The advances made in vacuum technique in the last ten years have given a new lease of life to the apparently outmoded idea of continuously pumping a vacuum tube during operation.

The getter ion-pump forms a compact, convenient vacuum pump, immediately set in operation and capable of pumping small quantities of gas to maintain a low pressure for a long period of time.

The principle of this pump has been known for some years 1): a getter material, such as zirconium or titanium, is continuously or intermittently evaporated, and the gas molecules are ionized in the same way as in a hot-cathode ionization gauge 2) or a Penning vacuum gauge 3). The ions formed are then trapped in the getter film deposited on the inside of the envelope.

In this article a getter ion-pump will be described in which a certain quantity of titanium is evaporated, and where the titanium vapour itself simultaneously sustains a discharge of the type occurring in a Penning vacuum gauge. In conclusion, various examples of the pump's application will be discussed.

Construction and operation of the getter ion-pump

The pump consists of a glass envelope containing an electrode system. The electrode assembly (fig. 1) is similar to that in a Penning gauge. The Penning system is formed by the loop-shaped anode A, made of molybdenum, the cathodes K₁-K₄, and a magnetic field. The cathodes carry a supply of getter material. The direction of the magnetic field, with an induction of 0.04 Wb/m², is perpendicular to the plane of the anode. The electrodes are mounted on a glass base. The cylindrical glass bulb measures 33 mm in diameter and 60 mm in length. The weight of the pump (40 g) together with the permanent magnet is 450 g. The complete assembly is therefore conveniently light and easy to connect up with the object to be evacuated.

The pump is set in operation by applying a DC potential of 2 kV between anode and cathodes, the latter being heated by an alternating current. It is also possible to heat only one cathode. The cathodes consist of stranded tungsten and titanium wires, and are heated to a temperature at which the titanium evaporates. The rate of evaporation is governed by the temperature and the number of cathodes heated. Part of the evaporated getter material settles directly on the glass walls of the pump; another part contributes to the Penning discharge, in that, during evaporation, titanium atoms are ionized and electrons are released. If the total pressure of the gases present is less than $10^{-3}$ torr ($10^{-3}$ mm Hg), the discharge is sustained not by these gases but almost entirely by the titanium vapour. The molybdenum shield P, together with the protective caps T, serves to prevent short-circuiting between anode and cathode if the titanium were to

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Titanium is only evaporated at low pressures, the mean free path of the titanium atoms to become shorter than the distance to the glass wall. In that case, as a result of collisions in the gas, titanium atoms may arrive on the base. If the pump is to be used for producing very high vacua, so that the titanium is only evaporated at low pressures, the shield $P$ can better be removed. The reason for this is that, for such low pressures, all metal parts must be degassed by heating; this can be done very simply for the electrodes by passing a current through them, but this is not practicable in the case of the shield. (The anode loop would be led out through the base via two pins to enable current to be passed through it.)

The power supply for the pump consists merely of a DC voltage source of 2 kV, 2 mA, and an AC voltage source of 10 V, 10 A.

The pump operates as follows.

1) The getter material deposited on the glass wall adsorbs the molecules of the chemically active gases impinging on the surface, such as oxygen, hydrogen, nitrogen, etc.

2) The Penning discharge contains a vast number of ions and electrons. The ions, but especially the electrons, which can describe a long path owing to the presence of the magnetic field, have a considerable chance of colliding with gas molecules entering the discharge from the space to be evacuated. The chemically active as well as the inert gas molecules are thereby ionized. The gas ions formed are then, under the action of the electric field, shot into the getter film — which is kept at cathode potential by the contact spring $F$ — and there they are trapped.

As a result of continuously evaporating the titanium, the getter ion-pump, as its name implies, has a double action in that a fresh surface is continuously created for trapping ions, and a fresh chemically active surface for gettering.

Properties of the pump

The characteristic properties determining the performance of a getter ion-pump are:

- the maximum permissible initial pressure,
- the pumping capacity,
- the pumping speed, and
- the lowest attainable pressure (ultimate pressure).

The maximum permissible initial pressure, which is determined by the method of evaporation chosen, amounts in the pump described here to a few tenths of a torr.

