the data is what one would expect to obtain from response-time tests of enclosed gages. Mounting the gage as shown in figure 12(b) decreases the conductance of the flow of the incoming gas.

When the response-time studies were made, the gage was subjected to pressures on the order of 2×10^{-2} torr $\left(2.67\ \text{N/m}^2\right)$ at each gas injection. This pressure is beyond the normal operating range for the gage; however, no significant change was noticed in the gage characteristics. Frequent cleaning of the gage over a prolonged operating time was not required. It was concluded that the gage is rugged enough to survive high pressure for short durations and require little maintenance for long periods of operation.

The associated time lags are displayed with the gage in positions 1 and 2. This time-lag difference for each gage position is assumed to be due to the location of the gage with reference to the gas inlet. It can be seen from the previous discussion that, where response time is important, consideration must be given to the methods of creating a pressure change, to the location of the pressure-sensing element with reference to the region of pressure change, and to the conductance of the immediate region where pressure measurements are desired.

CONCLUSIONS

A nude fast-response cold-cathode gage was constructed. The design data and operational characteristics were obtained and the following conclusions are made:

1. From the design data, it is concluded that:

(a) The construction of a cold-cathode gage which can be effectively operated above 10^{-3} torr $\left(1.33 \times 10^{-1}\ \text{N/m}^2\right)$ is doubtful.

(b) Data from cold-cathode gages are repeatable when the gages are properly constructed.

(c) Subjecting the gage to overpressure for a short duration causes no significant change in the gage characteristics.

(d) The use of a perforated shroud around the gage improves its stability at higher pressures.

2. From the operational data, use of this type of gage as a means to measure very rapid pressure changes leads to the following conclusions:

(a) Location of the gage and conductance of the system is an important factor in the calculation of pressure as a function of time.

(b) Gages to be used for response-time measurements should have a maximum conductance and should be placed directly in the region for which the measurements are desired.

(c) The total system including the process for raising the pressure is capable of indicating a pressure change from 10^{-6} torr to 10^{-3} torr $\left(\text{from } 1.33 \times 10^{-4}\ \text{N/m}^2 \text{ to } 1.33 \times 10^{-1}\ \text{N/m}^2\right)$ in less than 100 microseconds; thus, the gage must respond in less than 100 microseconds.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., October 26, 1965.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960, in Resolution No. 12 (ref. 9). Conversion factors for the units used herein are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI unit
Magnetic flux density (field) . . .	gauss	1.00×10^{-4}	tesla
Length.	in.	2.54×10^{-2}	meter (m)
Pressure	torr	1.333×10^{2}	newton/meter^2 (N/m^2)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI unit.

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TABLE I.- PARAMETERS OF TEST GAGE

Electrode material	Copper, molybdenum, stainless steel, and aluminum
Gage geometry:	
Cylindrical anode:	
Length	1/8 to 3/4 in. (0.32 to 1.91 cm)
Diameter	1 in. (2.54 cm)
Thickness	0.060 in. (0.152 cm)
Circular cathode:	
Diameter	$1\frac{1}{2}$ in. (3.81 cm)
Spacing	3/8 to 1 in. (0.95 to 2.54 cm)
Thickness	0.030 in. (0.076 cm)
Magnetic field	400 to 1000 gauss $\left(4 \times 10^{-2}\text{ to }1 \times 10^{-1}\text{ tesla}\right)$
Applied voltages	300 to 2500 volts

TABLE II.- PARAMETERS USED FOR GAGE CONSTRUCTION

Electrode material:	
Anode	Molybdenum
Cathode	Copper
Gage geometry:	
Cylindrical anode:	
Length	1/4 in. (0.64 cm)
Diameter	1 in. (2.54 cm)
Thickness	0.060 in. (0.152 cm)
Circular cathode:	
Diameter	$1\frac{1}{2}$ in. (3.81 cm)
Spacing	1/2 in. (1.27 cm)
Thickness	0.030 in. (0.076 cm)
Magnetic field	800 gauss $\left(8 \times 10^{-2}\text{ tesla}\right)$
Applied voltage	1750 volts

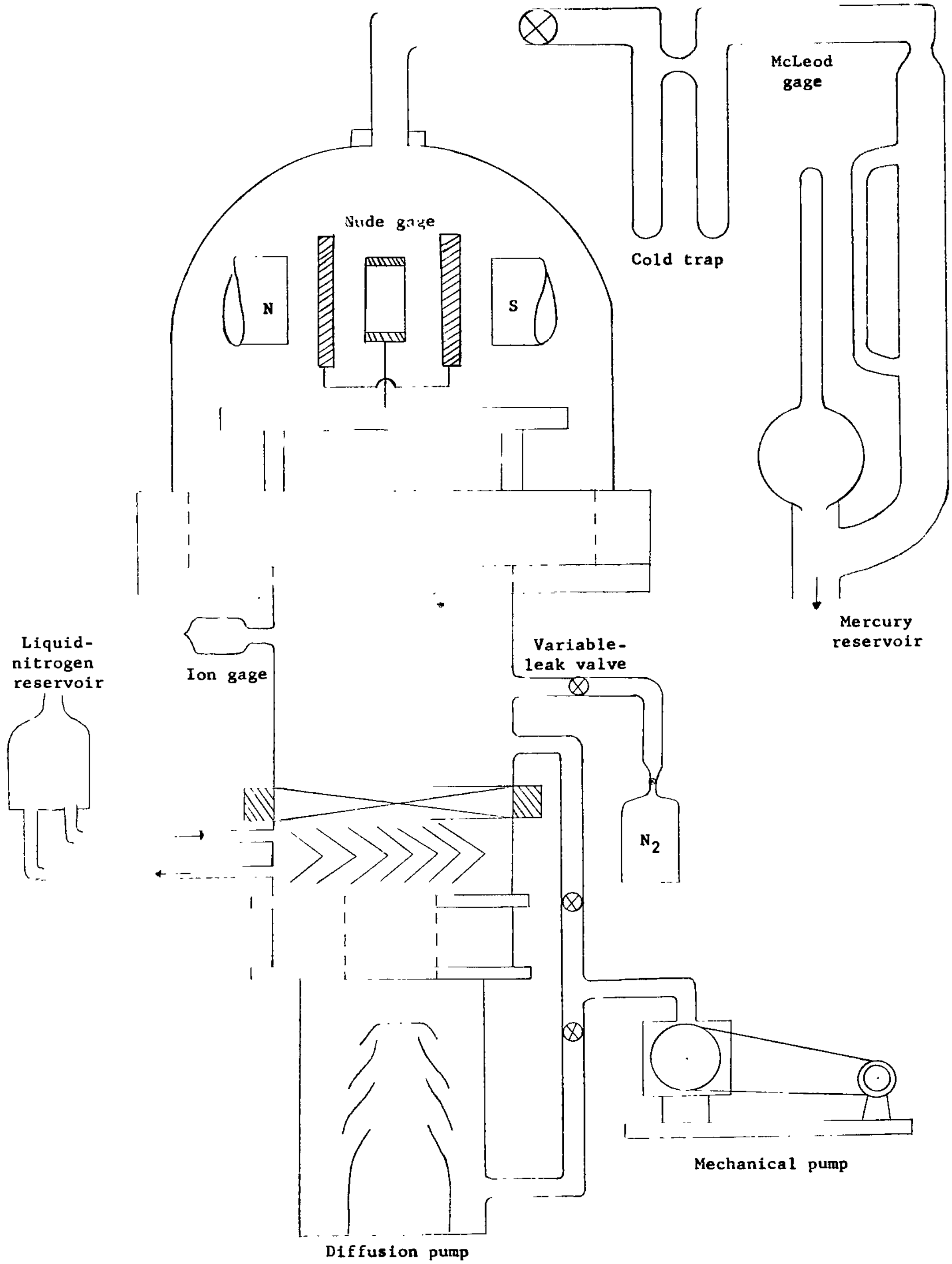


Figure 1.- High-vacuum system.

