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# The Return of Permanent Gas Pressure in Sealed Vacuum Interrupters

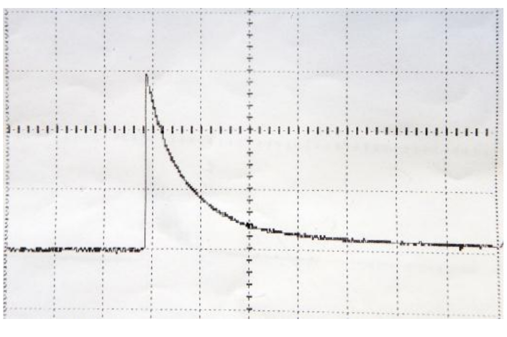
R. Reeves[1] and L. T. Falkingham[1]
[1]Vacuum Interrupters Ltd, Rugby, UK

***Abstract-*** **The vacuum pressure in Vacuum Interrupters (VI) is usually measured by inducing a magnetron discharge inside them. We have previously reported evidence that if this discharge is continued for long enough it causes the gases to be chemically bonded to solid surfaces in the interrupter, resulting in a permanent reduction of pressure. In a small proportion of interrupters however the pressure returns to a stable level similar to the pre-discharge pressure over a period of hours or days. We now report on measurements of this pressure recovery. It was found that with these VI the cycle of pumping and pressure return is repeatable. With this information it may be possible to adapt magnetron testing procedures to distinguish between pressure rise due to return of permanent gas, which will level off, and continuous pressure rise due to internal outgassing.**

## I. INTRODUCTION

### *A. Magnetron vacuum measurement*

The vacuum level in newly made vacuum interrupters is normally checked at the end of manufacture by an instrument which uses a magnetron discharge to measure gas pressure [1]. The device on test is placed inside a magnetising coil, and when a high voltage is applied across the vacuum a small pulse of current occurs due to ionisation of the residual gas. The peak of the pulse, as shown in Fig. 1, gives a measure of the vacuum level.



Time (200mS/div)

Fig. 1. A typical magnetron pulse. The vertical scale is from 2μA/div to 2mA/div, depending on the vacuum pressure.

### *B. The form of the pulse*

It can take a little while for a pulse to initiate after the fields are applied, but then an avalanche discharge occurs and the pulse rises very rapidly to its peak. After that the pulse dies away more slowly. It is believed that the discharge occurs in quite a small part of the vacuum space and that the gas in the rest of the vacuum space migrates into the discharge volume and is ionised in turn. The ionized particles are thought to be attracted to surfaces in the vacuum space and adhere there. The relatively slow decay of the discharge curve shows the pressure dropping to a low level as most of the gas is thus removed.

In manufacture the most common practice is to measure the vacuum level in newly made interrupters on at least two occasions, separated by a number of days. It is widely believed that the ionized atoms or molecules adhered to surfaces inside the interrupter slowly become neutralised and return to the vacuum space over minutes and hours.

The theory is that after the first test time is allowed for this pressure to return, and then the second measurement then allows any pressure increase due to leakage of gas during the interval to be detected, and the leak rate measured.

### *A. A surprising finding from measurements on old interrupters*

This theory was called into question when we tested a batch of 19 old interrupters that had been in service for at least 30 years [2]. With sixteen of the batch the vacuum pressure behaved quite differently. Readings for a typical one of these interrupters are shown in Table 1.

TABLE 1. VACUUM MEASUREMENTS AT DIFFERENT TIMES ON AN OLD INTERRUPTER

| Likely pressure when new *mbar* | Pressure after ~30 years *mbar* | Pressure 7 days later *mbar* | Pressure two years after that *mbar* |
|---|---|---|---|
| $1x10^{-6}$ | $9.4x10^{-5}$ | $1.4x10^{-5}$ | $3.4x10^{-6}$ |



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The interrupter was known to be at least 30 years old, and when new its vacuum pressure would have been in the order of $1x10^{-6}$ mbar. A reading made in 2013 however measured a pressure close to $1x10^{-4}$ mbar. This pressure rise from new is not unusual. It is not due to a leak of air from outside, but instead to slow emergence of gases dissolved in the solid parts of the interrupter, or from their surfaces, which is called virtual leakage.

When after 7 days a new reading was made, the pressure had not returned at all: it was still very low. Two years later, in 2015, another measurement was made, and the pressure still had not returned to a significant degree. The magnetron discharge had apparently made the gas disappear almost permanently. A very small rise in pressure over the two years following the measurements gave a measure of the intrinsic virtual leak rate (i.e. outgassing) of the interrupter and was consistent with the pressure rise seen after thirty years.

Similar results were found in another 15 of the batch of old interrupters.

The substantial difference between this finding and what is generally believed to happen in magnetron testing may be due to a substantial difference between the test procedure in this laboratory and normal factory production procedure.

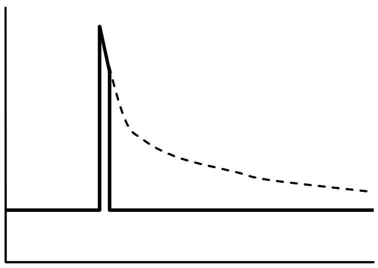

Fig. 2. Short duration pulse probably used in manufacture.

