AMERICAN VACUUM SOCIETY STANDARD (tentative)
AVS 6.5—1971

Procedures for the Calibration of Hot Filament Ionization Gauge Controls

Foreword

This Foreword is not a part of AVS 6.5—1971.

This publication specifies practices tentatively approved as standard by the American Vacuum Society for the calibration of hot filament ionization gauge controls and is one of a series published by the American Vacuum Society. It contains data secured from many sources and represents the best thinking of a number of experts in the field. After several years of use this standard will be forwarded to the American National Standards Institute with the request that it be used as a basis for a USA Standard. Suggestions for improvement gained in use of this standard will be welcome. They should be sent to the American Vacuum Society, 335 East 45 Street, New York, N. Y. 10017. The AVS Committees which drafted and approved this standard had the following personnel at the time of approval:

AVS Subcommittee 6

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1.0 Scope

Guidelines and methods are provided for the electrical calibration of hot cathode ionization gauge controls.

2.0 Introduction

2.1 An ionization gauge comprises an independent sensor (the ionization gauge tube), electronic circuits necessary to energize the sensor (tube), and an ion current ammeter. In the hot cathode ionization gauge, electrons emitted from the cathode are accelerated by the anode potential to ionize gas molecules within the confines of the tube, which then produce an ion current at the collector. The value of the collected ion current is related to the gas pressure, the electron emission current, the applied potentials, and the structure of the tube.

Vacuum calibration may be applied to an ionization gauge as a complete system, i.e., to a particular tube in conjunction with a particular control. In this case precision and stability must be derived for the particular gauge with the vacuum calibration stand. After calibration, operation of either part with another gauge tube or control circuit will not necessarily provide a calibrated system. See AVS 6.4—1969. Vacuum calibration may also be applied to a tube itself as an independent sensor which requires that a properly calibrated control be used. From this, a tube characteristic is obtained. A tube so calibrated may then be used with any other compatible, electrically calibrated ionization gauge control to provide a calibrated gauge. Electrical calibration of the control requires that operating potentials be measured, the emission and ion current ammeters be calibrated, and regulation and drift be determined. The uncertainties arising from this electrical calibration are then transferred to any subsequent measurement made with the gauge control.

2.2 Because of the complexity and diversity of ionization gauge control circuits, precautions must be exercised in applying the procedures given below. Alternate, equivalent methods may be more appropriate for specific equipment. Manufacturer's recommendations should be adhered to.

3.0 Definitions and Referenced Documents

3.1 Definitions

3.1.1 Ionization gauge: A vacuum gauge comprising a means of ionizing the gas and a means of correlating the ion current to the collector with the pressure of the gas.

3.1.2 Hot filament ionization gauge tube: The part of the ionization gauge which contains the filament, anode, ion current collector, and other elements exposed directly to the vacuum system, including the envelope or means of supporting the operating elements and any connecting tube attached permanently to the envelope.

3.1.3 Ionization gauge control: That part of the ionization gauge which comprises the electrical circuits and cables necessary to energize the tube, to control and measure currents or voltages, and in some cases to supply power for degassing of tube elements.

3.1.4 Regulate: To control a parameter for the purpose of maintaining it constant.

3.1.5 Regulation: The amount of change in the controlled parameter versus the causative variation in the line, load, temperature, and time.

3.1.6 Drift (or stability): The maximum change of an output parameter during a specified period of time with all external operating and environmental parameters maintained constant.

3.1.7 Warmup time: The time required after turning on the power for the output parameters to reach steady state within stability specifications.

3.1.8 Ambient temperature: The temperature of the immediate environment in which the control is immersed.

3.1.9 Temperature coefficient: The ratio of the fractional change in stabilized output to a specified change in ambient temperature, expressed as a per cent change per degree Celsius with all other operating parameters held constant. Of the form $(\Delta y/y\Delta T)\times 100$.

3.2 General Terms

"Glossary of Terms Used in Vacuum Technology," issued by the American Vacuum Society (Pergamon, New York, 1958).