The pumping capacity for chemically active gases, such as CO and $H_2$, i.e. the total quantity that can be extracted, is given by the getter supply present in the cathode. For chemically active gases the pumping capacity is equal to the gettering capacity. This differs according to the gas, the maximum value being achieved when each getter atom traps as many gas molecules as corresponds to the chemical reaction equation. In practice this situation seldom obtains. For each cathode we generally use 12.5 mg of titanium in the form of three wires, each of 100 microns diameter, stranded with the tungsten heater wire. The four cathodes together thus contain 50 mg of titanium. The quantity of gas that can be removed under favourable conditions with this quantity of getter material is about 2.5 torr.litre in the case of CO, calculated for a maximum specific gettering capacity of 0.05 torr.litre/mg. Since a vacuum system may contain a mixture of the most diverse chemically active gases, one can generally reckon only with an average specific gettering capacity of 0.01 torr.litre/mg.

For inert gases, such as He and $CH_4$, the pumping capacity is considerably less. Measurements have shown, however, that in the case of He it is certainly more than 0.05 torr.litre.

In principle the cathodes could accommodate a larger supply of getter material.

The quantity of gas removed per second in the steady state is given for a chemically active gas by the expression:

$$\frac{dQ}{dt} = C \frac{dM}{dr} = Sp \quad \ldots \ldots (1)$$

Here $dM/dt$ represents the rate of evaporation of the getter material, $C$ the specific gettering capacity, $S$ the pumping speed (governed by the speed with which the getter takes up gas and the geometry of the glass envelope of the pump) and $P$ the resultant pressure at the pump mouth, i.e. the place where the getter ion-pump is connected to the vessel to be evacuated. Fig. 2 shows the measured pumping speeds $S$ in l/sec as a function of the rate of evaporation $dM/dt$ in mg/sec, for various quantities of CO supplied per unit time in torr.litre/sec. The maximum value for $S$, in this case 62 l/sec, is determined by the orifice of the pump mouth. For other chemically active gases the pumping speed $S$ is of the same order of magnitude. The curves in fig. 2 were obtained irrespective of whether the anode was under high tension or not. This means that, for CO, the contribution of ion trapping to the total pumping speed in the measuring range investigated is small compared with the contribution of the gettering action alone.
In order to use equation (1) it is desirable to determine the relation between the specific gettering capacity $C$ and the pumping speed $S$. From the curves in fig. 2 we can calculate for any value of $S$ the corresponding values of $C$ for the various quantities of CO supplied. The surprising result is that the same value of $C$ is always found for a given $S$. A plot of $S$ versus $C$ is shown in fig. 3. Along the abscissa at the top the specific gettering capacity is set forth in torr.litre/mg, and at the bottom the quantity $C$ as the ratio between the number of CO molecules trapped and the number of titanium atoms incident on the getter surface. Only at large values of $S$ is the relation between $S$ and $C$ no longer certain, for it is here, as we have seen, that the size of the pump orifice imposes an upper limit on the pumping speed. Apart from this, the pumping speed is established for any given value of $C$. We may therefore deduce that a constant $S$, independent of the influx rate of gas, can only be obtained if the rate of evaporation varies in proportion to the pressure in the pump, since it follows from (1) that

$$S = C \left(\frac{dM}{dt} / p \right). \quad \ldots \ldots \ldots \ldots \ldots (2)$$

A fairly good approximation to the rate of evaporation of the hot cathode is arrived at by deducting from the discharge current $I$ in the pump the discharge current when the cathode is cold. The relation between the rate of evaporation and the discharge current is represented by the curve in fig. 4 (corrected for residual gas).

The above considerations make it evident that the discharge current when the cathode is hot is no measure of the gas pressure. It is, however, when the cathode is cold, and — which is sometimes convenient — the pump may then be used for pressure measurements in a certain range of pressures, as shown by the curves in fig. 5. These curves relate to both $N_2$ and CO at a magnetic induction of 0.04 Wb/m² and an anode voltage of 1 and 2 kV, respectively, with an anode resistor of 1 MO.

The pumping speeds found for chemically inactive gases, such as the rare gases and methane, are much
lower (see Table I). It can be seen from the table that the pumping speed varies only slightly with the discharge current. The rare gases are not chemically bound by the layer of evaporated titanium, and in this case the pumping action relies entirely on the ionization in the gas. The ions formed are shot into the titanium layer and trapped there. How long they remain trapped will depend entirely on the rate of diffusion in the titanium layer. As the rate of diffusion is temperature-dependent, it is advisable to cool the pump wall with a fan. Where methane is concerned, thermal decomposition at the hot cathode also makes an essential contribution to the pumping speed.

