Active vacuum gauges: application to inverted magnetrons

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Inverted magnetron gauges are characterised primarily by their robust construction and low power consumption. Traditionally they have suffered from mode changes, unreliable starting—particularly at low pressures—and inferior accuracy compared with hot cathode ionisation gauges. A new gauge in which the electronics and tube are combined into one fully integrated unit addresses these problems. The active inverted magnetron gauge described has major advantages when applied to large and computer controlled systems such as particle accelerators and vacuum furnaces, which include small size, ease of interfacing to data acquisition systems and improved immunity from the effects of electrical interference and humid environments.

1. What is an active gauge?

Consider a traditional cold cathode discharge or inverted magnetron (see Figure 1). It consists of a gauge head connected to a control unit by a high voltage coaxial cable. The control unit contains a high voltage power supply, gauge head current measurement and signal processing circuitry, pressure indication and external control/indication facilities such as a chart recorder output.

The active inverted magnetron described here combines all of the features of the gauge head and control unit into one compact unit (see Figure 1). The term active is used since the gauge head contains active electronic components such as amplifiers and a switched mode power supply control micro-chip. The use of surface mount electronic components and the optimisation of gauge power requirements allows the size of the electronics to be considerably reduced when compared with conventional designs (up to 50% reduction in size).

Figure 2 illustrates the main features of the active inverted magnetron gauge. The gauge has an overall cylindrical geometry. A stainless steel body tube contains two cathode cups held in place with a circlip. The anode assembly is held in place at one end of the tube by a threaded collar which compresses a fluoroelastomer O-ring to provide the vacuum seal. The other end of the body tube is open to the vacuum system and terminates in an ISO NW25 flange. The entire body tube assembly is a bayonet fit into the polymer case housing the magnet and active electronics. The case can rotate allowing the user to select the position of the side entry socket.

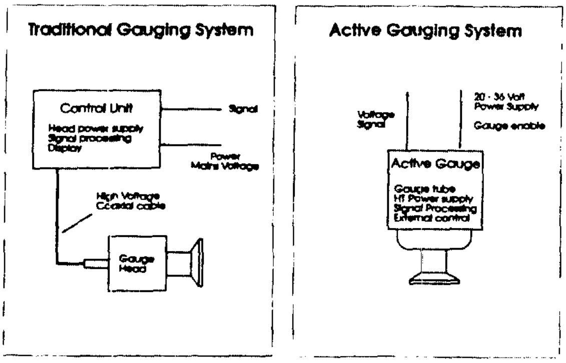

Figure 1. Illustration of the active inverted magnetron gauge concept compared with a conventional gauge.

The active inverted magnetron gauge requires a 20–36 V dc power supply. Power consumption is 3 W maximum when the gauge electrodes are short circuited. However, at high vacuum this value is reduced to 1.5 W.

The gauge pressure reading is available as a voltage output in the range 0–10 V dc. This can be monitored with a voltmeter or the analogue to digital converter of a data acquisition system.

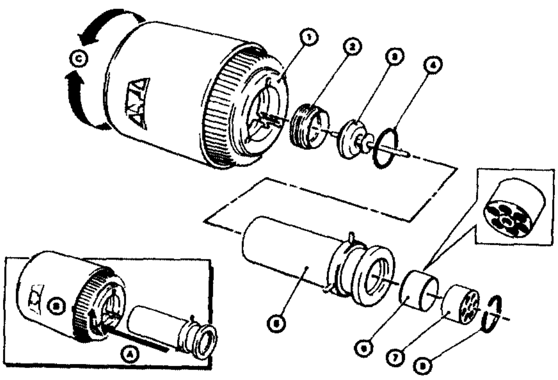

Figure 2. General view of the active inverted magnetron. (1) Magnet housing; (2) collar; (3) anode assembly; (4) 'O'-ring; (5) body tube; (6 and 7), cathode cups; and (8) circlip. (A) and (B) illustrate action of bayonet fitting; (C) shows how the case can be rotated allowing for variable socket orientation.

The operating pressure of the gauge is 1×10^{-2} to 1×10^{-8} mbar, the gauge output is 10 V, at 1×10^{-2} mbar and 2 V at 1×10^{-8} mbar. Output voltages less than 2 V and greater than 10 V are used to indicate fault conditions.

