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**ATOMIC ENERGY  
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**EXPERIMENTS WITH A DIFFERENTIAL  
PIRANI GAUGE LEAK DETECTOR**

An A. E. R. E. Report

**BY**

**A.H. TURNBULL**

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EXPERIMENTS WITH A DIFFERENTIAL PIRANI  
GAUGE LEAK DETECTOR

by

A. H. Turnbull

A.E.R.E. G/R 477

ABSTRACT

The principle of the differential leak detector is explained. With a differential Pirani gauge detector located on the backing side of a diffusion pump, where the average pressure was 15 microns Hg., the "noise level" of pressure fluctuations registered by the galvanometer in the detector control circuit was seven times less than that registered by a single Pirani gauge. The minimum air pressure change which could be detected by the differential arrangement was  $10^{-5}$  mm. Hg.. With the optimum leak hunting conditions employed here, this corresponds to a leak on the high vacuum side of about  $10^{-3}$  lusecs.

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## 1. Introduction

The sensitivity of a single Pirani gauge as a leak detector in a continuously evacuated system is limited by the presence of a "noise level" due to pressure fluctuations superimposed on the mean gas pressure in the system. The amplitude of these fluctuations may be from 10% to 30% of the mean pressure. As a means of overcoming this limitation, Jacobs and Zuhr (Reference 1) suggested that a differential Pirani gauge leak detector could be used. The experiments described below were carried out in order to explore the possibilities of this type of leak detector.

## 2. Principle of the Differential Leak Detector

Two Pirani gauges with identical characteristics have their filaments connected in adjacent arms of a Wheatstone bridge which is balanced. If the two gauges are connected to the same point in a vacuum system, pressure fluctuations in the system will affect each gauge equally and the bridge will remain balanced. Further, if a refrigerated trap is interposed between the vacuum system and one of the gauges, then when a leak is probed with a condensable vapour, the latter will only be able to make its way into the untrapped gauge and there will be a differential change in the indication of the two gauges.

A suitable condensible probe gas must have a vapour pressure of about 1 atmosphere at room temperature and a negligible vapour pressure at the temperature of the refrigerated trap. There are several vapours which fulfil these requirements but they suffer from the disadvantage of either being toxic or producing an explosive mixture in the atmosphere. With these objections in mind it was suggested by Blears (Reference 2) that rather than use a condensable probe gas it might be possible to use a gas which could be chemically absorbed by a suitable substance placed inside the vacuum system. Carbon dioxide has a vapour pressure of more than one atmosphere at room temperature and is readily absorbed by soda lime, which has a vapour pressure low enough to permit it being used in a high vacuum system.

In the experiments reported here, carbon dioxide was used as the probe gas and "Carbosorb" (soda lime) as the absorbent.

## 3. Apparatus

### (1) Vacuum system

The differential Pirani gauge detector is shown in Figure 1. The body was made from two A.E.R.E. standard  $\frac{1}{2}$ " right angle vacuum unions and one  $\frac{1}{4}$ " vacuum tee-piece. The right angle union which held the "untrapped" gauge was soft soldered to the tee-piece while the other right angle union which fitted the "trapped" gauge was made demountable so that it could be conveniently recharged with soda lime if necessary. The body of this second right angle union was filled with soda lime granules (14 to 20 mesh) which were maintained in position by pieces of wire gauze.

The complete vacuum system is shown in Figure 2. The leak detector was tied into the line between two oil diffusion pumps ("Metrovac" type O3B and O2) and a single Pirani gauge for absolute pressure measurement was also

connected into this line. The backing space volume, i.e. the volume from the top jet of the O3B pump to the top jet of the O2 pump, was estimated at one litre so that for optimum leak hunting conditions the effective pumping speed at the leak detector should be 0.1 litres/second (Reference 3). In order to reduce the speed to this value, a suitable length of  $4\frac{1}{2}$  mm. copper tube was connected between the O2 pump and the leak detector. The high vacuum side of the system consisted of a 10 litre capacity vessel and a needle valve by means of which various leaks could be set.