The lowest pressure obtainable with this getter ion-pump depends very much on the way in which the pump itself and the vessel are degassed. Degassing is necessary for various reasons, mainly to reduce the hydrogen content of the getter reserve and to prevent the unwanted formation of non-active gases such as CH\textsubscript{4} as a result of reactions between getter and gas \textsuperscript{4).} The formation of chemically inactive gases is undesirable because of the low pumping speed for such gases.

On a small vacuum system having a volume of 0.5 l, which consisted of an omegatron, an ion gauge of the Bayard-Alpert type and a getter ion-pump of the type here described, we measured with the omegatron the partial pressures of the various gas components during the process of evacuation. Four such systems, in various degassed states, were investigated.

\textsuperscript{4) A. Klopfer and W. Ermrich, Vakuum-Technik 8, 162, 1959.

A system which had not been degassed at all was found to contain, after evaporation of the getter, mainly water vapour, carbon dioxide and hydrocarbons. The pressure of H\textsubscript{2}O and CO\textsubscript{2} is governed by the release of gas from the glass surfaces and by the effective pumping speed at the position of the omegatron. The presence of hydrocarbons is attributable to two reactions: in the first place, during the evaporation, hydrogen and carbon present as impurities in the getter may react with one another and form hydrocarbons with up to five carbon atoms. In the second place, hydrocarbons may be formed from water and carbon at temperatures as low as room temperature, as we were able to demonstrate. As a result of the above-mentioned gas desorption and gas reactions, the lowest pressure in a system that has not been degassed lies between \textsuperscript{5)} 10\textsuperscript{−7} and 10\textsuperscript{−8} torr.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Discharge current I µA</th>
<th>Pumping speed S (10^{-3}) 1/sec</th>
<th>Pressure p (10^{-9}) torr</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>100-1000</td>
<td>2</td>
<td>0.01-0.03</td>
</tr>
<tr>
<td>Ne</td>
<td>500</td>
<td>5.5</td>
<td>(\approx 1)</td>
</tr>
<tr>
<td>Ar</td>
<td>{</td>
<td>{</td>
<td>{</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>3.5</td>
<td>(\approx 1)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>7.5</td>
<td>(\approx 1)</td>
</tr>
<tr>
<td>CH\textsubscript{4}</td>
<td>{</td>
<td>{</td>
<td>{</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>74</td>
<td>(\approx 1)</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>210</td>
<td>(\approx 1)</td>
</tr>
</tbody>
</table>

\textsuperscript{5) G. Reich and H. G. Nöller, Vacuum Tech. Trans. 4, 97, 1959.


Even slight preliminary degassing causes a marked drop in the release of H\textsubscript{2}O and CO\textsubscript{2}. The pumping time and the final pressure attainable are then entirely governed by the formation of hydrocarbons from H\textsubscript{2} and C during the evaporation of the getter, and by the pumping speed of the ion pump in respect of hydrocarbons. The pumping times are shorter the more thoroughly the vacuum system and the getter wires have been degassed. Pressures of about \(1 \times 10^{-9}\) torr can be achieved after relatively little preliminary degassing. The residual gas is principally composed of CH\textsubscript{4}, CO and H\textsubscript{2}. Thorough degassing, as described by Alpert \textsuperscript{6)}, makes it possible to reach extremely low pressures (< \(10^{-10}\) torr). The final pressure is then determined by the equilibrium pressure of the hydrogen dissolved in the titanium, and by the diffusion of atmospheric helium through the glass wall \textsuperscript{7)}. Heating of the getter film by the hot cathode promotes the formation of CH\textsubscript{4} and raises the equilibrium pressure of the hydrogen.
For this reason too it is advisable to cool the pump wall with a fan.

Some applications

In order to produce vacuum required in electron tubes, the tubes are subjected during manufacture to two different evacuation operations. First of all, the electron tube is degassed and evacuated at suitable temperatures for a sufficiently long period with the aid of a good high-vacuum pump, usually a diffusion pump. Because of the bulk of the pumping equipment, the tube during this period is virtually immovable. At the end of this major evacuation process, the system consisting of electron tube and getter is sealed off. Further degassing can be effected by letting the tube operate normally or by even overloading it, whereby the evaporated getter material together with the ionizing electron current in the tube is responsible for reducing the residual gas pressure. The loading of the tube must not be increased so fast as to cause the pressure to assume values at which components, e.g. a photo-cathode, might be damaged.