2. Gauge starting

The gauge's ability to start or 'strike' at high vacuum (1×10^{-7} mbar) has been improved by the addition of a 'striker' consisting of a very sharp edged disc concentric to and close to the central anode rod. The striker forms part of the cathode assembly. In operation, the intense electric field produced by the sharp edge causes ionisation (field ionisation) of any gas molecules/atoms that are in the vicinity. This action is further enhanced by the generation of a high voltage 'spike'. The spike (5 kV maximum) is generated when the gauge is 'enabled' by grounding pin 7 of the connector. The spike has a maximum duration of 10 ms, after this period the normal operating potential of 2.9 kV is applied to the anode relative to the cathode (earth).

3. Mode changes

A problem that exists with many designs of cold cathode discharge gauges is that of instabilities in the discharge termed 'mode changes'. Mode changes manifest themselves as sudden changes or hysteresis in the output signal of the gauge at well-defined pressures, usually in the 1×10^{-4} mbar region. Experiments have shown that the mode change problem is linked to the anisotropy of the magnetic field and the concentricity of the electrodes. Based on these observations, and the use of ion trajectory software (SIMION[1]) to model the processes occurring within the gauge tube, mode changes have been designed out of the active inverted magnetron gauge. The following key features evolved : (i) automatic alignment of the electrodes by using a self centring anode assembly, and (ii) controlled alignment of the magnetic field by using a bayonet method of attaching the body tube to the electronics and magnet assembly. This latter feature ensures that the body tube can always be re-assembled in a predefined orientation after cleaning. Figure 3 shows some typical electron trajectories produced using SIMION[1]. Initial electron energies were restricted to the range 0–150 eV (ref 2).

4. Pressure response and accuracy

The pressure characteristic of the gauge is shown in Figure 4. Electronic manipulation of the signal within the active gauge serves to improve the resolution available in the region 1×10^{-3}–1×10^{-2} mbar. The design features discussed in Section 3 reduce the spread in the gauge tube characteristic. At a given pressure the current generated by any given tube falls within a narrow tolerance band as shown in Figure 4. For a batch of 16 gauges the spread in output signal was found to be within ±150 mV (i.e. 1.5% full scale voltage) across the normal operating range. At 1×10^{-6} mbar this tolerance corresponds to 8×10^{-7}–1.2×10^{-6} mbar or ±20% of reading. This compares favourably with the accuracy of conventional cold cathode discharge gauges which is normally in the range ±50% of the reading.

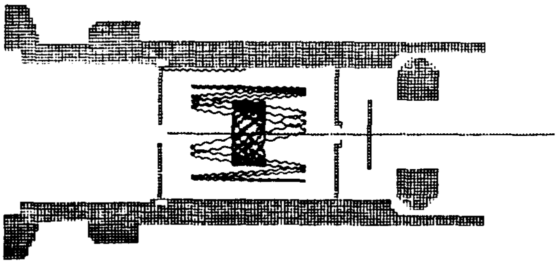

Figure 3. Typical electron trajectories in the gauge tube produced using SIMION[1] simulation software.

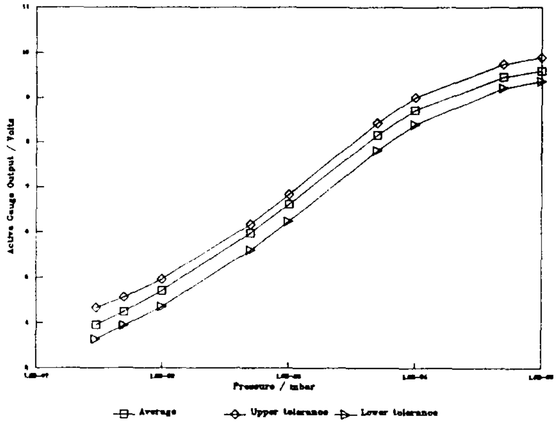

Figure 4. Pressure characteristic of the active inverted magnetron gauge. Tolerance band from a batch of 16 gauges is shown.

5. Guard ring

A guard ring has been incorporated into the design of the active inverted magnetron gauge. The guard ring consists of a metal ring concentric to the anode of the gauge of the vacuum feedthrough and is extended onto the high voltage power supply circuitry in the form of a guard track on the PCB. The vacuum feedthrough is essentially triaxial with the earth electrode formed by the body tube. The guard ring 'traps' any leakage current that would normally flow between the anode and earth so that it is not measured by the gauge electronics. Current leakage occurs with conventional gauges when the feedthrough or high voltage connector becomes contaminated or when the gauge exterior is exposed to high humidity levels. The leakage current causes the gauge to indicate an artificially higher pressure than actually present in the vacuum system. Figure 5 shows the drift of the active inverted magnetron gauge at 1×10^{-6} and 1×10^{-8} mbar when subjected to combinations of temperature (10–50°C) and relative humidity (10–90%) over a 34 h period. Each temperature was held constant for 4 h whilst the relative humidity level was incremented from 10 to 90% in four steps. Figure 5 shows that at 1×10^{-6} mbar the drift is within ±0.25% of the full scale voltage. The drift correlates well with the temperature fluctuations thus indicating that the gauge is insensitive to the humidity level.