## (2) Control circuit

The circuit diagram is given in Figure 3. From a batch of twelve Metropolitan-Vickers Pirani gauges which had been individually calibrated against a McLeod gauge, the two with the most nearly identical characteristics were chosen to form the leak detector. Their filaments, marked Pirani A and Pirani B in Figure 3, were connected in adjacent arms of a Wheatstone bridge as shown. Pirani B was known to be the more sensitive of the two and was therefore shunted by a 150 ohm fixed resistor and a 5K.ohm potentiometer R1. By suitable adjustment of R1, the sensitivity of the two gauges could be made equal. One of the two fixed arms of the bridge was also shunted as shown so that by adjustment of R2, the resistances of these two arms could be made equal. For a given setting of R1, the bridge could be balanced by means of R3. A 6 volt battery connected across the bridge provided a steady voltage. Out-of-balance current was indicated by a Cambridge spot galvanometer (450 ohms resistance) to which was connected a universal shunt.

## 4. Experimental Procedure

### (1) Gauge matching

The two Pirani gauges A and B were matched as follows. With a negligible pressure (less than  $10^{-4}$  mm. Hg.) at the detector and with R1 at its maximum value, the bridge was balanced by means of R3. The needle valve on the high vacuum side was opened until a steady pressure of 10 microns Hg. (measured by Pirani C) was obtained at the detector. The resultant deflection of the galvanometer was reduced by adjustment of R1. The apparatus was again pumped down to "zero" pressure when it was found, of course, that the bridge was no longer balanced owing to the change in R1. An approximate balance was again obtained by means of R3. A pressure of 10 microns Hg. was again set and R1 adjusted to obtain an approximate balance. By repeating this procedure of successive approximations several times, the gauges were finally matched so that the pressure rise of 10 microns Hg. resulted in a 1 cm. deflection on the galvanometer (without shunt). This was the best that could be achieved.

### (2) Pressure fluctuations

With both diffusion pumps in operation and the needle valve adjusted so that a pressure of 15 microns Hg. was obtained at the detector, the reading of the galvanometer was observed at 5 second intervals over a period of 5 minutes. The results are plotted in Figure 4 (lower curve).

By measuring the voltage across it and the current through it, the resistance of Pirani A was found to be 148 ohms. It was then replaced by a 150 ohms fixed resistance and pressure fluctuations were observed as before. These are also plotted in Figure 4. (upper curve). Still with only one Pirani gauge in the circuit, the galvanometer was replaced by a milliammeter of known internal resistance and the out-of-balance current for a pressure rise from zero to 5 microns Hg. was observed. Knowing the resistances of the arms of the bridge it was then possible to calculate the sensitivity of the galvanometer in terms of pressure. (The method used is described in Reference 4).

It was found that, with a single gauge in circuit, a  $10^{-5}$  mm. Hg. pressure change produced a galvanometer deflection of 0.6 cms.

### (3) Sensitivity of leak detector

A preliminary experiment was carried out to correlate leakage rate through the nozzle valve with resultant pressure rise on the high vacuum side and on the backing side of the O3B diffusion pump. A three-way tap was scaled to the needle valve. One inlet of the tap was open to the atmosphere while the other was joined to a 1 c.c. burette mounted vertically, with its lower end dipping into a beaker of tetralin (tetra-hydro-naphthalene). With the tap open to atmosphere a suitable leak was set by means of the needle valve and when conditions were steady the pressure rise caused by the leak on the high vacuum side of the O3B pump was measured by means of an ionisation gauge and on the backing side by means of Pirani C. The three-way tap was then turned so that the burette communicated with the vacuum system, and the time required for 1 c.c. of air to be displaced by the rising column of tetralin was measured. This enabled the leak rate (in lusecs) to be calculated. From the results two curves were drawn, one (Figure 5) of leak rate against high vacuum side pressure rise and the other (Figure 6) of backing side pressure rise against high vacuum side pressure rise.

The three-way tap was now removed from the apparatus. The needle valve was adjusted to give a suitable rise in the reading of the ion gauge. From Figures 5 and 6 it was then possible to read off the corresponding leak rate and backing side pressure rise. The reading of the galvanometer in the differential Pirani bridge circuit was noted. A rubber tube leading from a carbon dioxide cylinder was then connected to the needle valve so that the inleaking air was replaced by CO<sub>2</sub>. The change in galvanometer deflection was observed. By repeating this process for various leak rates and plotting the results it was possible to determine the minimum detectable values of leak rate, high vacuum side pressure change and pressure change at the leak detector on the backing side.