In manufacturing companies, we believe that the high voltage and the magnetic field are switched off as soon as a measurement of the peak current has been secured, thus terminating the discharge before the pressure has fallen very much, as shown in fig 2. In contrast, the procedure which we used in these tests has been to continue the discharge until the trace reaches the end of the oscilloscope screen, as in Fig. 1, and to switch off when convenient after that. It appears that this extended discharge has had the effect of permanently removing the gas. This effect can be called Permanent Magnetron Pumping.

Details of the work just described are given in [2] where it is suggested that the magnetron discharge breaks down the gas molecules and that the ionised gas atoms then combine chemically with the very clean metal surfaces inside the interrupter. Metals, especially copper, normally have an oxide layer on their surfaces which would prevent this happening, but because this layer would hold absorbed gas well, and be an outgassing source, it is chemically etched away during the manufacture of interrupters.

### B. *Interrupters containing permanent gas*

Some interrupters however showed very different behavior. With these the pressure did reduce in the magnetron discharge, but not to such a low level, and it then returned to its original level in a few hours or days, in accordance with the general belief. Table 2 shows data for the three interrupters in the batch which showed this behaviour. The pressure after two years is not shown because it is not relevant when the pressure returns in hours or days.

This paper reports pressure return measurements on specimen 1 of these interrupters.

TABLE 2. OLD INTERRUPTERS SHOWING EVIDENCE OF PERMANENT GAS.

| Specimen No. | Likely pressure when new *mbar* | Pressure after ~30 years *mbar* | Pressure 7 days later *mbar* |
|---|---|---|---|
| 1 | $1x10^{-6}$ | $1.4x10^{-3}$ | $2.0x10^{-4}$ |
| 2 | $1x10^{-6}$ | $2.0x10^{-3}$ | $1.6x10^{-4}$ |
| 3 | $1x10^{-6}$ | $3.6x1-^{-3}$ | $1.9x10^{-5}$ |

## II. MEASUREMENTS OF PRESSURE RETURN

### A. *Method*

The objective was to measure the progress of pressure return over time. The procedure had to take into account the fact that each measurement would pump the gas at least to some degree. It was decided that at each measurement the gas would be completely pumped by keeping the discharge going for sixty seconds from the initiation of the pulse. This period was thought to be sufficient to pump the gas pressure as low as it was likely to go.

Measurements like this were then separated by time intervals of 1s, 2s, 4s, 8s and so on in a logarithmic progression.

### B. *Results of pressure return measurements*

The pressures found are shown in Table 3. It can be seen that the pressure remained substantially constant for 8 seconds and then began to rise until leveling off at around 32 minutes.

The experiment was repeated twice, with similar results. The data for all three sets of measurements is plotted on log/log scales in Figure 3. The curve with square markers corresponds to the data of Table 3. The pressure appears to follow a classical S curve.

Electrical discharges are often unsteady, and pulses are often less well formed than shown in Fig. 1, which can make the estimation of peak values, and hence vacuum levels, subject to a degree of error, which is thought to be why the curves shown are a little irregular.

TABLE 3. PRESSURE MEASUREMENTS AT INCREASING INTERVALS AFTER THE PREVIOUS MEASUREMENT. THE FIRST READING IS AFTER A LONG INTERVAL FROM PREVIOUS TESTS.

| Minutes from previous test | Seconds from previous test | Vacuum Pressure *mbar* |
|---|---|---|
| 7 days | | $1.9x10^{-4}$ |
| | 1 | $3.6x10^{-6}$ |
| | 2 | $3.9x10^{-6}$ |
| | 4 | $4.2x10^{-6}$ |
| | 8 | $4.1x10^{-6}$ |
| | 16 | $5.5x10^{-6}$ |
| | 30 | $8.7x10^{-6}$ |
| 1 | 60 | $1.6x10^{-5}$ |
| 2 | 120 | $4.0x10^{-5}$ |
| 4 | 240 | $1.2x10^{-4}$ |
| 8 | 480 | $1.4x10^{-4}$ |
| 16 | 960 | $2.6x10^{-4}$ |
| 32 | 1980 | $4.2x10^{-4}$ |
| 60 | 3600 | $5.5x10^{-4}$ |
| 120 | 7200 | $4.4x10^{-4}$ |

*C. Measurements at extended times.*

Table 3 shows saturation of the pressure at about 32 minutes. To confirm that there was no continued pressure rise, extra measurements on the specimen were made at intervals up to nearly 3 days. These are shown in Table 4. It can be seen that in all these readings the pressure returned to a level the same as that at the top of table 1, at the start of that series.

*D. Possible temperature effect*

In Fig. 3 it can be seen that two of the curves reach a peak and then dip down a little. The peak value of all three curves is higher than the pressure at the start of the whole measurement session, which was made at a time long after the specimen would have recovered from any previous magnetron pumping events. This point is shown at $1.9x10^{-4}$ on the vertical axis. We suggest that the high pressure at the peak is due to heating of the specimen.

