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IMPROVED HELMER GAUGE FOR MEASURING PRESSURES DOWN TO 10^{-12} PASCAL

by

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IMPROVED HELMER GAUGE FOR MEASURING PRESSURES DOWN TO 10^{-12} PASCAL

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Abstract

An ionization pressure gauge of the Helmer type was selected at CERN ISR for measuring pressures below 10^{-10} Pa. Tests of several such gauges commercially available showed a low pressure limitation of about 2.5×10^{-10} Pa. This limit was initially reduced by a factor ten upon thoria coating the tungsten cathode, as originally suggested by Helmer. A further important improvement was achieved by introducing the following modifications. The sensitivity was increased by enlarging the grid diameter and other geometrical parameters were varied and optimized. These included the diameter of the openings in the bottom cover of the grid and in the collector shielding cage and the transparencies of the deflecting and suppressor electrodes. The resulting gauge presents a sensitivity of about 0.30 Pa^{-1} (or 40 $torr^{-1}$) and a measured pressure equivalent residual current lower than 2×10^{-12} Pa.

Introduction

The measuring accuracy of an ionization gauge at very low pressure is determined by the relative importance of the pressure independent or residual, current (I_R) with respect to the ion current to be measured. Historically, the main component of I_R was always the electron current (I_X) ejected from the ion collector by the X rays produced by the impact of the ionizing electrons on the grid. Therefore, measuring low pressures mainly consisted in rendering the collector less and less accessible to X rays, without simultaneously reducing its efficiency for collecting ions. In the case of the Bayard-Alpert gauge (BAG), in which the collector protrudes in the centre of the grid cylinder, the collector diameter may be reduced to below 25 μ while still maintaining an ion collection efficiency close to 100% (1). Consequently, the pressure equivalent to I_R can be decreased to below 10^{-10} Pa. A different approach consists in moving the collector to outside the grid and driving the ions to it by means of electrostatic fields. Among the external collector gauges which were developed so far (2,3,4,5) the Helmer gauge (HG) has been studied most extensively in our Laboratory. The HG is shown schematically in Fig. 1. The ions entering the shielding box are deflected to the collector by a negative voltage applied to the upper deflecting electrode D_1. Photoelectrons extracted from the collector by X rays entering the box are suppressed by a transparent electrode biassed negatively. Many commercially available HG's were limited at about 2.5×10^{-10} Pa by W sublimation from the cathode (6). Upon thoria coating the cathode and reducing the

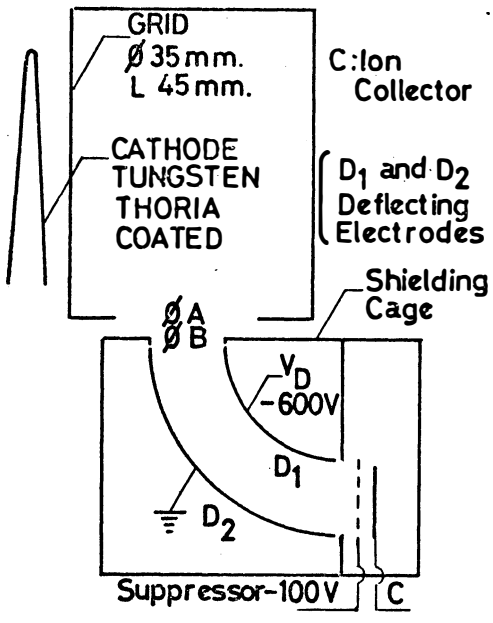

Fig. 1 Schematic of the HG

electron emission current (I^-) to 4 mA, this limit was reduced to 10^{-11} Pa. The purpose of the present work was to gain a further order of magnitude by : a) increasing the sensitivity (S) of the gauge, b) decreasing I_R, c) reducing thermal outgassing of gauge components.
The vacuum system which was used for this development consists of a small stainless steel vessel to which 3 titanium sublimation pumps (SU) and a 400 s^{-1} sputter ion pump are connected. One of the SU's can be cooled to liquid N_2 temperature. All system components were degassed at 950°C and 10^{-4} Pa in a vacuum furnace. After baking, a pressure close to 10^{-10} Pa is usually recorded when the vacuum system is still above 50°C. One day later the pressure is about 10^{-11} Pa and falls in the 10^{-12} Pa range upon cooling the SU with N_2. The ultimate pressure of the system depends on many variables, particularly on the presence of new components, but values in the low 10^{-12} Pa range are usually recorded. These low pressures are monitored by a commercial HG and by the newly developed improved version (IHG). Electric currents down to 10^{-16} A are measured by means of vibrating reed electrometers.