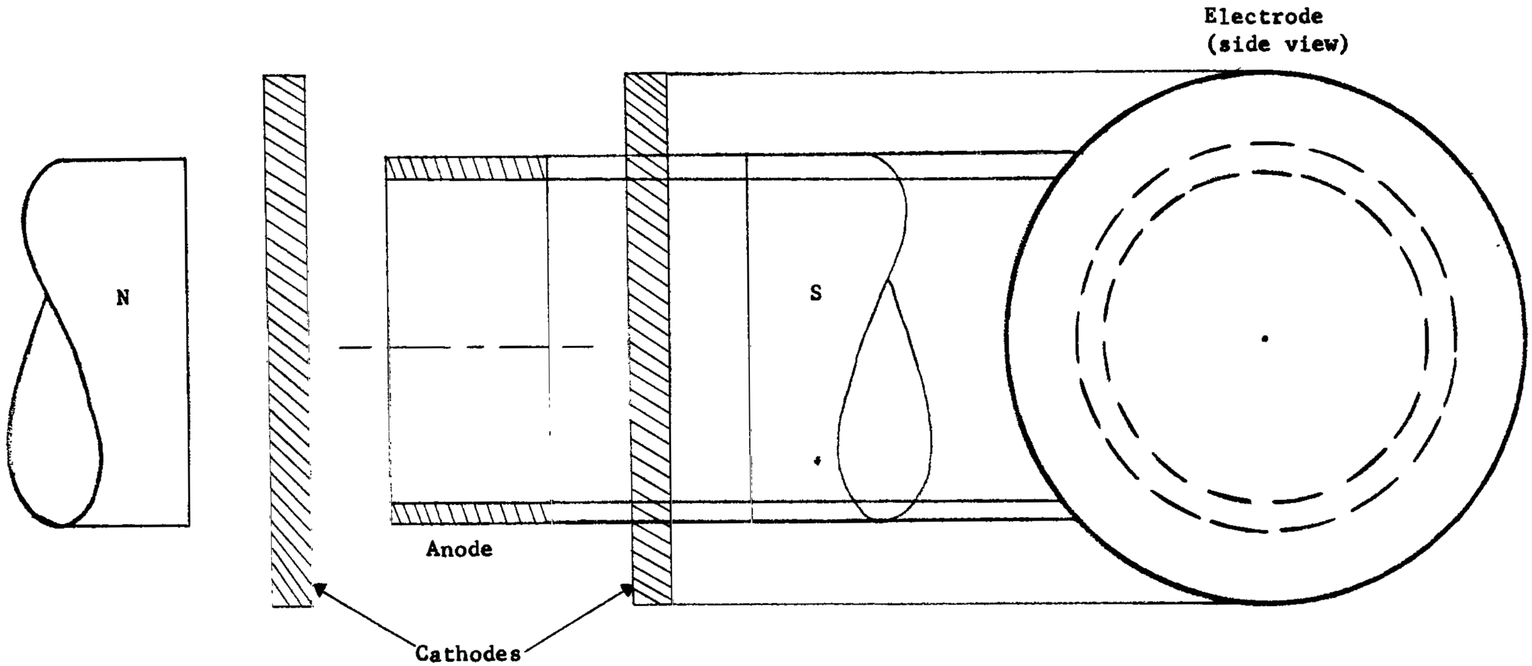


Figure 2.- Gage geometry.

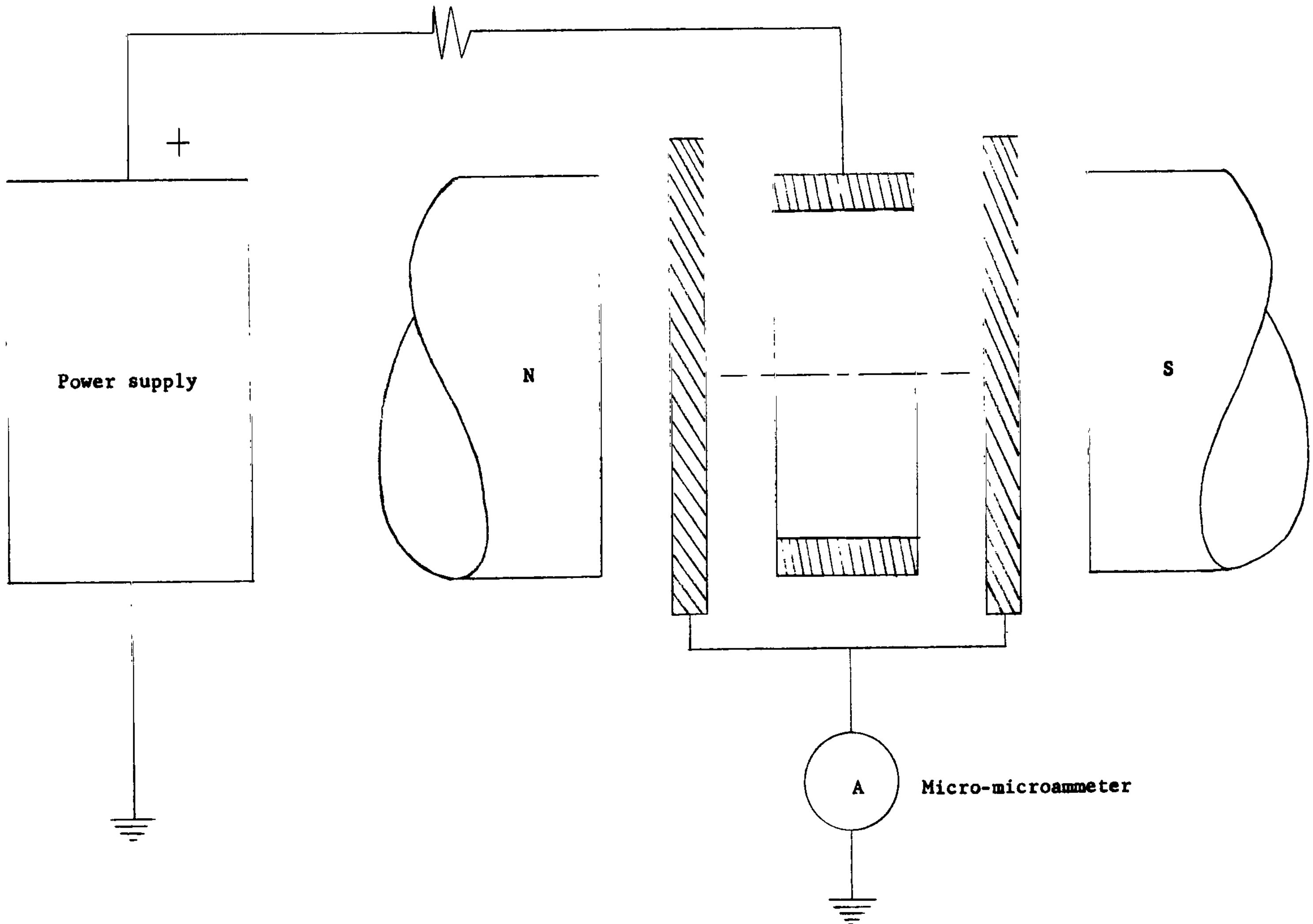


Figure 3.- Diagram of electrode geometry and supporting equipment.

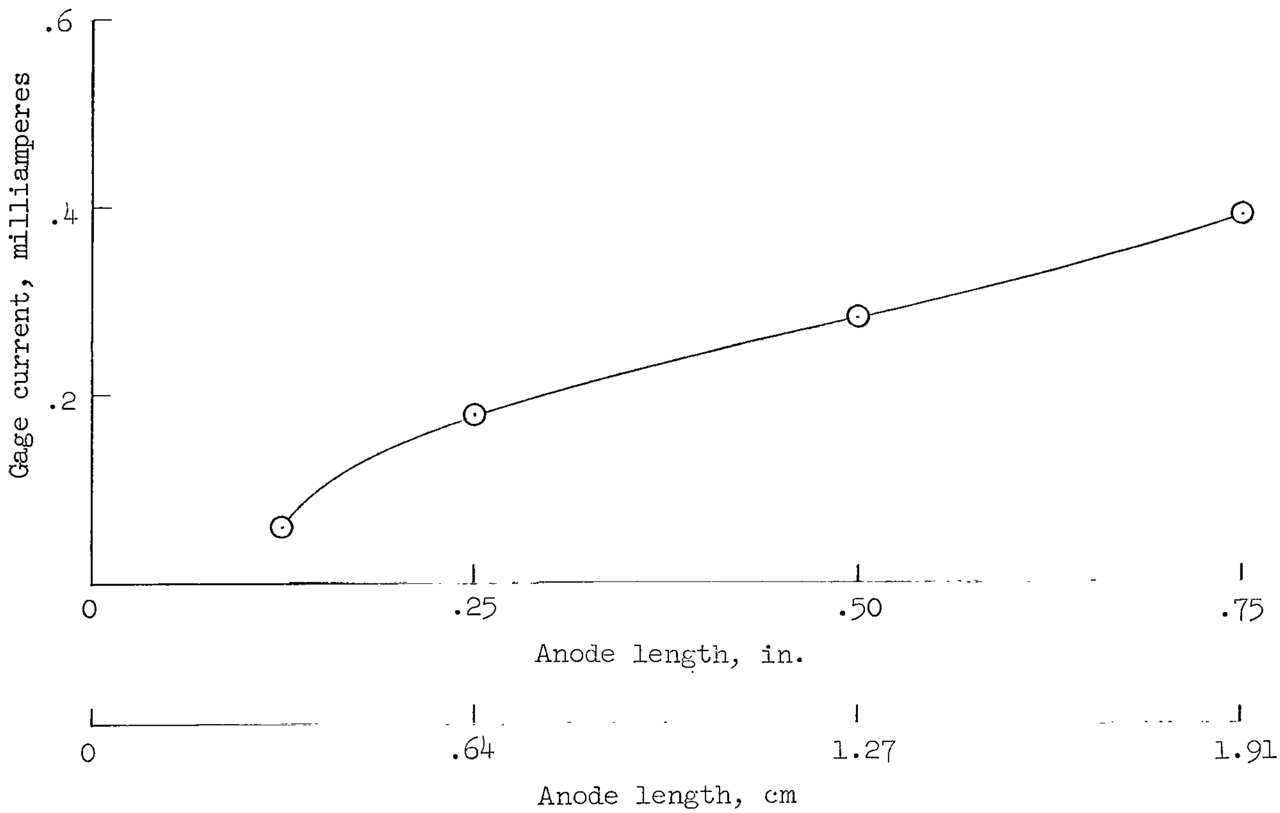


Figure 4.- Variation of gage current with anode length. Applied potential, 1750 volts; magnetic field, 800 gauss (8×10^{-2} tesla); pressure, 1.0×10^{-4} torr (1.33×10^{-2} N/m^2).