The magnetizing coil has no cooling, and it heated up significantly during the early measurements because it was kept on for a minute each time, while at first the intervals with the coil off were only a few seconds. Even when the intervals were a few minutes heating continued because the coil heats up more quickly than it cools down. The effect was that the coil also heated up the device on test inside. The temperature rise of the specimen was thought to be of the order of 30°C.

According to the gas laws only a roughly 10%

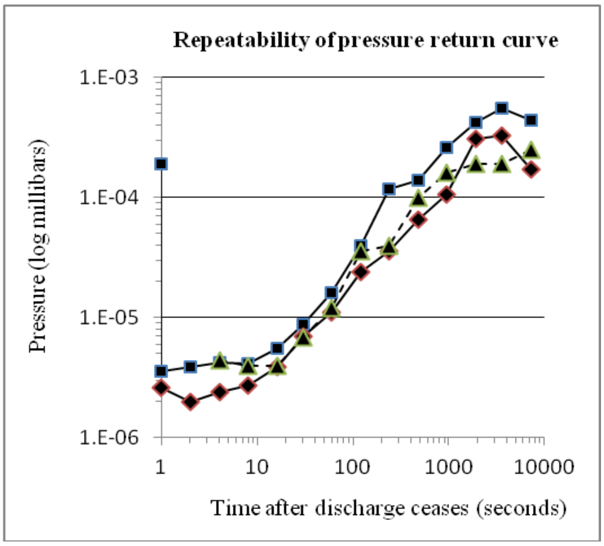


Fig. 3. Three repeats of the pressure return curve of Table 3 for an interrupter containing permanent gas. The logarithmic scales mask some scatter in the readings.

pressure rise would be expected, but this temperature rise may also increase the vapour pressure from gases adsorbed onto internal surfaces which would explain the larger rise in pressure.

TABLE 4. PRESSURE MEASUREMENTS AT LONGER TIME INTERVALS FOLLOWING THE SERIES SHOWN IN TABLE 1.

| Days from previous test | Hours from previous test | Vacuum Pressure *mbar* |
|---|---|---|
| | 2 | 2.15E-04 |
| | 4 | 1.80E-04 |
| | 4 | 1.90E-04 |
| 3 | 71 | 1.40E-04 |
| 2.75 | 66 | 1.90E-04 |
| 6.7 | 160 | 1.90E-04 |

## III. DISCUSSION

It is clear that some vacuum interrupters do contain gas that returns after being pumped by magnetron discharge, thus supporting the general theory. Others are clearly permanently pumpable by a long discharge, as shown by the previous work. However, these would not be pumped much by a pulse of short duration.

In table 2 it can be seen that when first measured in 2013 specimen 1 had a pressure of $1.4x10^{-3}$ mbar but 7 days later its pressure was $2.0x10^{-4}$ mbar. There was no return to the $1.4x10^{-3}$ value, but in the tests reported here a value consistent with the $2.0x10^{-4}$ value was returned to three times. This indicates that in 2013 the

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specimen contained both permanent and temporary gas and that the temporary gas was permanently pumped away by the 2013 measurements.

This company has an interrupter that contains permanent gas which is used frequently to check on the magnetron equipment. Its pressure has pumped and returned to the same value hundreds of times, showing that permanent gas can be very permanent.

### *A. Possible reasons for the presence of permanent gas*

Two explanations for the presence of permanent gas come to mind

1. **Noble gases**. The interrupter may contain a gas such as Argon or Helium which does not react chemically. These would not be removed by gettering or by chemical reaction with surfaces in the vacuum. Their presence might indicate contamination from a process such as argon arc welding of bellows. Gentsch and Fugel [3] punctured a vacuum interrupter in a high vacuum container connected to a residual gas analyser and found Argon present in greater quantities than gases such as Nitrogen, Methane and Carbon Dioxide
2. **Limited chemical capacity**. If the etching of oxide from the copper surfaces had been omitted or was incomplete, the capacity of those surfaces to react with gas particles would be reduced or non-existent. Another possibility is that the interrupter contained too much gas when made, which saturated the chemical capacity available. If either of these was correct then the presence of permanent gas would indicate manufacturing variability.

### *B. The possible use of remanent levels*

The trace in Fig. 1 can be seen to fall to close to the base line at the end of the trace, but at a definite level above it, which we call the remanent level. At the settings used, a time of 1.4 seconds after the start of a pulse is displayed. Using a much slower time base and greater gain the trace was seen to continue to fall. With temporary gas the trace approached the baseline asymptotically and was lost in the instrumental noise. With permanent gas the trace fell asymptotically too, but towards a level above the base line.

This suggests a simple way to determine in one measurement whether an interrupter contains permanent gas or not. As well as measuring the peak value, the remanent level should be measured after a suitable interval, such as one minute. If the remanent level is high, then this is an indication of permanent gas, and the pressure will return.

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**E-mail of the author(s):** reeves@vil.org.uk, falkingham@vil.org.uk