3.3 Instrument References

3.3.1 Ionization gauge: AVS Standard (Tentative) 6.4—1969 "Procedure for Calibrating Hot Filament Ionization Gauges Against a Reference Manometer in the Range 10^{-2}–10^{-5} Torr."

4.0 Outline of Procedures

4.1 Calibration of the ionization gauge control comprises measurement of the potentials as would be applied to an ionization gauge tube under operational conditions, determination of drift and regulation, and calibration of the emission and ion current ammeters. Figures 1 through 3 are representative schematic circuits for these procedures.

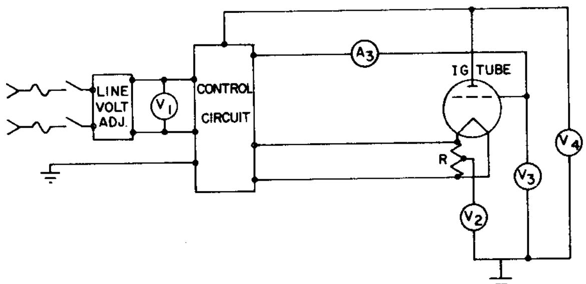


FIGURE 1. Calibration of ionization gauge control circuit. V_1—line voltage; V_2—filament potential; V_3—anode potential; V_4—collector potential; A_3—anode or emission current.

4.2 Accuracy

The accuracies with which these measurements should be made are determined by the capabilities of the control under calibration and the eventual accuracy desired from the operational gauge. Refer to AVS 6.4—1969, Appendix B, for guidelines.

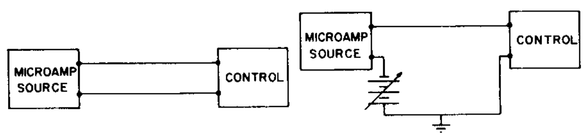
5.0 Measurements

5.1 Test Conditions

Calibration is to be made under operational or simulated operational loads. Ambient temperature is to be 23°C ± 3°C.

5.2 List of Measurements

5.2.1 Anode Potential: Magnitude, regulation, drift, and variation with emission current.



(a) (b)

FIGURE 2. (a) Method 1—calibration of ion current ammeter with microampere supply. (b) Method 2—calibration of ion current ammeter with microampere supply when collector is biased.

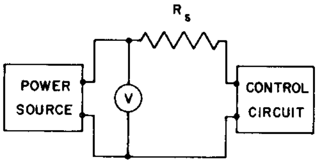


FIGURE 3. Method 3—calibration of ion current ammeter with precision resistors and voltmeter.

5.2.2 Filament (cathode) potential: Magnitude, regulation, drift, and variation with emission current.

5.2.3 Ion current collector potential: Magnitude, regulation, and drift.

5.2.4 Electron (emission) current:

5.2.4.1 Emission current ammeter. Calibration.

5.2.4.2 Regulation and drift. In principle, the emission current can be adjusted to the desired value for each measurement made with the ionization gauge as determined with the emission current ammeter. Most controls, however, employ emission regulating circuitry to hold the emission current to set values. The degree of regulation may then be an important factor in the final uncertainty of measurements with the gauge and is usually a factor in the selection of a control. Determination of regulation as a function of line voltage is straightforward. Determination of regulation as a function of load can only be done partially by electrical calibration, as the load presented by a tube is also affected by the gas environment. See Appendix A for calibration procedures.

5.2.4.3 Filament supply. See Appendix A.

5.2.5 Ion current: Calibration, drift, stability for ion current ammeter.

5.2.6 Temperature coefficient: In most instances temperature variations within the band of 23°C±3°C will not cause significant effects. When greater accuracy is needed, the control should be used at the same temperature at which it was calibrated or its temperature coefficient should be measured. See Appendix B.

6.0 Apparatus (Refer to Figs. 1–3)

6.1 Line Voltage Adjust

Means to vary line voltage by ±10% around nominal line voltage standard or manufacturer's specifications. Such means should cause no significant distortion of the ac waveform. An autotransformer will usually suffice.