Sensitivity

To increase the sensitivity, the same electrode structure as developed for the ISR BAG gauge was adopted (1). The grid is a closed cylinder of 35 mm diameter and 45 mm length made from 0.13 mm Pt-Ir wire with 2 mm pitch.The filament is a thoria coated, hair pin tungsten wire placed 3 mm from the grid. The improvement is shown in Fig. 2, where S is plotted versus the electron emission current (I^-) for a typical commercial HG and two IHGs. An interesting feature is that when decreasing I^-, S increases while the optimum energy of the ionizing electrons (V_{gf}) decreases. Operating at low I^- provides the double advantage of reducing both the thermal degassing and the production of X rays (which is roughly proportional to V_{gf}^2). Therefore I^- is fixed at 3 mA and V_{gf} at 150 V, unless otherwise stated.
The S values of the IHGs shown in Fig. 2 are very close to the average value of 0.32 Pa^{-1} (or 42 $torr^{-1}$) which was measured for the BAG gauges of the ISR.

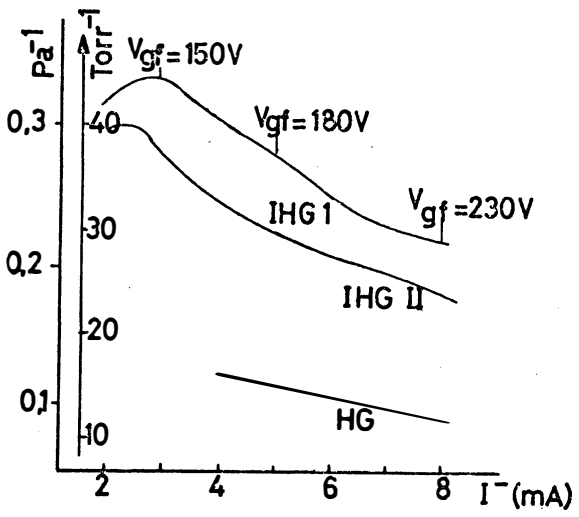

Fig. 2 Sensitivity (S) variation as a function of the electron emission current (I^-) for the HG and the IHG. Also shown the values of the electron energies (V_{gf}) for which maximum S is obtained at various I^-.

However, in the absence of the radial electric field due to a collector at ground potential, the ionizing electrons travel a longer path inside the grid and produce more ions (7,8). Thereforethe IHG should present a higher S unless ions are lost in their travel to the collector. To clarify this point, the diameters of the apertures in the lower end of the grid and in the collector cage were varied and the ion currents were measured on the collector or on the lower deflecting electrode D_2. The results are shown in Table 1. From this table the following information can be derived. Firstly, a ratio A/B not smaller than about 2 is needed for efficient extraction from the grid. The extracted ions amount to about 80% of the total produced inside the grid for B=10 mm, and about 50% for B=6 mm. The quoted 'total' was determined by means of a large collector disc (20 mm diameter) placed just below the aperture of the grid. Secondly, only

Table 1

diameter A of the grid aperture, mm	30	20	10	20	10
diameter B of the cage aperture, mm	10	10	10	6	6
a) S (Pa^{-1}) as measured on D_2	0.57	0.65	0.40	0.39	0.40
b) S (Pa^{-1}) as measured on the collector	0.33	0.33	0.18	0.22	0.20
c) same as b) after final improvement	-	0.43	-	0.28	-

about 50% of the ions which initially entered the cage reached the collector (line b). This was subsequently improved to about 70% by enlarging the distance between the deflecting electrodes to 10 mm and increasing the transparency of the suppressor to about 95% (line c). In the final choice A was 20 mm and B 6 mm. With respect to A=20 mm, B=10 mm, this choice provides a sensitivity 1.5 times lower but reduces by a factor 3 the X rays which enter the cage. In all cases the collector and the suppressor are quasi-elliptical with axis of 10 mm and 20 mm.