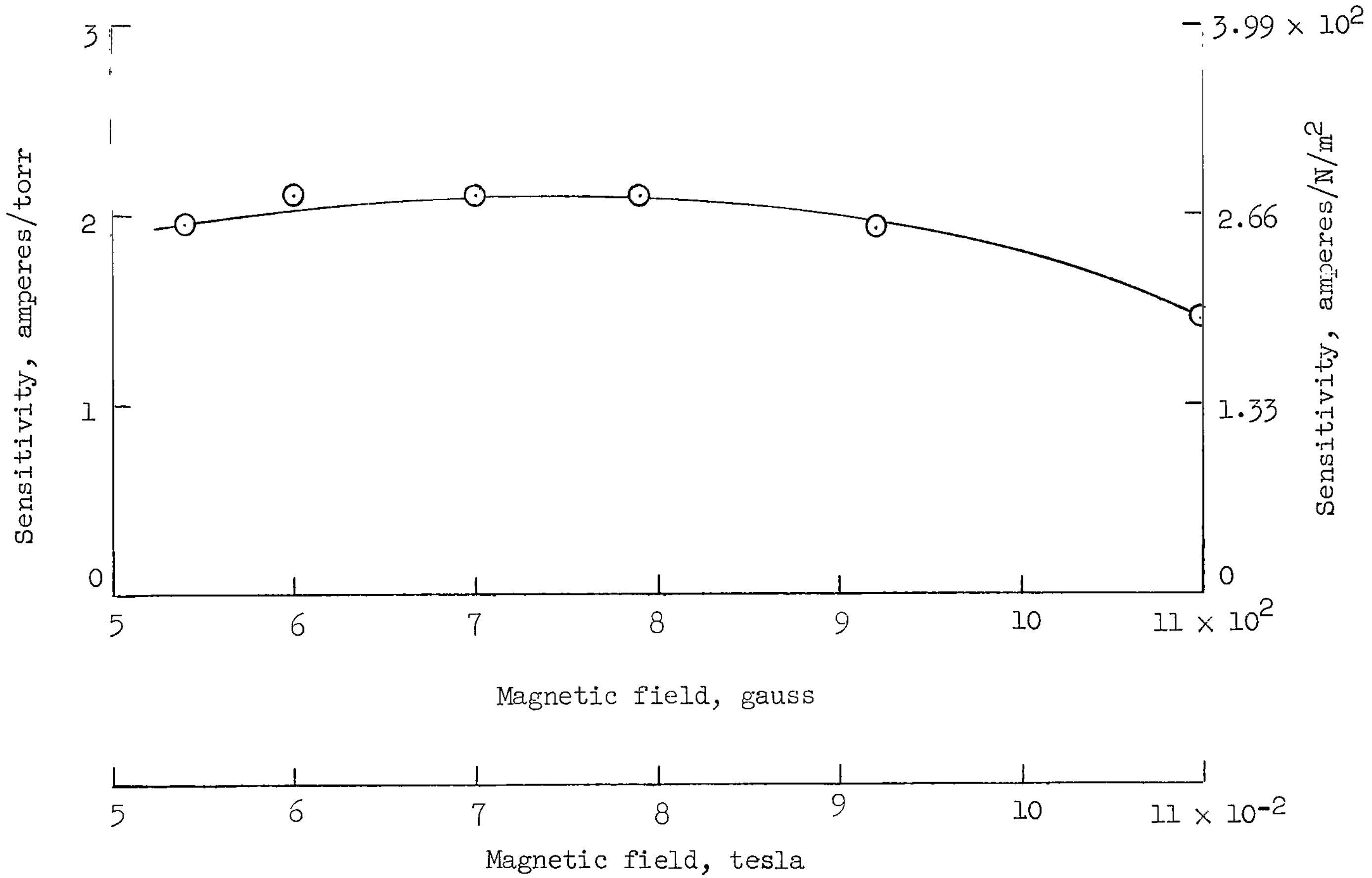


Figure 5.- Gage sensitivity as a function of magnetic field at 2×10^{-4} amperes. Applied potential, 1750 volts; anode length, 1/4 in. (0.64 cm); gage current, 2×10^{-4} amperes.

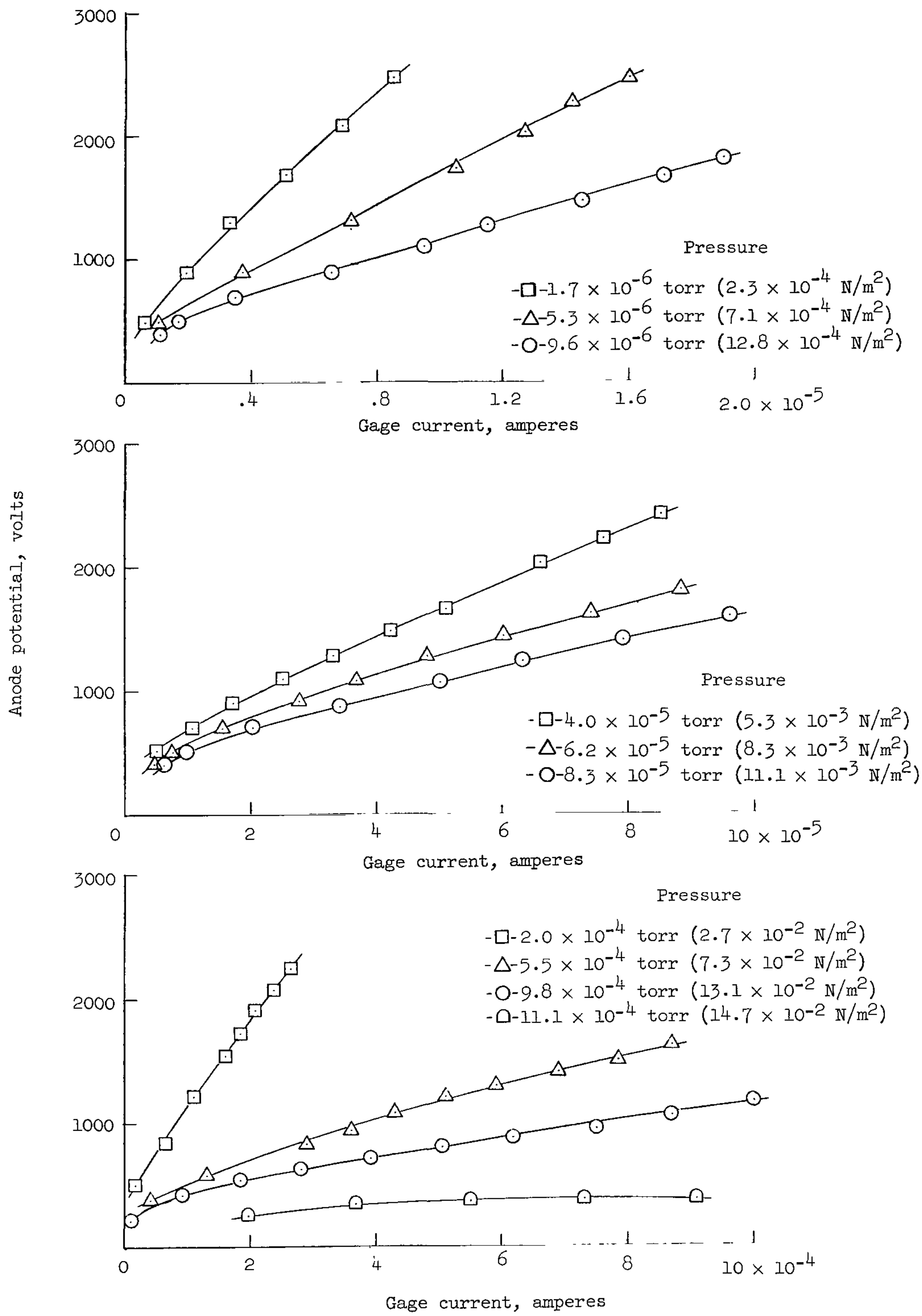


Figure 6.- Voltage-current characteristic curves. Magnetic field, 800 gauss (8×10^{-2} tesla); cathode spacing, 1/2 in. (1.27 cm).