6.2 Line Voltmeter (V_1)

Alternating current meter of sufficient accuracy to set operational value and to allow test of control circuit regulation. Note: A meter giving an accuracy to within 2% of full scale and operated above 60% of full scale is satisfactory.

6.3 Filament Bias Voltmeter (V_2)

If emission current ammeter is in the filament circuit, the voltmeter resistance must be large enough to minimize current drain.

6.4 Anode Potential Voltmeter (V_3)

Meter resistance must be large enough to cause insignificant emission current drain. A high impedance or differential voltmeter should be used.

6.5 Collector Bias Voltmeter (V_4)

Where applicable. Meter resistance must be large enough to prevent off scale deflection of ion current ammeter. Caution should be maintained in the use of a differential voltmeter.

6.6 Emission Ammeter (A_3)

Direct current milliammeter suitable for accuracy desired, in anode or filament lead, as required.

6.7 Filament Resistor (R)

Center tapped resistor of such value as to cause small change in filament current.

6.8 Test Load

An operational ionization gauge tube or an equivalent diode. A sealed off ionization gauge tube will serve where tube pressure is compatible with normal use.

6.9 Variable dc Microampere Supply

For ion current ammeter calibration. One of the following is appropriate:

6.9.1: Constant current supplies are commercially available for the purpose. See 7.7.1 and 7.7.2 and Fig. 2 for further requirements.

6.9.2: A dc power supply with a series limiting resistor and microammeter. See 7.7.4 for further requirements.

6.9.3 A dc voltage supply of nominal range 0–10 V, precision calibrated resistors and precision voltmeter. Resistors may range from the order of 10^3–10^{10} Ω. Any resistors above 1×10^{10} Ω may need voltage compensation. Voltmeter preferably precision differential or potentiometer. See Fig. 3 and procedure 7.7.3 for further requirements.

6.10 All reference meters should be calibrated before use.

7.0 Procedures

7.1 Assemble the control unit, operational gauge tube or equivalent, and test fixtures as shown in Fig. 1. Make connections for anode potential and emission current to test jacks provided by manufacturer or to ionization gauge tube leads. Heed manufacturer's precautions for connection of current return lines.

7.2 Turn on control circuit and make preliminary check to assure that line voltage, electrode potentials, and currents are nominally correct. Allow equipment to satisfy warm up time requirements; see 3.1.7.

7.3 Emission Current

7.3.1 Emission current ammeter: Calibrate: vary emission current with the emission current controls. Compare readings of control circuit meter to reference emission meter. Record data.

7.3.2 Regulation and Drift: See Appendix A.

7.4 Anode (Accelerator) Potential

7.4.1: Measure potential to ground with the high impedance or differential voltmeter and record.

7.4.2 Line voltage: Vary line voltage over specified range and record variation in anode potential.

7.4.3 Emission current: Vary emission current over desired range and note variation in anode potential.

7.4.4 Drift: With emission current at operational values, record anode potential for a long enough time to determine uncertainty. See AVS 6.4—1969 Appendix B4.3.

7.5 Filament Potential

7.5.1: Measure potential from centertap of filament resistance divider to ground observing precautions of 6.3 and 6.7.

7.5.2 Line voltage: Follow procedure of 7.4.2.

7.5.3 Emission current: Follow 7.4.3.

7.5.4 Drift: Follow procedure of 7.4.4.

7.6 Collector Potential

This procedure may be omitted when the potential drop across the collector ammeter is small and one end of the meter is at ground potential. Refer to AVS 6.4—1969.

7.6.1: Set ion current ammeter for low input resistance (high pressure) and measure potential to ground with high impedance meter, observing precautions of 6.5. Caution must be exercised in the use of a differential voltmeter because of possible loading effects on ion current ammeter when voltmeter is off null position. Use in VTVM mode initially to determine approximate value.