## 5 Results

### (1) Pressure fluctuations

The results plotted in Figure 4 show that at an average pressure of 15 microns Hg. the maximum pressure fluctuation registered by the galvanometer in any period of one minute is  $3.4 \times 10^{-5}$  mm. Hg. with a single Pirani gauge and  $5.0 \times 10^{-6}$  mm. Hg. with the differential arrangement. This implies

that the use of the differential leak detector results in a 7 - fold reduction in "noise level" so that the minimum detectable pressure change will be 7 times less than with a single gauge, at this average pressure.

The advantage of the differential method over the single Pirani gauge leak detector becomes less apparent as the mean pressure is reduced, since the fluctuations will reach a limit which is imposed by inherent instabilities (mechanical, thermal and electrical) in the gauges themselves and in their control circuits. However, a detector located on the backing side of a diffusion pump works well above this limiting region.

## (2) Minimum detectable pressure change

In the region of the optimum working pressure of the leak detector the background pressure fluctuations are of the order of  $5 \times 10^{-6}$  mm. Hg. It is fairly safe to say, therefore, that a galvanometer deflection corresponding to an air pressure rise of  $10^{-5}$  mm Hg. (twice the noise level) can be detected with certainty. This corresponds to a pressure rise of about  $3 \times 10^{-7}$  mm. Hg. on the high vacuum side of the apparatus and to a leak of about  $9 \times 10^{-4}$  lusecs or 0.09 clusecs. It is pointed out elsewhere (Reference 3) that the minimum leak detectable in any apparatus depends on the volume of the apparatus and the speed of the pumps. The above figure of 0.09 clusecs is therefore peculiar to the apparatus used here, where optimum leak hunting conditions were employed. The important property of the differential Pirani gauge leak detector is that at a working pressure of 15 microns Hg. it can detect an air pressure change of  $10^{-5}$  mm. Hg. (This agrees fairly well with Blears' value of  $5 \times 10^{-6}$  mm. Hg. at a working pressure of 10 microns Hg., quoted in Table I, Reference 3).

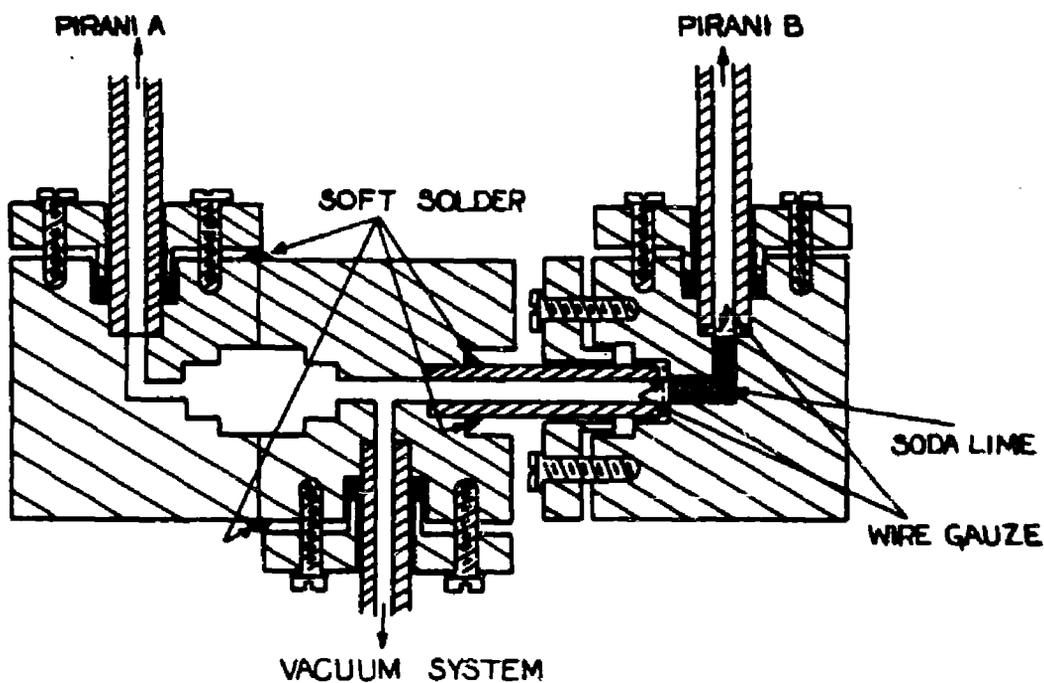
## 6. Conclusions

The 7-fold reduction in background pressure fluctuations which results from the use of a differential Pirani gauge leak detector instead of a single gauge at a working pressure of 15 microns Hg. means that, under similar conditions, the minimum leak detectable by the differential method is 7 times smaller than with a single gauge.