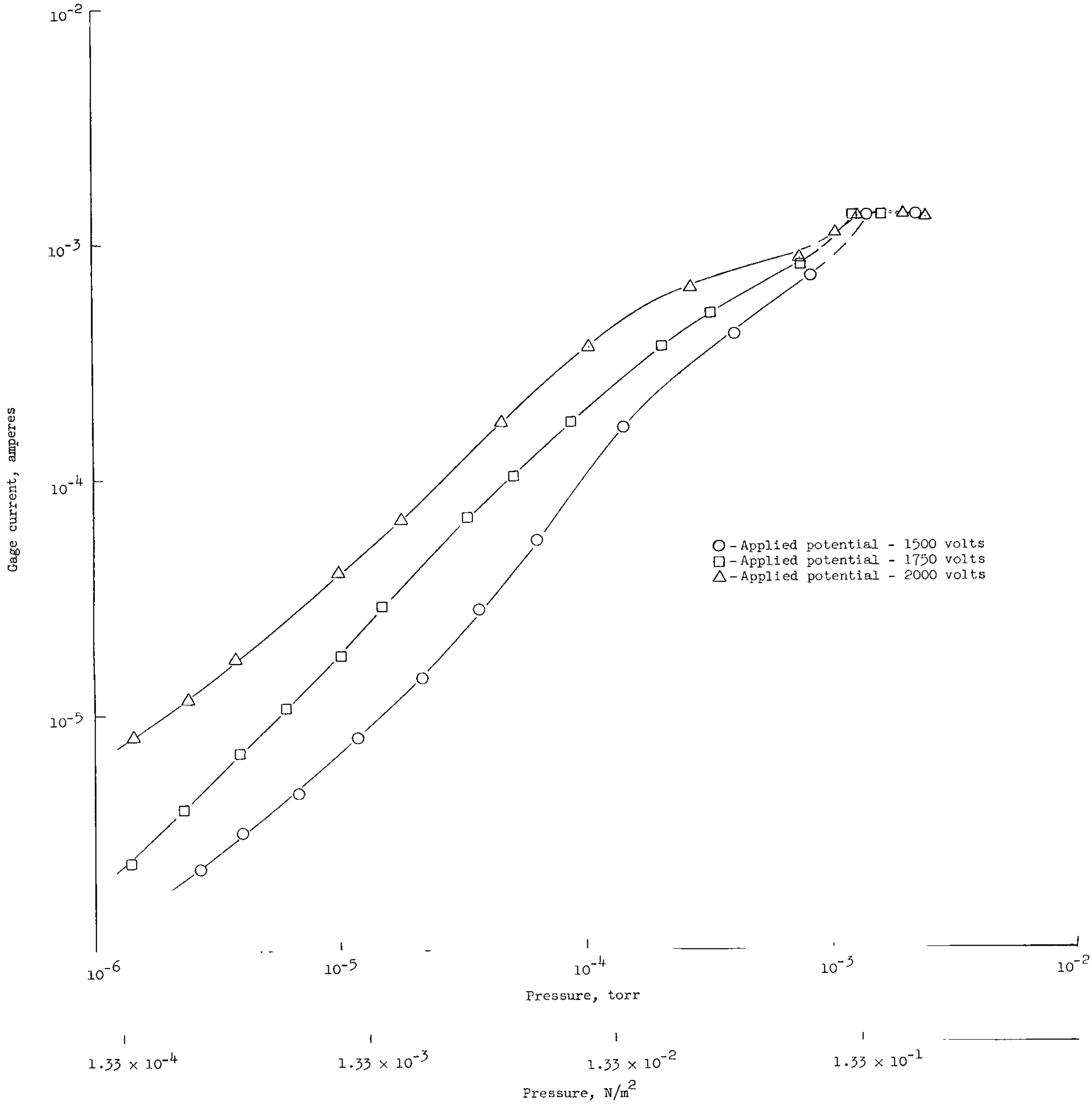


Figure 7.- Gage-calibration curves. Cathode spacing, 1/2 in. (1.27 cm); magnetic field, 800 gauss (8×10^{-2} tesla).

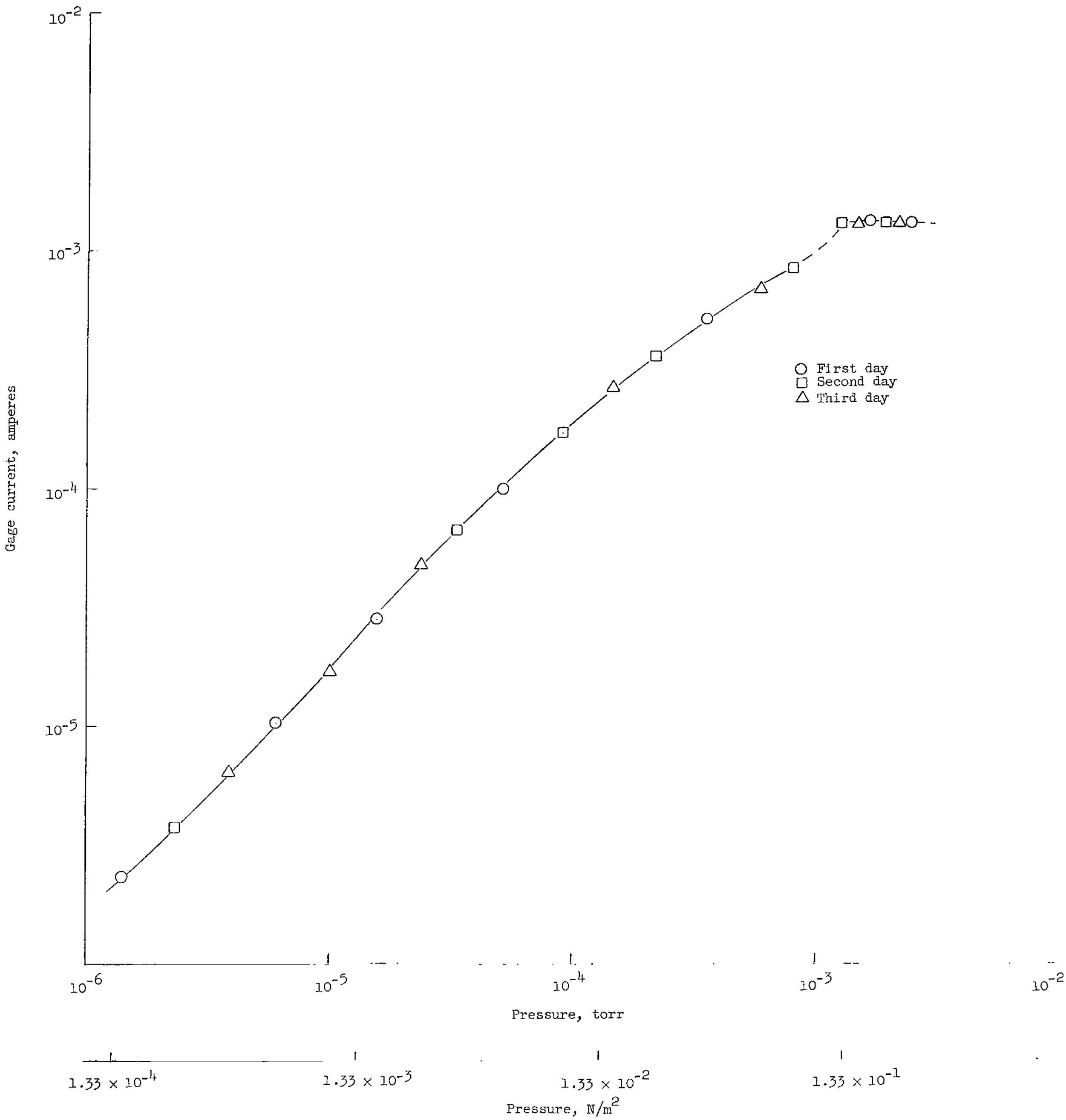


Figure 8.- Gage-repeatability curve. Applied potential, 1750 volts; cathode spacing, 1/2 in. (1.27 cm); magnetic field, 800 gauss (8×10^{-2} tesla).