7.7 Ion Current Ammeter

Note: It is common practice to display the ion current on a meter that is graduated in pressure units. The relationship is assumed that

$$i_c = i_e K P,$$

where i_c is the value of the ion current, i_e is the emission current, K is the value of tube calibration factor representative of the type of tube to be used, and P is the pressure. Thus, the correlation of the pressure scales to the ion current ammeter calibration requires a knowledge of the values assumed for K and i_e.

7.7.1 Method 1: Use of microampere current supply with ion current ammeter isolated or one end grounded. See Fig. 2(a).

7.7.1.1 Connect ion current ammeter i_c directly to the microampere current supply. Where the ion current ammeter is internal to the control console, connect the microampere current supply to the collector cable. Zero ion current ammeter initially and calibrate with at least five points at equal scale intervals per range. Where the gauge control circuit meter indicates in pressure units, conversion may be obtained with the relevant value of tube calibration factor.

7.7.1.2 This method is applicable for the case of zero collector bias, i.e., where one end of the ion current ammeter is grounded or where both ammeter leads can be isolated from the bias circuit.

7.7.1.3 Commercially available microampere current supplies are usually stable voltage sources with a large valued series range resistor. Use of these to the specified accuracy requires voltage drop across the ammeter under test to be a small fraction of the internal microampere current supply voltage, typically 1/1000.

7.7.1.4 Since minute currents are to be measured, careful attention must be given to reduce stray currents arising from thermal emf's, leakage, etc. Thermal emf's and other zero offset currents are accommodated by adjusting the control unit to "zero" with the input current source set to "zero." Stray currents, leakage, etc., should be minimized by careful mounting of components, use of high quality insulators, shielding, etc.

7.7.2 Method 2: Use of microampere current supply when collector is biased.

7.7.2.1 Place a precision, variable voltage supply in series with the microampere current supply to set an identical bias on the source, as shown in the schematic of Fig. 2(b).

7.7.2.2 Set microampere current supply for 0 output current and adjust variable voltage supply until ion current ammeter indicates zero current, or until the ion current ammeter indicates the minimum on-scale ion current when a logarithmic—or other suppressed—zero pressure scale is used. The input calibration current is then to be assumed to be the value of the current supply plus the value of the minimum scale current.

7.7.2.3 Calibrate per 7.7.1.

7.7.2.4 The microampere current supply must be of a nature to operate off ground at a potential at least equal to the collector bias without reduction of current accuracy.

7.7.2.5 The precision voltage supply must be shielded and guarded to eliminate stray signal pickup and current leakage that would cause reduction in accuracy. Refer to 7.7.1.4.

7.7.2.6 Accuracy of this method is limited by the stability of the collector bias. Such instability, however, is not so critical in normal gauge operation because of relative insensitivity of collector current to bias fluctuation.

7.7.3 Method 3: Power supply, series resistors, and voltmeter. Note: This procedure may cause some problems with certain feedback or operational amplifier circuits. See 7.7.3.3 and heed manufacturer's recommendations.

7.7.3.1 See 6.9.3. Connect circuit according to Fig. 3.

7.7.3.2 Choose a value of R_s and a setting of V to give an approximate full scale setting on the ion current ammeter.

7.7.3.3 Set power supply voltage to 0 and zero ion current ammeter. If zero drift is abnormal, select a larger value of R_s. Too small a value can cause loading in feedback circuits.

7.7.3.4 Set power supply voltage to give desired scale deflection on the ammeter. Record values of V and R_s. Then

$$i_c(R_{s1}+r)=V_1+e,$$

where r represents the internal resistance of the ammeter for that deflection and e any residual potentials. Replace R_{s1} with another value of resistor and set power supply to give the identical deflection as before. Record second values. As r and e are constant, compute current from

$$i_c=(V_1-V_2)/(R_{s1}-R_{s2}).$$

7.7.3.5 Values of R_s and V must be of such a difference and of such initial accuracy that the determination of i_c is within the desired accuracy.

7.7.3.6 Repeat 7.7.3.4 for at least five points at equal scale intervals per range.

7.7.3.7 This method can also be applied both to biased collector and to ion current ammeters with large input voltage drop. The accuracy is, however, degraded by bias supply fluctuation.

