A simple vacuum leak detector using a radio-frequency mass spectrometer

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A simple vacuum leak detector using a radio-frequency mass spectrometer*

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A simple vacuum leak detector, based on the radio-frequency mass spectrometer principle is described. In the pressure range of 10^{-3}–10^{-7} torr leaks of the order of $2\cdot 8 \times 10^{-8}$ l. torr/s can be detected. The instrument may also be used as a conventional ionization manometer. A brief description of the principles and some details of the construction of the tube and of the portable electronic equipment are given.

As a Tesla spark coil cannot be used to find small leaks in a high vacuum system constructed of metal, or of metal and glass or ceramics, many other methods have been investigated and developed.[1–3] Of these the use of the mass spectrometer is most promising.[4] The principal drawbacks of the conventional mass spectrometer (even when adjusted to respond only to the search gas) are high cost and rather complicated maintenance. It is possible to build a very simple, but highly sensitive, leak-detector by using Bennet's type of radio-frequency mass spectrometer.[5] The design and construction of such a detector is described below.

The principle of Bennet's mass spectrometer may be briefly summarized as follows: an ion beam of high velocity is sent through a system of plan-parallel grids, similar to a linear accelerator. Alternate grids are grounded and the others have a radio-frequency voltage applied to them. If the time of transit of an ion between two grids is nearly half of the radio-frequency period, this particular ion gains energy from the radio-frequency field. All ions of the gas-mixture encounter a retarding potential barrier which allows only ions having the highest energy to pass through to the collector. As there is a relation between the charge/mass of the ions, the radio-frequency and the ion-accelerating voltage, the system can be used as a mass spectrometer.

THE LEAK-DETECTOR TUBE

In designing the radio-frequency leak detector, the following requirements had to be satisfied:

(i) pinhole leaks had to be detected in the high vacuum range (about 10^{-3}–10^{-7} torr†);

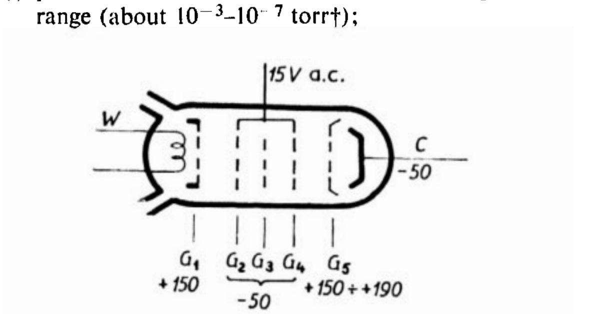

Fig. 1. Leak detector tube

W, *W*-cathode; G_1, grid of ion source; G_2, G_3, G_4, negative grids; G_5, retarder grid; *C*, collector

(ii) it had to be possible to use the instrument as a conventional hot-cathode ionization gauge;

(iii) the tube itself had to be inexpensive, simple, easy to manufacture and de-gas, and suitable for building into any kind of high-vacuum system;

(iv) only a portable electronic equipment suitable for use in factories should be required.