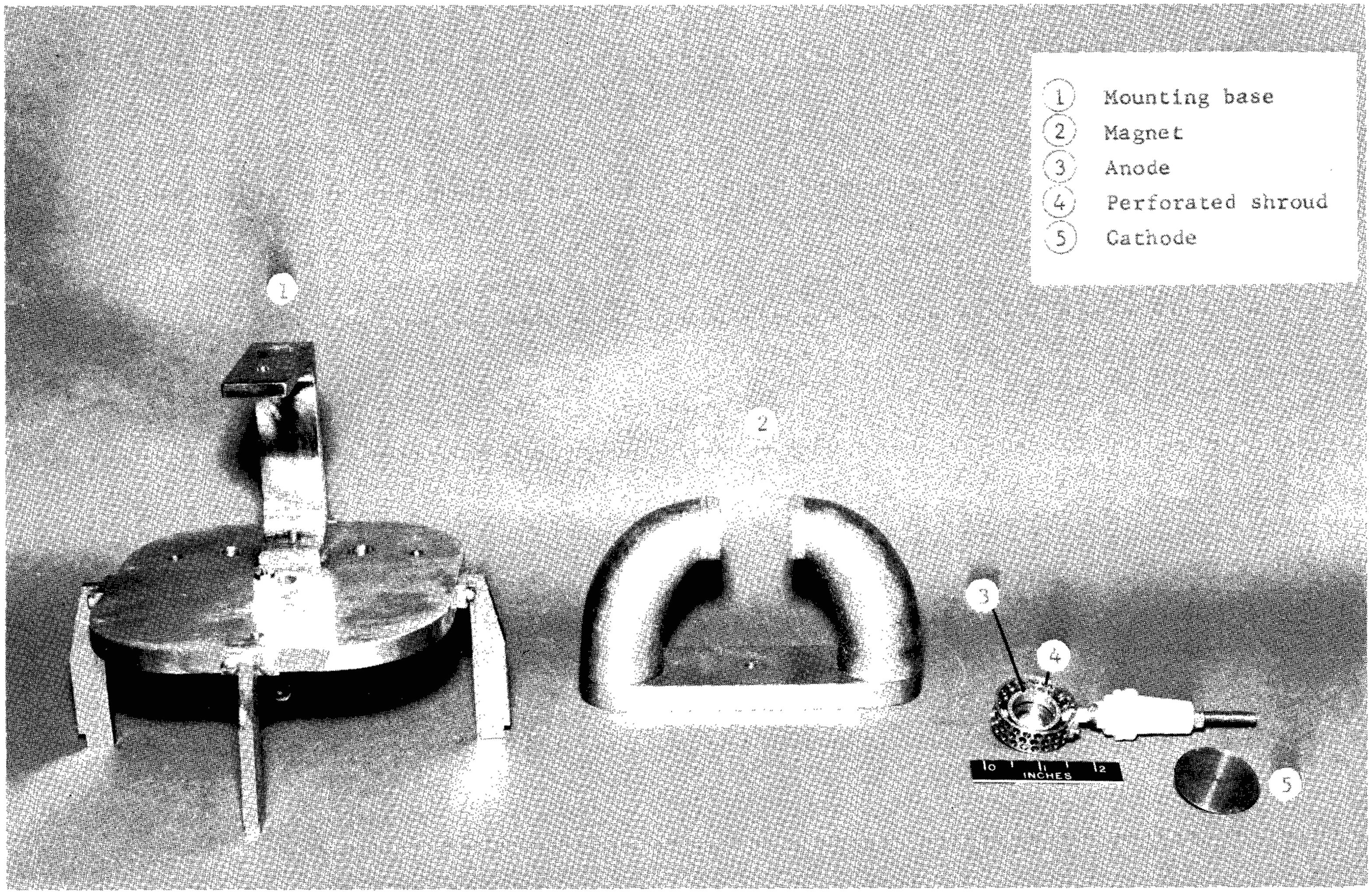


Figure 9.- Gage assembly. L-64-4020.1

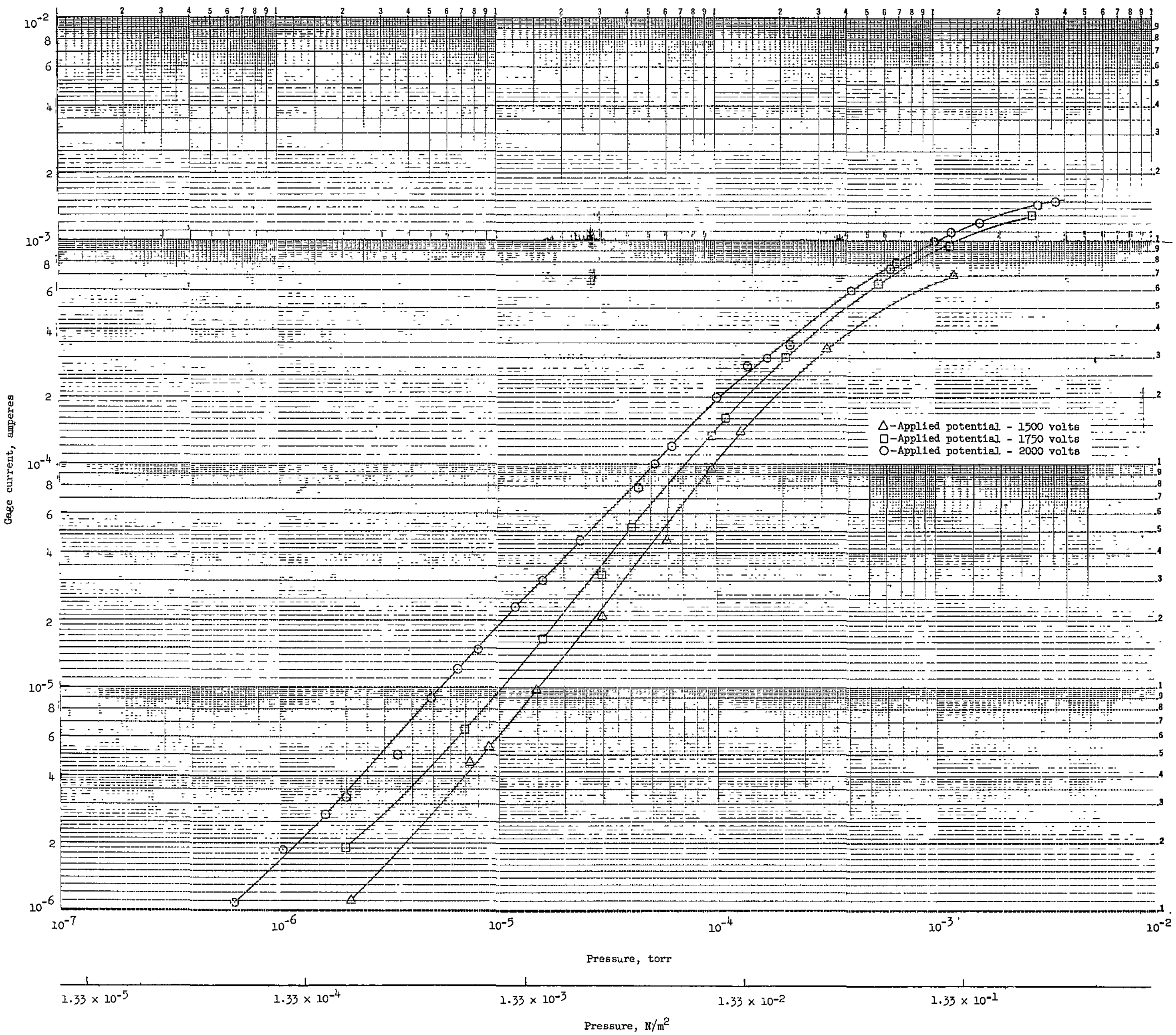


Figure 10.- Gage-calibration curve. Cathode spacing, 1/2 in. (1.27 cm); magnetic field, 800 gauss $(8 \times 10^{-2}$ tesla).

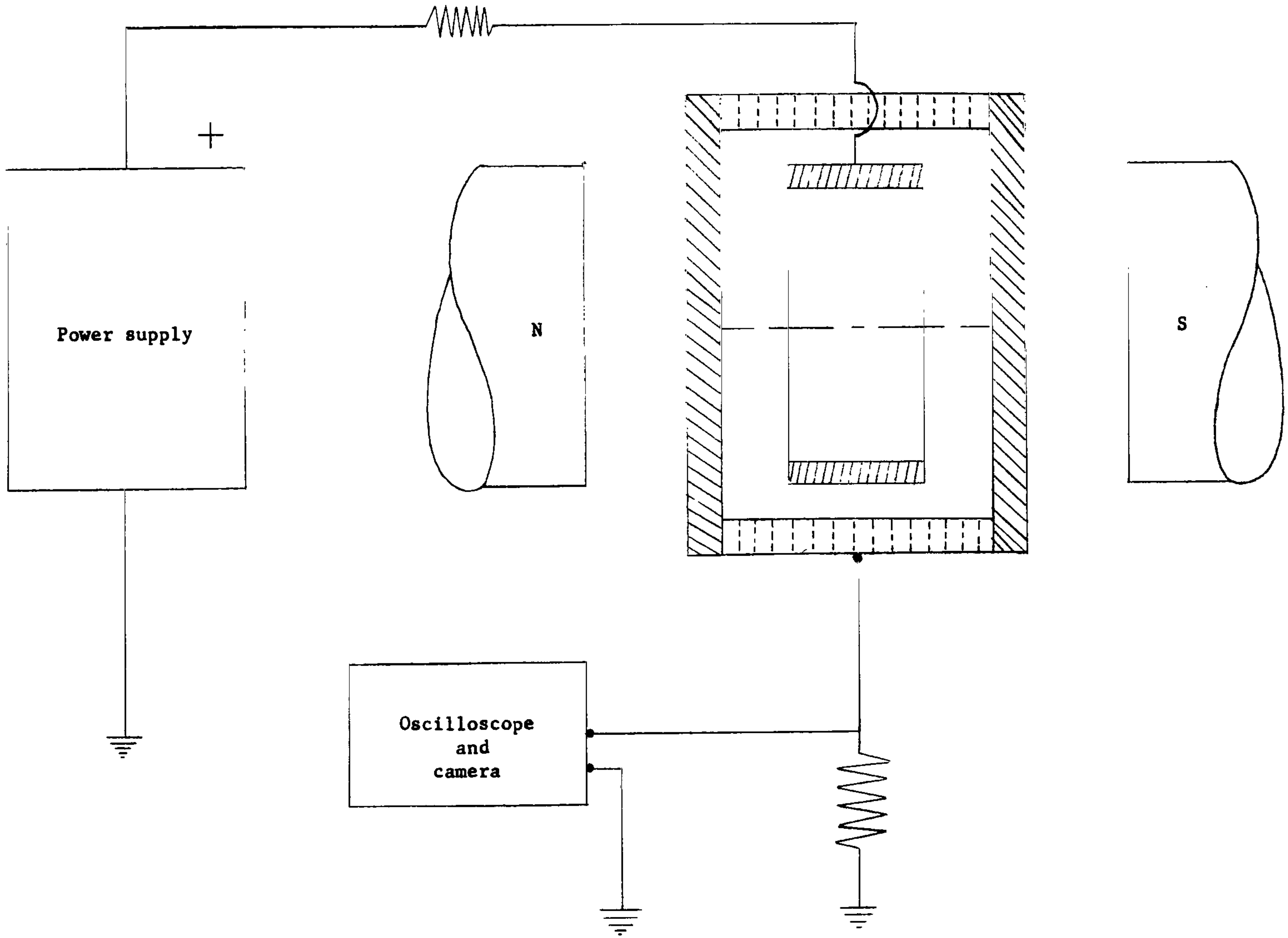
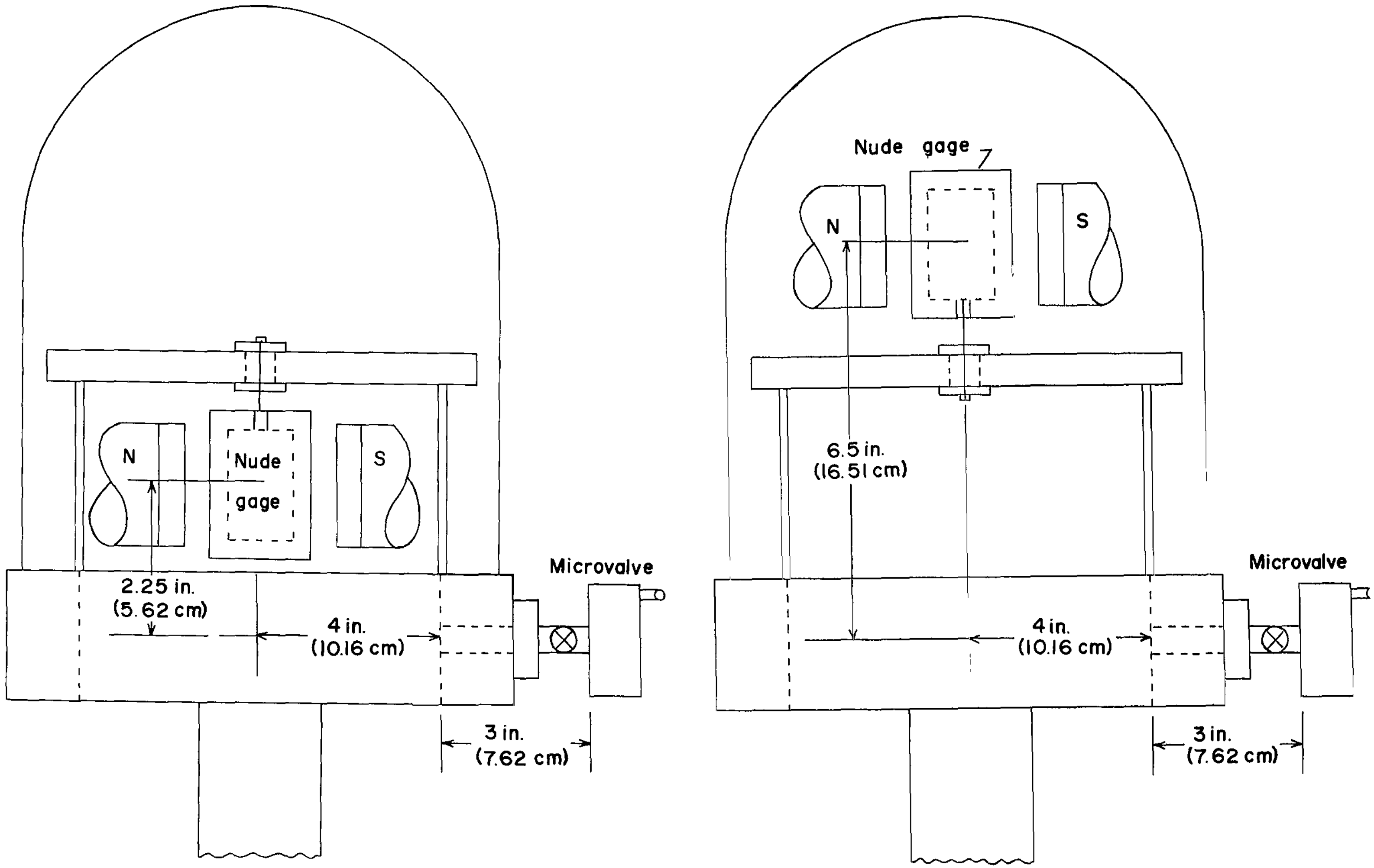