7.7.3.8 Shielding and isolation of components as in 7.7.1.4.

7.7.3.9 If a potentiometer is used as the precision voltmeter, interaction can result between the ion current ammeter and some potentiometer null detectors. In this case a suitable switching sequence should be used to alternately disconnect the potentiometer or ammeter when reading the other. An equivalent load will have to be substituted for the ammeter in such instance.

7.7.3.10 If the input resistance of the ion current ammeter is known and independent of scale reading, only one value of R_s and V need be known for each data point.

7.7.4 Method 4: Precision microammeter, power supply, and series resistor.

7.7.4.1 This procedure is similar to 7.7.1 and 7.7.2.

7.7.4.2 The precision microammeter may be of the moving coil variety, or equivalent electronic type. See 7.7.1.4 and 7.7.2.4.

7.7.4.3 The resistor should be of sufficient magnitude to limit the current to the range of the ion current ammeter.

7.7.4.4 Connect the resistor, precision microammeter and ion current ammeter in series. Connect the series to the power supply. Calibrate.

7.7.5 Zero drift: With the ion current ammeter on the most sensitive scale, with input disconnected and preferably shorted, record reading for a period of time sufficient to satisfy accuracy desired. Caution: Before shorting input terminals heed manufacturer's recommendations.

7.7.6 Regulation, line voltage: Calibrate for one point per decade of near full scale deflection, e.g. 0.8 full scale at each end of specified line voltage range.

8.0 Presentation of Data

8.1 Control circuit identification by manufacturer, model number, and serial number.

8.2 Date of Calibration

8.3 Electrode Potentials

State magnitude, maximum variation with line voltage variation, maximum variation with emission current, maximum drift for the measured time interval, and uncertainty of measurement.

8.4 Emission Current

Plot the calibration curve or give a table for the emission ammeter. Give uncertainty of measurement.

8.5 Ion Current

Plot calibration curve or give a table for the ion current ammeter. Give maximum variation for line voltage variation. State drift. Give uncertainty of measurement.

8.6 Operating Line Voltage during Calibration

Appendix A: Filament Supply Characteristics

A1. In principle, examination of filament voltage is only necessary to assure that the control circuit can power a representative load. This load varies among tubes and with gas environment in a given tube. In practice, control circuits normally incorporate circuitry not to produce constant filament voltage but to cause the filament voltage to vary as may be required to produce a constant emission current. The degree of regulation is usually an important factor.

A2. Measurements

A2.1 Voltage and current as a function of load.
A2.2 Regulation for line voltage and load variations.
A2.3 Drift.

A3. Apparatus (See Fig. 4)

A3.1 Filament load adjust: Variable power resistor of at least five times the filament resistance. Filament requirements are usually of the order of 3–6 V and 4–6 A.

A3.2 Voltmeter (V_5)*:* True rms.
A3.3 Ammeter (A_5)*:* True rms.

Note: The intent is to determine the power output capacity of the control. As harmonic content in the ac waveform can cause error in rms readings, type of meter used will depend upon accuracy required.

A3.4 Emission current ammeter (A_3)*:* dc milliammeter of appropriate sensitivity.

A4. Procedures

A4.1: Filament supply voltage should be measured at load end of cable.

A4.2: With the variable resistance at full value, and with the emission current set to a low value, turn on control and make preliminary check to assure that line voltage, electrode potentials, and currents are approximately correct. Allow control to operate for sufficient interval to satisfy warmup time requirements.

A4.3: Adjust both the emission current with the emission current control and the filament load resistor to obtain values of emission current and filament voltage–current ($V_5 - A_5$) that fall within the range of control specifications. With the load resistor fixed, vary emission current over the available control range and record volt–ampere characteristic. *Caution:* Do not allow the emission current shown by A_3 nor the volt–ampere values ($V_5 - V_5$) to exceed manufacturer's specifications.