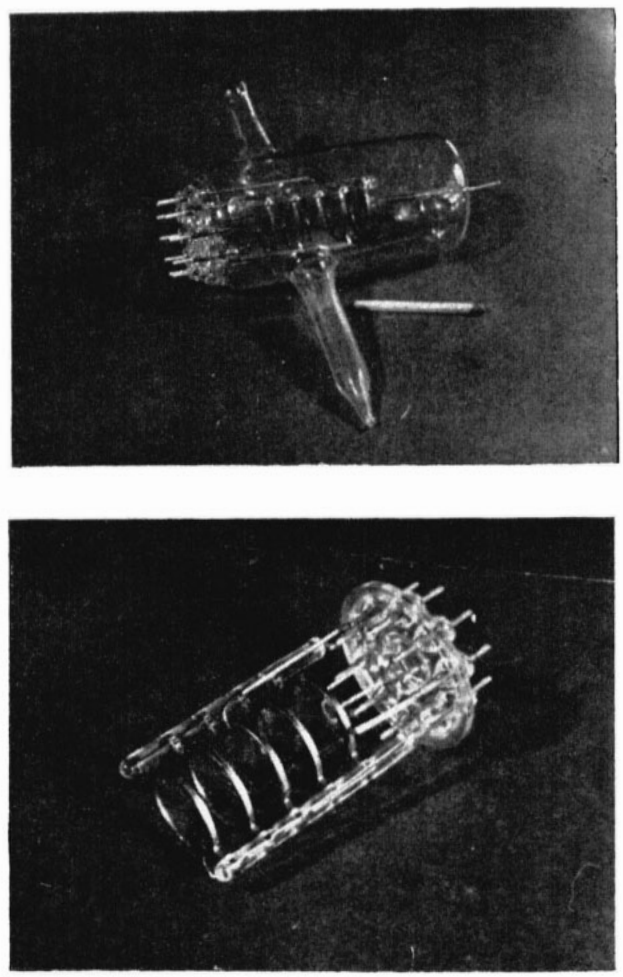

Fig. 2. Photographs of the leak detector

For good resolution it is essential that the ion beam should be monoenergetic; this involves a complicated ion source. Using hydrogen or helium as search gases (the ion masses of which are very different from other gases contained in air), a high resolution is not necessary. The length of the tube is determined by the fact that it has to be less than the mean free path of the hydrogen ions at the highest permissible

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† 1 torr = 1·333 22 mb and is equal to the conventional barometric millimetre of mercury, within one part in seven million.

pressure. Because of these reasons, five grids have been chosen: the cathode and grid one form the ion source; grids two, three and four are negative with respect to the cathode, and on grids two and four a radio-frequency voltage is superposed. Grid five, being positive with respect to the cathode, forms the retarding potential barrier. The collector is separated from the grids on the top of the tube (Fig. 1).

Great care was taken to keep the metal parts of the tube at a minimum and to avoid the use of ceramics; in earlier tubes, where a distance-ring of steatite had been used, "virtual leaks" were observed. The grids spaced at 7 mm distance from each other, are wound with twenty loops per centimetre. The W-wire has a diameter of 0·03 mm, and the grid is mounted on a nickel frame. The frames are held by two glass rods; this construction makes it possible to keep the grid distances within narrow tolerances. The frames have a diameter of 18 mm; the tube is 70 mm long and has a diameter of 35 mm.

The grids near the hot cathode are gold-plated. The temperature of the pure W-cathode is about 2000° K and 6 W heating power is needed for 5 mA emission current. Photographs of the tube are shown in Fig. 2.

ELECTRONICS

The electronic circuit may be divided into three parts.

Firstly, the emission stabilizer (Fig. 3), which must keep the emission constant when the line voltage and the gas pressure in the tube vary. If the electron current of the

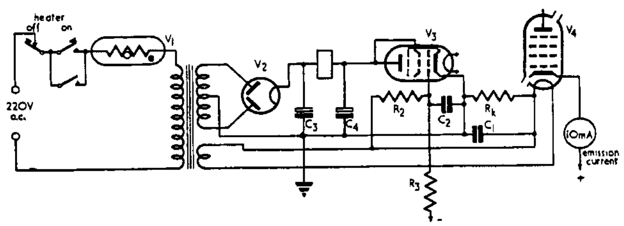

Fig. 3. Circuit of emission stabilizer

R_2, R_3 = 0 1 MΩ
R_k = 20 kΩ

C_1, C_2 = 0 1 μF
C_3, C_4 = 16 μF

V_1 = baretter
V_2 = AZ41
V_3 = EL41
V_4 = leak detector tube

leak detector deviates from the prescribed value, the deviation causes the voltage drop more or less on resistance R_k which regulates the plate current of V_3. This change of current causes a change in the heater voltage of the leak detector tube, re-establishing the original emission current. The relay in the circuit of V_3 breaks, if the pressure in the spectrometer tube becomes higher than the prescribed value, thus protecting the heater.