Figure 11.- Gage diagram for response-time measurements.



(a) Position 1.

(b) Position 2.

Figure 12.- Gage location for time-response measurement.

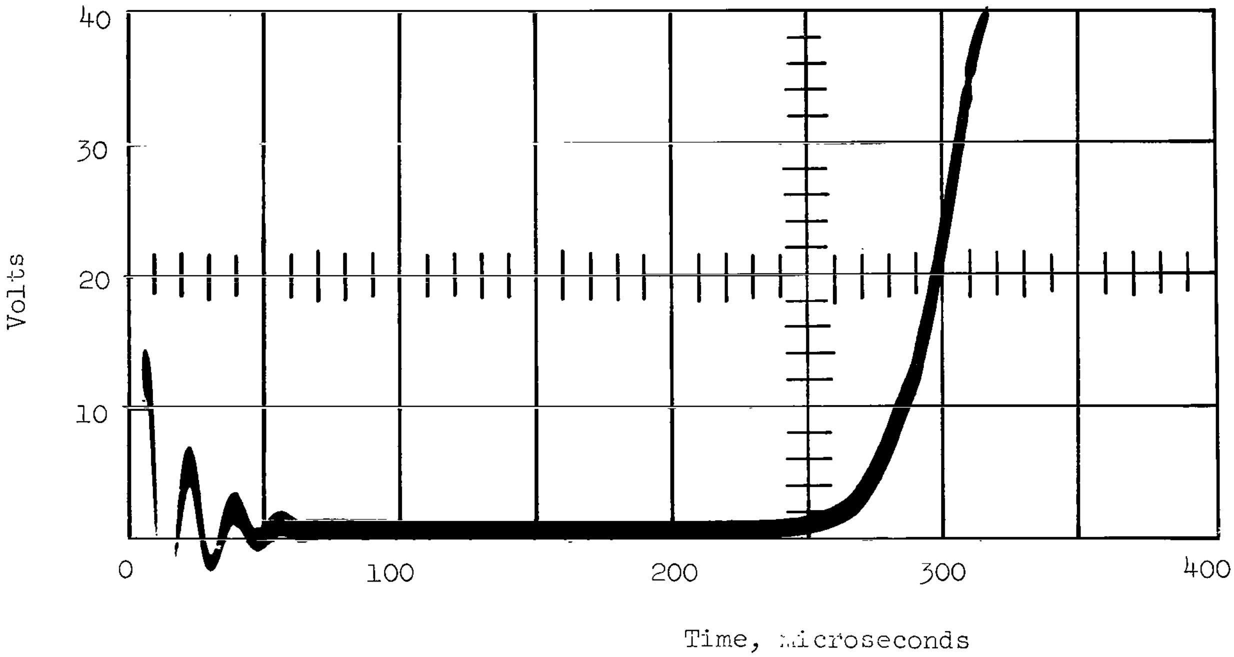


Figure 13.- Time-delay measurement.

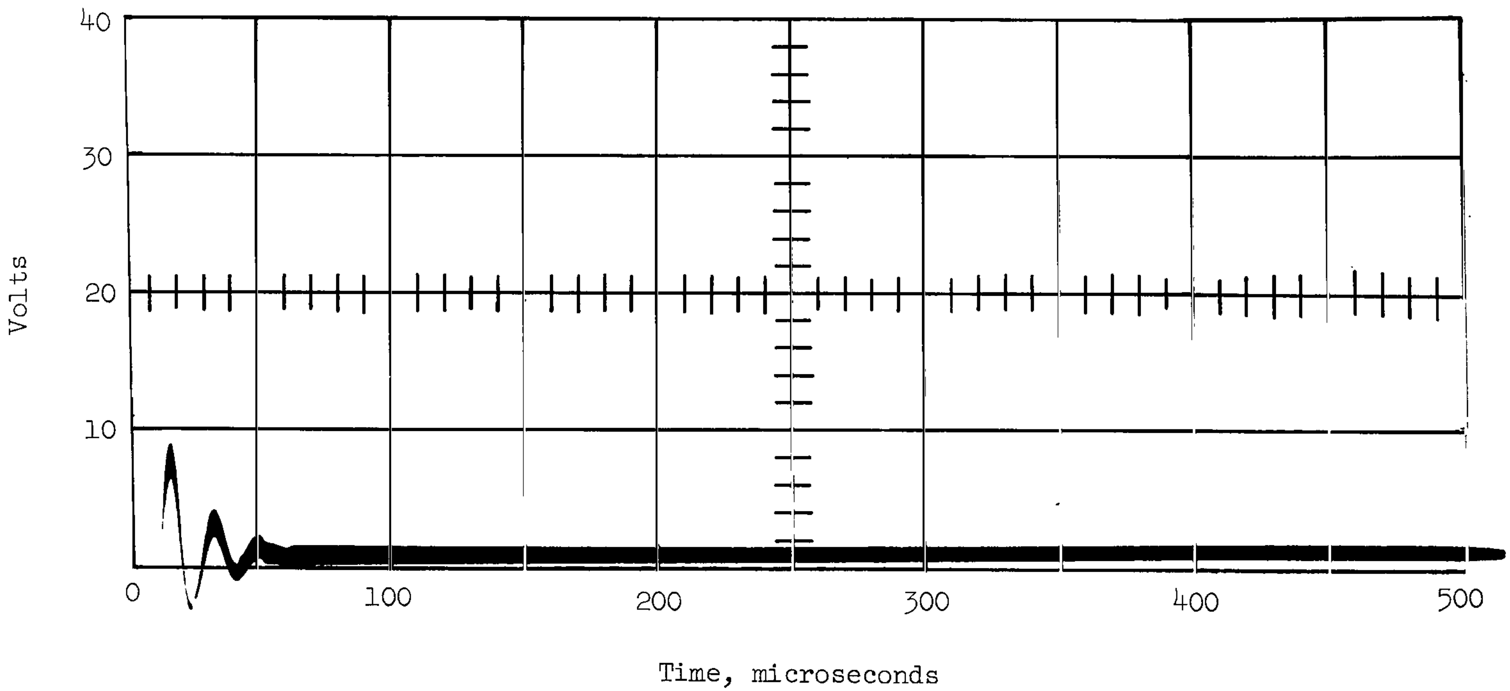


Figure 14.- Operating-time measurement of microvalve transient signal.