A4.4: Set emission current to the center of the range of operational values with line voltage at the center of the range for which automatic emission control is functional. Vary the line voltage over specified range and record variation in emission current. Determine regulation for line voltage change as the ratio in per cent of the change in emission current to change in line voltage. Use the differences in extreme values (max. minus min.) of emission current and line voltage for this ratio, i.e.,

$$[(A_{3\max} - A_{3\min})/(V_{1\max} - V_{1\min})] \times 100.$$

A4.5: With line voltage set and with the emission current set to the same value as in A4.4, vary the adjustable load and find the limits of the range of voltage and current for which emission current is constant to within the manufacturer's specifications. From these values compute the limits of load for which the emission current is stable. List the load limits and the value of emission current.

A4.6 Drift: Set the emission current to a representative value. With the line voltage and load constant, monitor the variations in emission current over a suitable time. Specify the maximum change for a specified period of at least one hour.

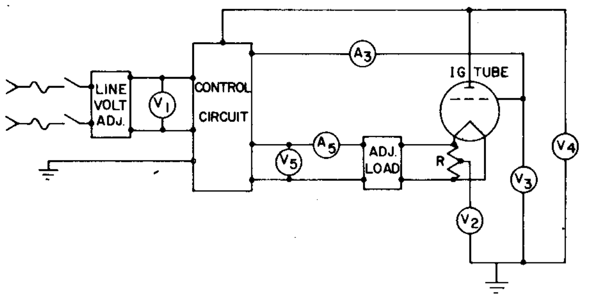


FIGURE 4. Filament load characteristics. V_5—filament voltage; A_5—filament current.

Appendix B: Temperature Coefficient

B1. Normally, temperature variations within the band of 23°C±3°C will not cause significant effects with most gauge controls. Where the control admits of greater precision and this is desired, the temperature coefficient should be determined, or the control should be operated at the same ambient temperature at which it was calibrated.

B2. Measurements

B2.1 Anode, filament, and ion current collector potentials
B2.2 Electron current
B2.3 Ion current

B3. Apparatus

B3.1 Enclosure: the temperature of which may be varied over the specified operating range of the ionization gauge control and shall not vary by more than 1°C at any given test temperature. A window shall be provided for observation of control meters. Reference—International Electrotechnical Commission Pub. 68-1.

B3.2 Reference meters: Expanded scale or differential type.

B4. Test Conditions

B4.1: Apparatus is to be arranged as in Figs. 1–3 with the control within the enclosure. Reference meters and load shall be placed outside the enclosure in a constant ambient temperature.

B4.2: The temperature within the enclosure shall be raised in steps of 10°C, then reduced in 10°C steps back to the lowest ambient level, and finally raised to the initial level. The range of temperature shall be great enough to include expected operational levels, but should not exceed manufacturer's recommendations.

B4.3: Measurement of the output quantity shall be delayed at least 30 min after the establishment of each new ambient temperature level and for an additional time until variation in the output quantity is less than 5% of the total change from the value at the previous ambient level.

B5. Procedures

B5.1: With the enclosure set at a nominal ambient temperature in the range of 23°C±3°C, follow steps 7.1 and 7.2.

B5.2: If the control is uncalibrated for nominal ambient temperature, complete the remainder of Sec. 7.

B5.3: Set the line voltage and load representative values and hold constant throughout the remainder of the test.

B5.4: Set emission current to a specified value.

B5.5: Increase the enclosure temperature by 10°C.

B5.6: Measure the emission current, anode potential, filament potential, and ion current collector potential (where applicable) with the external reference meters. See 7.3.1, 7.4.1, 7.5.1, and 7.6.1.

B5.7: Calibrate the ion current ammeter for one point per decade of near full scale deflection, e.g., 0.8 of full scale, following 7.7.

B5.8: Repeat 5.5 through 5.7 for each temperature level according to B4.2.

B5.9: Determine the change in output quantities due to each temperature increment and calculate temperature coefficient.

B6. Presentation of Data

B6.1: List the maximum temperature coefficient for each temperature interval, the corresponding interval and the value of the output quantity at which the determination was made.