Secondly, a d.c. feedback amplifier is used to detect the ion current. A pentagrid converter is used with 4 V heater voltage, the third grid being the signal grid. The input resistor is at maximum at 3×10^8 Ω, and full-scale deflexion of the output meter corresponds to 8×10^{-10} A (Fig. 4).

Lastly, a conventional tuned-grid type oscillator produces the radio-frequency voltage. At the chosen d.c. potentials and grid distances, a value of f equal to 7 Mc/s is needed for hydrogen gas. The amplitude of the radio-frequency voltage is 15 V. Special amplitude and frequency stabilization did not seem necessary.

PERFORMANCE

The method of leak location is the conventional one: a jet of hydrogen gas is passed over the surface of the vessel under test and its entry through the leak is indicated by a moving-coil instrument. The response time constant is very short; at leaks greater than about 10^{-7} l. torr/s there was practically no time lag.

The resolving power of the leak detector—using the $M/\Delta M$

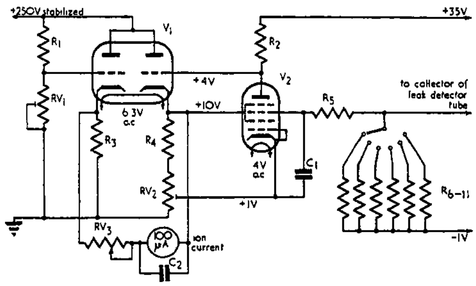

Fig. 4. Circuit of ion current detector

R_1 ≐ 0 12 MΩ
R_2 = 5 MΩ
R_3 = 4 kΩ
R_4 = 3 kΩ
R_5 = 0 1 MΩ
R_6–R_{11} = 3×10^8 Ω

C_1 = 100 pF
C_2 = 1 μF

V_1 = ECC40
V_2 = 6BE6

definition where ΔM is the peak-width at half height—is about five for hydrogen gas with the voltages shown on Fig. 1. It was found that leaks of the order of $2{\cdot}8 \times 10^{-8}$ l. torr/s (0·1 μl./h) could quite readily be detected. With a hydrogen to air mixture of 1 : 1000, ion current of 4×10^{-10} A was obtained, corresponding to half-scale deflexion of the ion current meter. As it was conveniently possible to make use of even 5% of full-scale reading, the ratio of minimum detectable hydrogen pressure to air pressure was about 1 : 10 000.

The radio-frequency spectrometer tube may be built into any vacuum system where the leak is to be detected, and no separate pump is needed.

If the pressure in the investigated system is higher than a prescribed value, a background is produced in the ion-current of the collector. This means that ions originating from residual gas components are able to gain sufficient energy to reach the collector; we are assuming that a part of the background is composed of secondary and reflected electrons. In the early experiments an attempt was made to eliminate the background by using higher retarding potential and a separate suppressor grid; this caused a loss in sensitivity. The d.c. compensating of the background proved to be more successful in obtaining the sensitivity already mentioned.

As an ionization manometer, grids G_2–G_5 are connected together and ion current on collector C is measured.

CONCLUSION

With the help of a relatively simple tube and electronic circuits an instrument was constructed which has proved to be an effective tool in finding leaks in high vacuum equipment in the pressure range of 10^{-3} to 10^{-7} torr. If the leak detector is built together with a separate pump, and a more sensitive detector for ion current is used, then it seems possible to attain the sensitivity reached by magnetic mass spectrometer leak detectors.

ACKNOWLEDGEMENT

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An instrument for the continuous measurement of shrinkage of textile yarns

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The yarn is fed from a bobbin at a fixed rate into a hot-air treatment chamber. After passing over a tensioning device it is withdrawn at a variable rate so that the tension and length of yarn in the chamber (and therefore the time of heat treatment) are held substantially constant. The tension is known and adjustable. The shrinkage under these controlled conditions is derived from the ratio of input to output rates, and is displayed numerically as a percentage. After a bobbin has been knotted in and the instrument started, a fixed length of yarn is tested automatically.