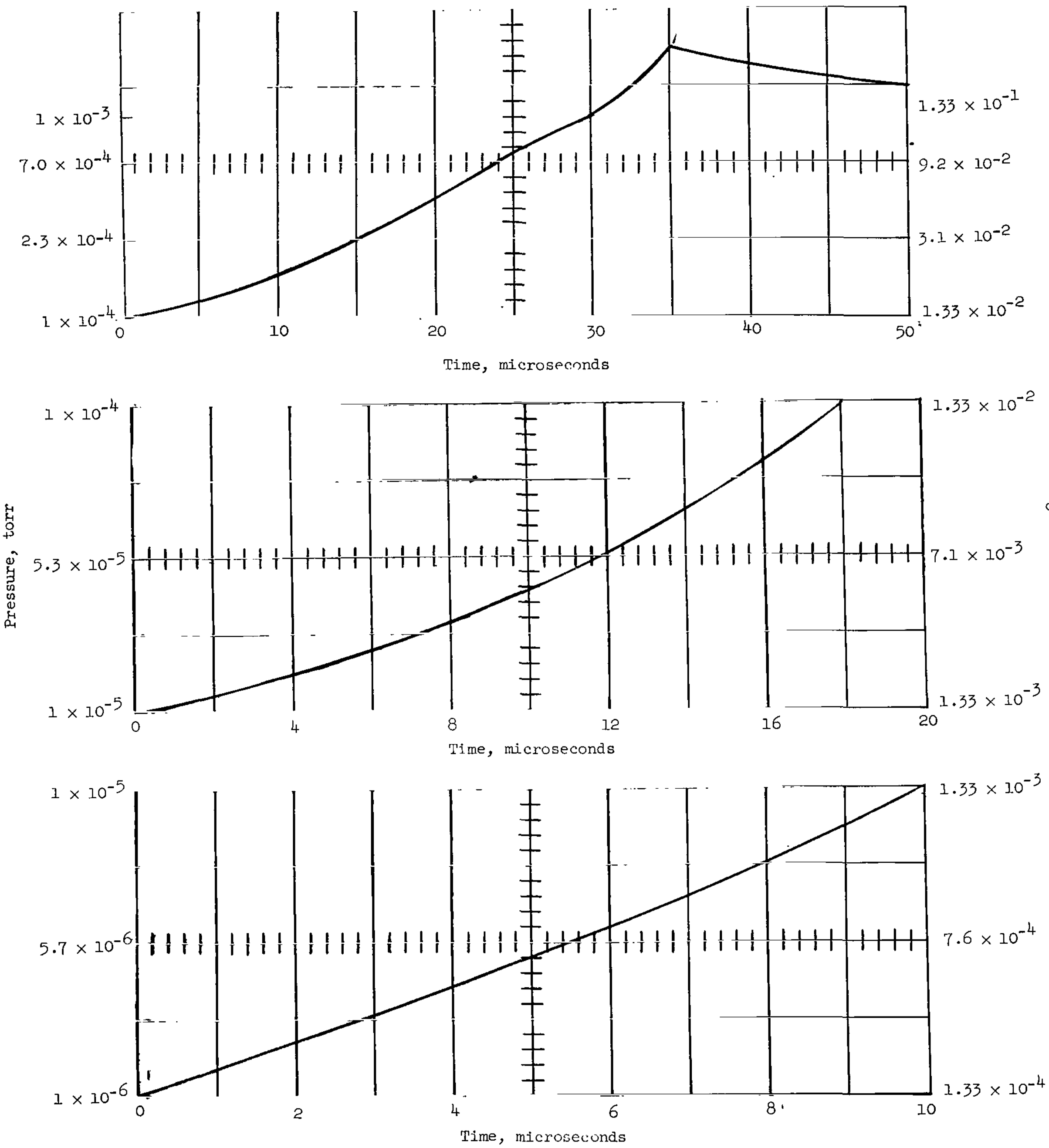


Figure 15.- Gage response-time curves (position 1 shown schematically in fig. 12(a)).

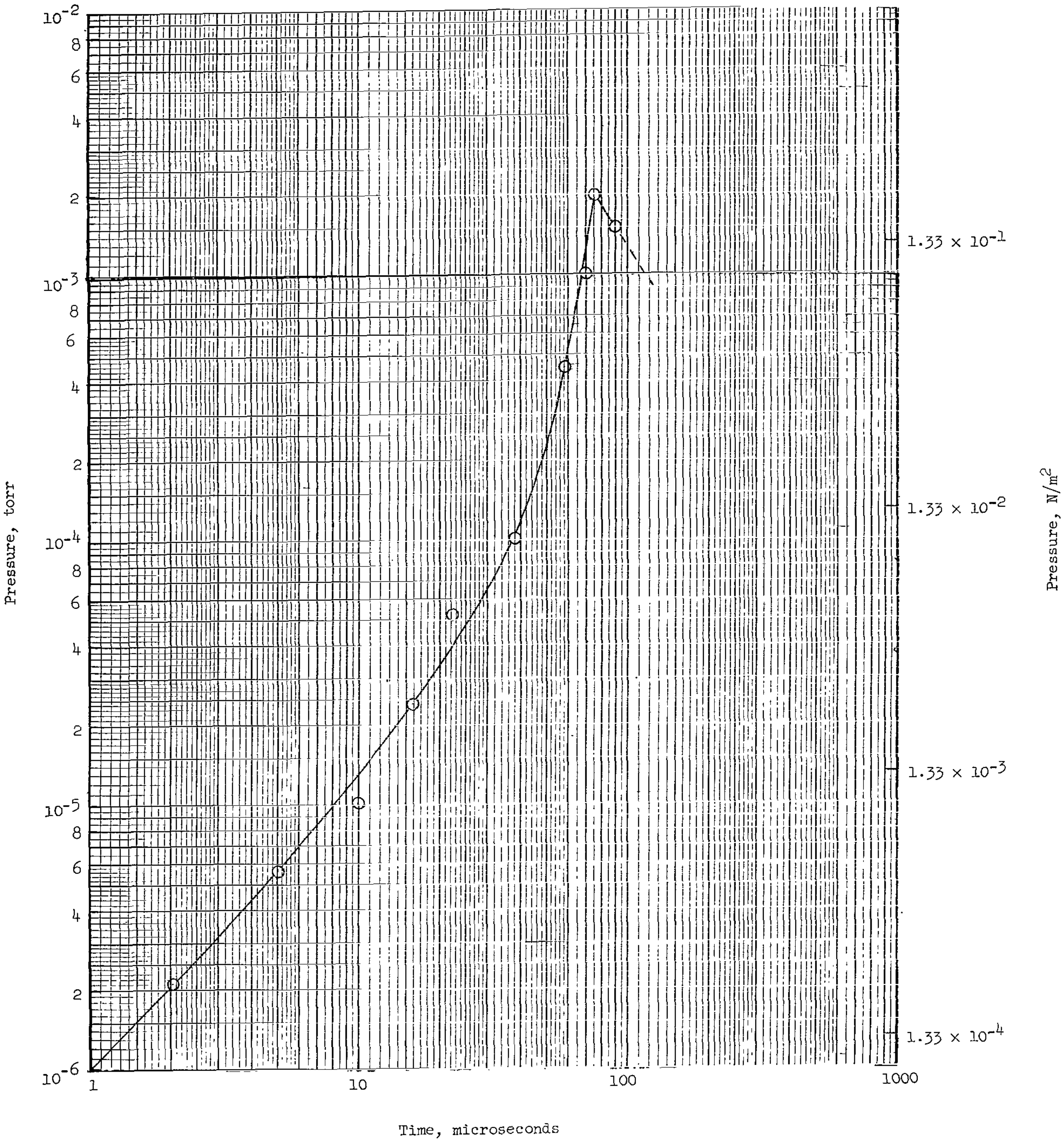


Figure 16.- Gage response-time curve.