Since the detector works in the 10 micron pressure region it can be located on the backing side of the main diffusion pump where the pressure change due to a given leak is many times greater (usually not less than twenty, depending on the apparatus) than on the high vacuum side.

## 7. References

- (1) Jacobs and Zuhr, J. Appl. Phys. 18 34, (1947).
- (2) J. Blears, Metropolitan Vickers Electrical Co.Ltd. private communication.
- (3) A.H. Turnbull, "The Principles of Leak Detection", A.E.R.E. Report No. G/R 478 (1950)
- (4) A.H. Turnbull, "A Simple Battery-Operated Pirani Gauge Power Pack," A.E.R.E. Report No. G/R 462 (1950)



**FIG 1. DIFFERENTIAL PIRANI GAUGE LEAK DETECTOR**

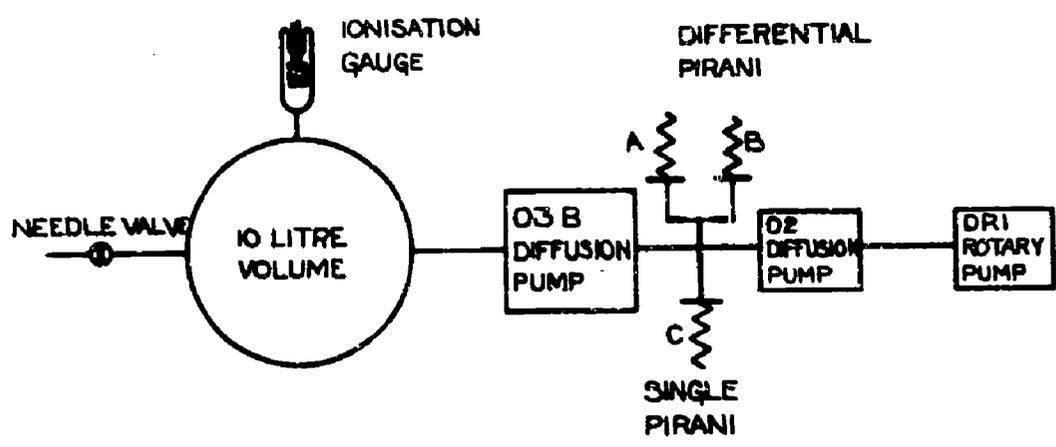


FIG.2 VACUUM APPARATUS.

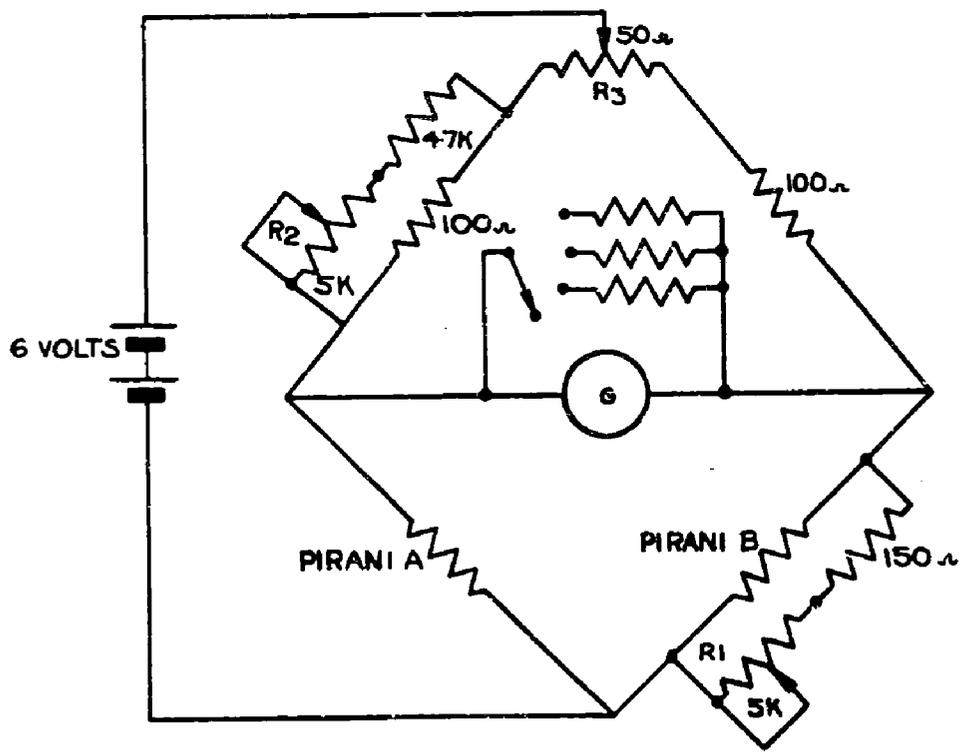


FIG.3 CONTROL CIRCUIT.