The use of the small getter ion-pump described has considerable advantages for the evacuation of special electron tubes, the degassing of which must often be very protracted. For example, the outgassing times during evacuation by the diffusion pump can be shortened, and the baking-out process and the degassing under initial load can be carried out whilst the getter ion-pump takes over the task of the diffusion pump. Because of the small weight and dimensions it is now possible to transfer the tube together with the pump to the test equipment. Since the getter ion-pump is inexpensive, one can be fitted to each electron tube, and in certain circumstances it is possible for the pump to remain connected to the tube for life. Whereas it was formerly the normal practice to work with tubes on the pump on the tube, it is here rather a question of working with the pump on the tube.

Generally speaking, it is cheaper to use a getter ion pump in cases where long periods of evacuation would be necessary on the diffusion pump. It is also better to use a getter ion-pump when lower pressures than are normally required are needed for certain experiments.

We shall now consider three examples to demonstrate the application of our getter ion-pump.

In various experiments with a type of oscillator tube related to the magnetron 7), designed for high-power pulsed operation at decimetre wavelengths, the object was to maintain a pressure of $10^{-6}$ torr during operation. The tubes had a volume of about 2 l and were all-metal, with a copper envelope and molybdenum electrodes. In the first place the tubes, to which an ion gauge and a getter ion-pump were connected, were evacuated on an oil-diffusion pump and degassed for 18 hours. The impregnated cathodes 9) of the tubes were heated up to about 1250 °C, and the cathodes of the getter ion-pump to about 900 °C at the end of the degassing period. Between the tube and the oil-diffusion pump two cold traps were mounted, one cooled with water and the other with liquid air. The pressure in the tubes, after seal-off from the diffusion pump, amounted to roughly $5 \times 10^{-7}$ torr. When the tubes were afterwards put into operation, the pressure without the getter ion-pump in operation rose to $10^{-4}$ torr. With the getter ion-pump in operation, however, it proved possible, after an initial rise in pressure, to pump off the released gas rapidly and to maintain a pressure lower than $10^{-6}$ torr during the further operation of the tube.

As a second example we shall mention the application of the pump in various experiments on low-noise travelling-wave tubes 10). To keep the noise level low, the condition imposed on the vacuum in these tubes is that the pressure under load should not exceed $10^{-9}$ torr. The travelling-wave tubes, which deliver an RF power of a few microwatts at 4 Ge/s, have a glass envelope measuring 40 cm in length and 2 cm in diameter (approximate volume 0.15 l); the electron source is a barium-oxide coated cathode, and the helix is a molybdenum wire. The vacuum system, which consisted of the travelling-wave tube, an ion gauge and a getter ion-pump of the type described (fig. 6), was evacuated with diffusion-pump equipment described in this journal some time ago 9). During the last hours of the degassing period, which lasted 48 hours and during which the tube was baked out at a temperature of 400 to 450 °C, the electrodes of the ion gauge and the getter ion-pump were glowed. The oxide cathodes of the tubes were activated shortly before seal-off, while the whole system was still at a temperature of 200 °C. After seal-off the pressure amounted to $10^{-7}$ torr. The getter ion-pump reduced the pressure to $10^{-9}$ torr, and it was possible to maintain this pressure throughout operation of the tube.

In the examples given, the getter ion-pump was used to maintain the vacuum in the tube during operation.


As a third example of the use that may in principle be made of a getter ion-pump, we mention in conclusion the evacuation of television picture tubes during manufacture \(^{11}\). Tubes having screen diagonals of both 43 and 53 cm were evacuated by using solely a two-stage rotary backing-pump and a getter ion-pump. This method proved to be highly satisfactory. As it happens, however, its application in mass production offers no special advantages over the usual method of pumping, which is already very economical.

**Summary.** For evacuating certain types of electron tubes, use can be made of a getter ion-pump. Because of its compactness, light weight and low cost, many special types of electron tubes can retain their own pump throughout their working life. This article describes a getter ion-pump using titanium as getter material. Ionization takes place as in a Penning vacuum gauge; the titanium itself sustains the Penning discharge. With its reserve of 50 mg of titanium the pump can remove a total of 2.5 torr.litre of CO. The maximum pumping speed is 62 l/sec. The lowest pressure achieved in small vacuum systems is roughly \(10^{-10}\) torr.

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\(^{11}\) These experiments were done partly by C. J. W. Panis and J. van der Waal in the Development Laboratory of the Electron Tubes Division, Eindhoven, and partly in the laboratory at Aachen.