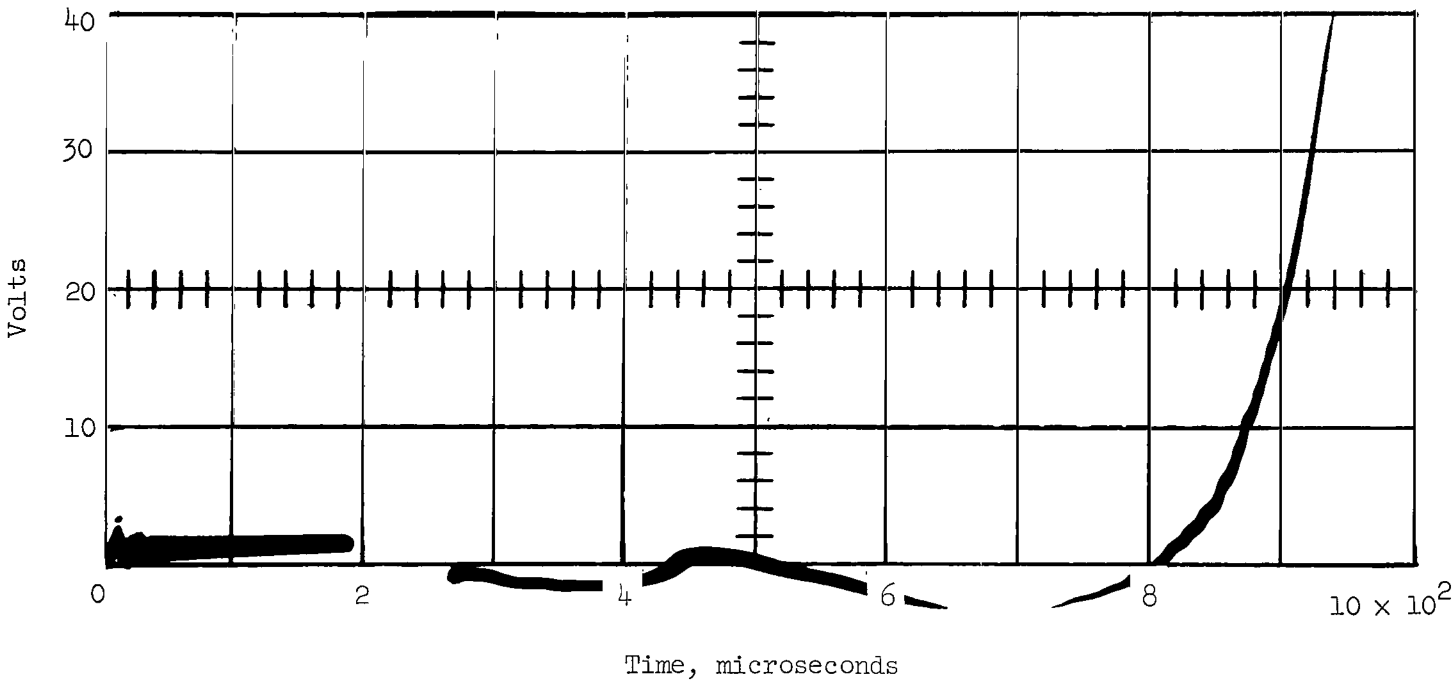


Figure 17.- Time-delay measurement.

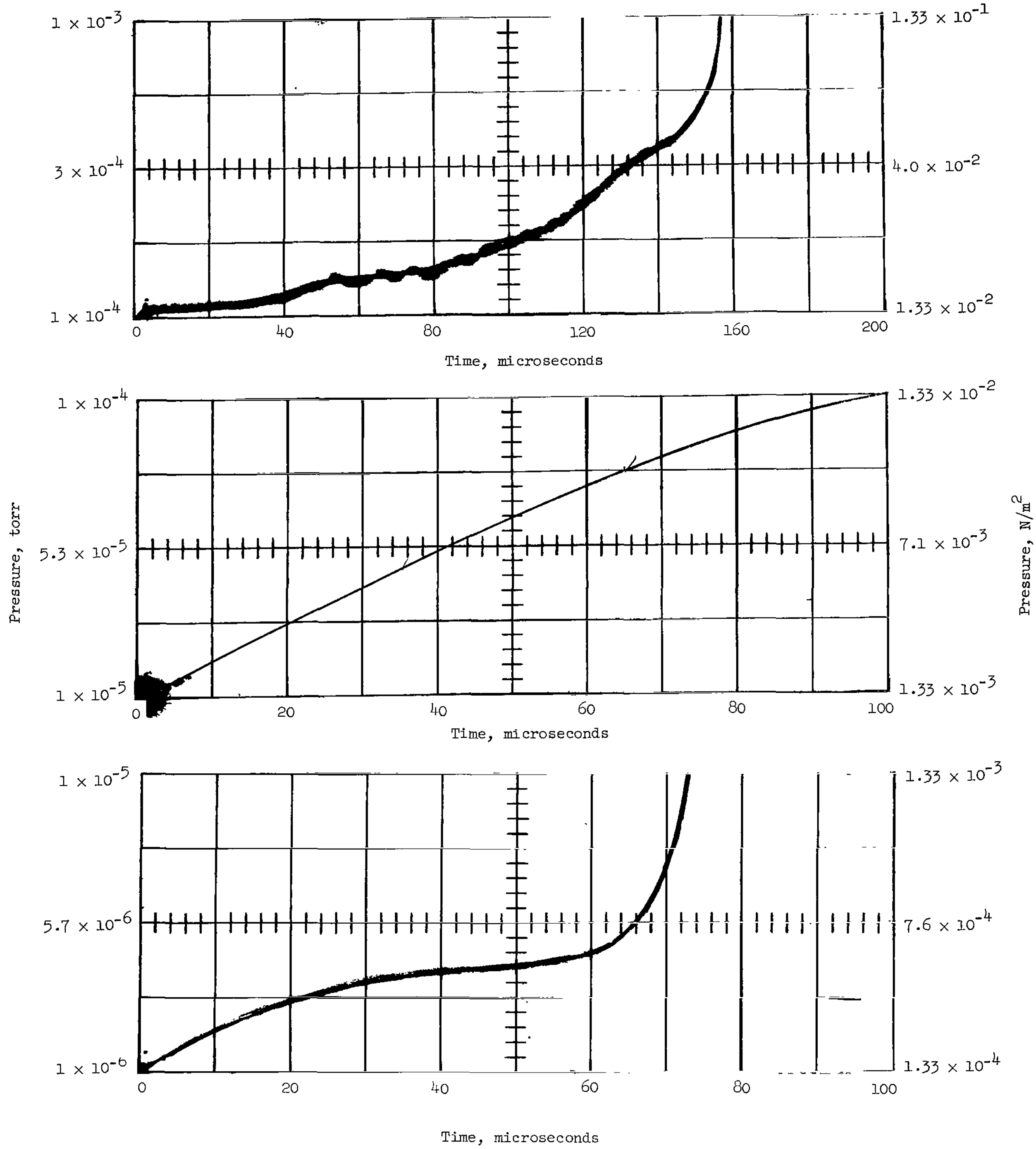


Figure 18.- Gage response-time curves (position 2 shown schematically in fig. 12(b)).

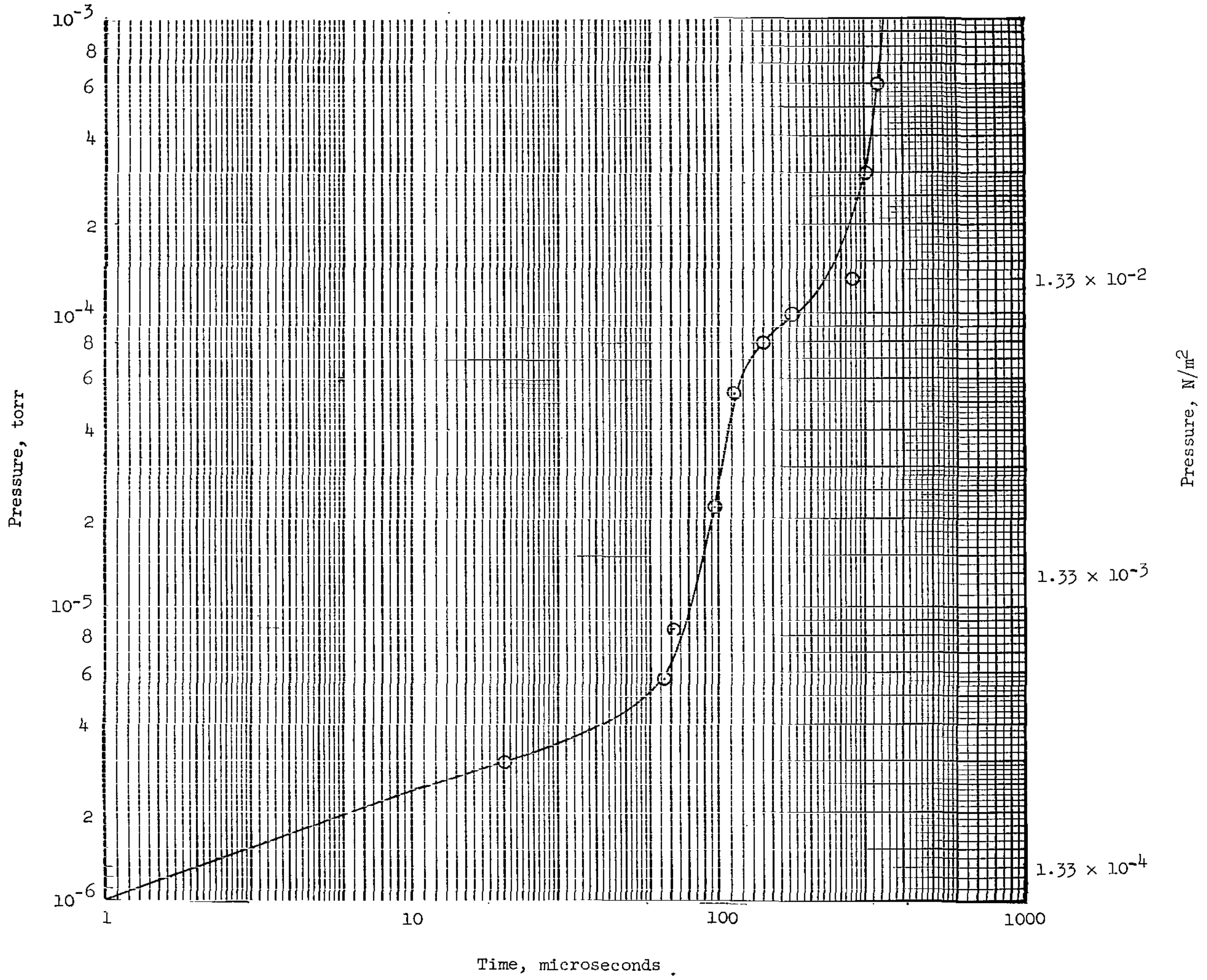


Figure 19.- Gage response-time curve.

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