6. Interfacing and noise immunity

The power supply inputs and signal outputs of the gauge are accessed via an 8-way FCC68 compatible connector (WECO).

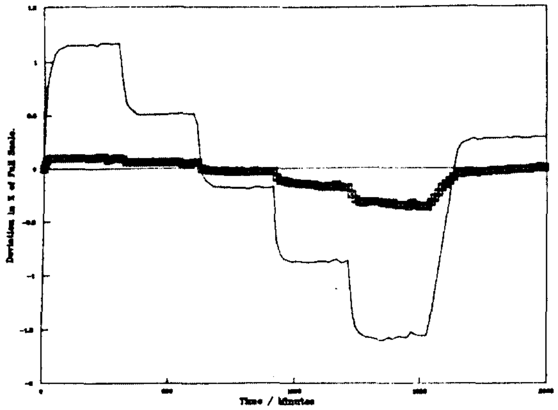

Figure 5. Temperature and humidity performance of the active inverted magnetron gauge. The drift at 1×10^{-6} mbar (thick line) and 1×10^{-8} mbar (thin line) is shown.

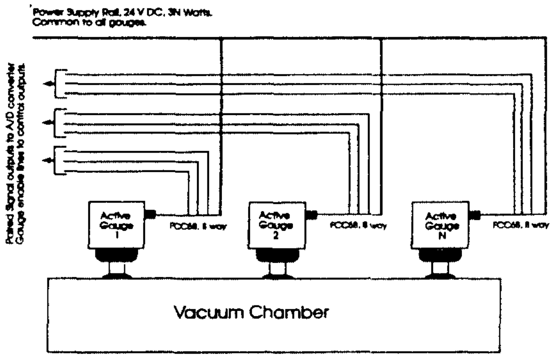

Figure 6. Interfacing several gauges to a data acquisition system or programmable logic controller. The gauges share a common supply rail which must have a rating of $3N$ W where N is the number of gauges. The signal output and signal common from each gauge is fed directly into the analogue to digital converter of the acquisition system.

Table 1.

Pin	Allocation
1	Power supply positive
2	Power supply common
3	Gauge output
4	Gauge identification
5	Signal common
6	No connection
7	Gauge enable
8	No connection

The pin out of the connector is shown in Table 1. Note that the signal outputs and power supply common are separate, allowing true differential four wire measurement.

The gauge has an integral switched mode power supply that accepts a wide range of inputs (20–36 V dc) with up to 1 V peak-to-peak ripple (the low power consumption of the gauge allows the unit to be powered directly from a battery). The 0–10 V signal output can be connected directly to the analogue to digital converter of a data acquisition system or programmable logic controller. Figure 6 shows how a system of many gauges can be built up sharing a common power supply rail. Each gauge can be turned on/off remotely by controlling the level applied to pin 7 of the connector. Grounding pin 7 'enables' or turns a gauge 'ON'.

Electromagnetic/radio frequency susceptibility and emissions have been effectively reduced by enclosing the gauge electronics within a metal Faraday shield connected to earth potential. The active gauge's signal output is decoupled from induced ac noise by the use of a 0.1 μF capacitor which filters out high frequencies. Low frequency noise (2 Hz) is reduced by an operational amplifier and protective resistor in the output circuitry (the amplifier feedback loop forms an active filter and compensates for resistive losses).

Improved noise immunity as discussed above combined with the relatively high level output signal (0–10 V) allows the active inverted magnetron gauge to be used with unscreened cables up to 100 m long without degradation of the signal. Applications include use in large vacuum systems such as particle accelerators and vacuum furnaces or in any system where the vacuum system is remote from the control/monitoring area.

7. Conclusion

The active inverted magnetron gauge described has major advantages when applied to large and computer controlled systems such as particle accelerators and vacuum furnaces, which include small size, ease of interfacing to data acquisition systems and improved immunity from the effects of electrical interference and humid environments. The active gauge exhibits improved starting characteristics at high vacuum and has increased accuracy compared with conventional 'passive' cold cathode discharge gauges.

References

[1] D A Dahl and J E Delmore, SIMION version 4.0, EG+G Idaho Inc., Idaho Falls, ID 83415 (1988).

[2] J H Leck, *Total and Partial Pressure Measurement in Vacuum Systems*, 1st Edn, p. 68. Blackie, London (1989).