In the course of research on the production and testing of Terylene polyester yarn, it became necessary to measure the shrinkage of textile yarns when subjected to thermal treatment under very low tension. The traditional method of making this measurement is to wind the yarn under a fixed tension to a loop of known size and allow it to shrink freely under the thermal treatment; its length is measured before and afterwards. That method is intermittent, it only gives the mean shrinkage over a long length of yarn, and, in order to cope with many samples in the laboratory, a batching method is necessary so that a long time elapses before an individual result becomes available.

It was required to know not only the average shrinkage (expressed as a percentage length change suffered by the yarn) but also to have some estimate of the variation in shrinkage along the length of yarn contained on a bobbin and the variation between bobbins of ostensibly identical make. The machine to be described has been used successfully to carry out measurements of the shrinkage of continuous filament Terylene polyester yarn when subjected to a heat treatment of 100° C for one minute at a very low predetermined tension.

The basic principle is to feed the yarn into a hot air chamber at a constant rate and under constant tension, and to feed it out, after treatment, at a rate controlled by the length under test, which is thus kept substantially constant. The feed-in rate is such that any portion of the yarn is within the hot chamber for one minute. The percentage shrinkage can be deduced from a knowledge of the differential input and output speeds of the yarn, and this result is presented digitally.

DESCRIPTION OF THE MACHINE

It must be emphasized that, for reasons to be described below, the actual machine is rather more complicated and differs slightly in principle (particularly regarding the gears, cams, and switches) from the following description and illustration; differences have only been introduced to present a consistent and simplified explanation.

Referring to the figure, yarn from the package (1) to be tested passes through a ball tensioning device (2) and is drawn at constant speed between a pair of rolls (3) driven by an electric motor (4). One of the rolls is rubber covered, is free running, and pressed on to the driven roll. The yarn

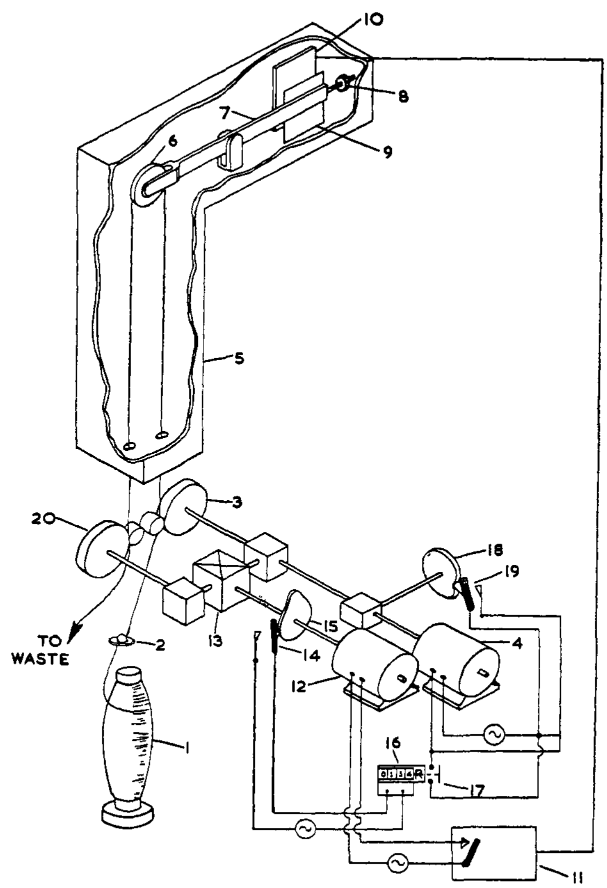

Diagram of continuous shrinkage measuring instrument