Residual Current

When varying the voltage V_D applied to D_1 from positive to negative the ions first impinge on D_2 (see Fig. 1). At very low pressure a negative current I_1 is measured on the collector, which was attributed by Helmer (5) to electrons extracted from the suppressor by X rays reflected on D_2. During normal operation the suppressor is held at negative potential, typically - 100 V. Our experimental data agree with this description, with the following additional evidence. I_1 varies proportionally to the electron emission current, to the area of the aperture in the collector cage and to V_{gf}^2. Furthermore, I_1 decreases when increasing the transparency of the suppressor. By selecting B=6 mm, reducing the X-ray reflection on D_2 (wire mesh instead of solid plate) and increasing the suppressor transparency to 95%, I_1 was reduced from $- 4 \times 10^{-15}$ A to $- 2 \times 10^{-16}$ A. The latter value would correspond to a (negative) pressure of about 2×10^{-13} Pa (I^-=3 mA). When the absolute value of the negative V_D is progressively increased, the ions reach the collector and a positive current I_2 is recorded. The maximum of I_2 is obtained for V_D = - 650 V.
When increasing the negative V_D even further, the ions impinge on D_1 and again a negative current I_3 is measured on the ion collector. This current was reported to increase with pressure and attributed to emission from D_1 of negative particles under ion bombardment (5). Although I_3 increases effectively above a certain pressure, it also presents a pressure independent component which is clearly produced by X rays because it shows the same dependence as I_1 on the area of the cage aperture, on I^- and on V_{gf}^2. The absolute value of I_3 was in all our results larger than I_1 and the ratio I_3/I_1 was constant for a given suppressor transparency. The transparency of the suppressor affects I_1 but not I_3. In the final version of the IHG, $I_3 = - 1.5 \times 10^{-15}$ A, current corresponding to a (negative) pressure of about 1.5×10^{-12} Pa.
In the light of these results it seems plausible that I_3 is produced by the addition to I_1 of the electron current which is extracted by X rays from the deflecting electrodes D_1 and D_2. When D_1 is positively biassed, it collects the electrons produced on D_2 and it retains those produced on D_1. For a negative V_D these electrons escape D_1 and can reach the ion collector. Since a very low negative potential is sufficient to produce this effect, it appears justified to assume that in the absence of ion current, I_3 would maintain its maximum value practically right across the negative range of V_D. Therefore, the current measured at V_D = - 600 V must be corrected before being transformed into a pressure by adding to it 1.5×10^{-15} A.

The measurements carried out with an IHG at different pressures are shown in Fig. 3. Observe that I_1 remains constant when the pressure varies over three orders of magnitude, while I_3 presents a pressure independent value to which a pressure proportional component is added. The currents I_2 are already corrected for I_3 and the pressure corresponding to the maximum value of I_2 can be read directly on the pressure scale.

Thermal degassing

The shielding box and all electrodes contained in it which cannot be degassed in situ by electron bombardment, were carefully degassed before assembling (950°C, 10^{-5} Pa). The effect of the degassing when operating may be as small as 10^{-12} Pa, as shown by the fact that total pressures close to this value were directly measured. An estimate of the effect of degassing on a particular pressure reading may be obtained by measuring the same pressure with different electron emission currents.

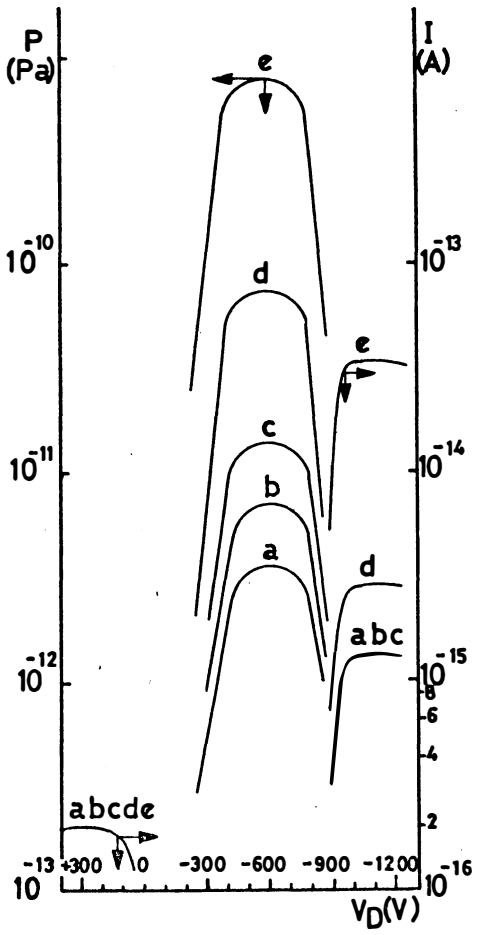

Fig. 3 Typical pattern of the collector current obtained in an IHG when varying V_D at various pressures

Conclusions

The IHG developed here appears to be suitable for measuring pressures in the 10^{-12} Pa range with an uncertainty smaller than 2×10^{-12} Pa. At $I^- = 3$ mA, 10^{-12} Pa correspond to an ion current of 10^{-15} A which is still well within the measuring possibilities of a vibrating reed electrometer.

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