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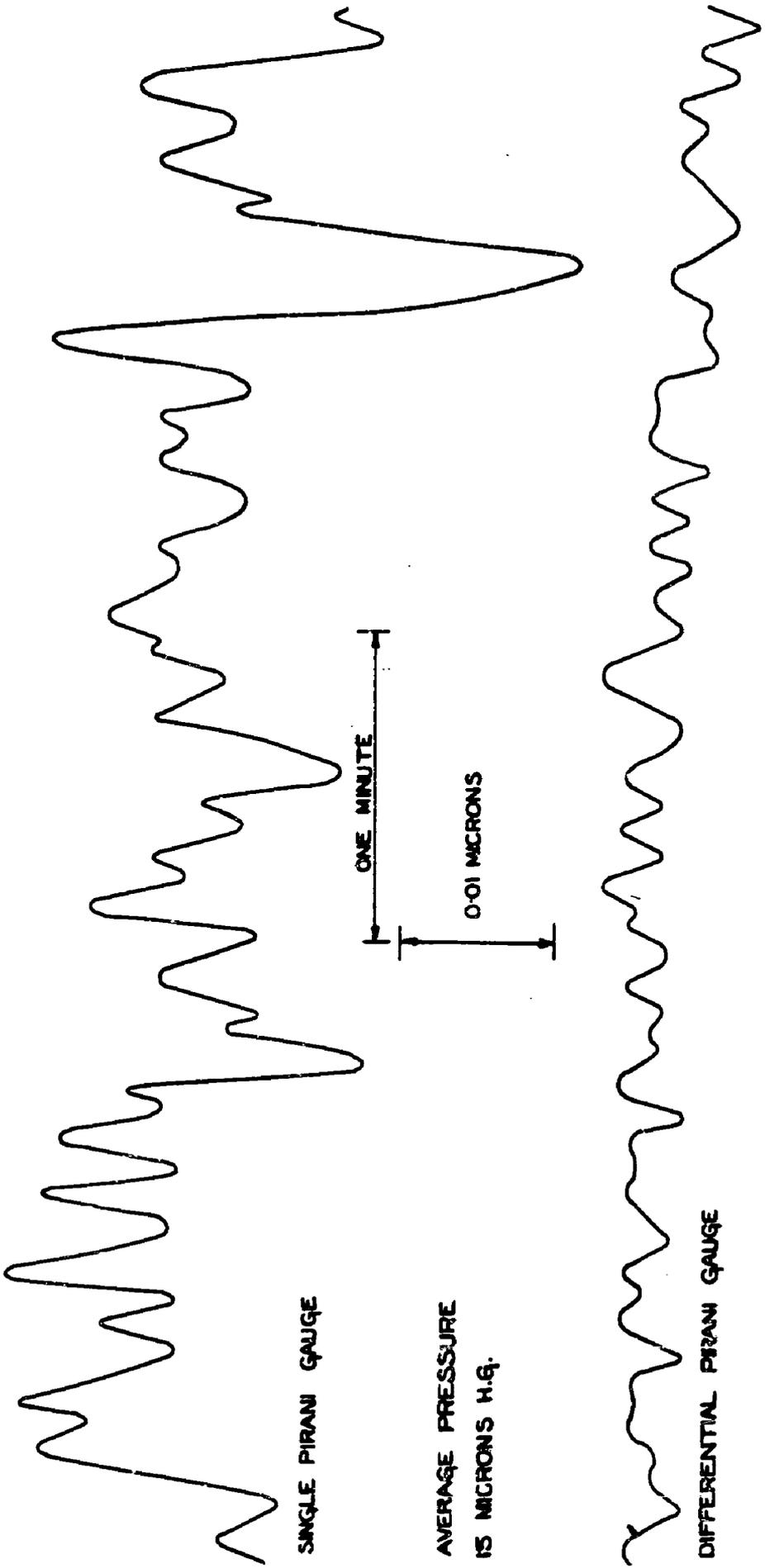


FIG. 4. PRESSURE FLUCTUATIONS.

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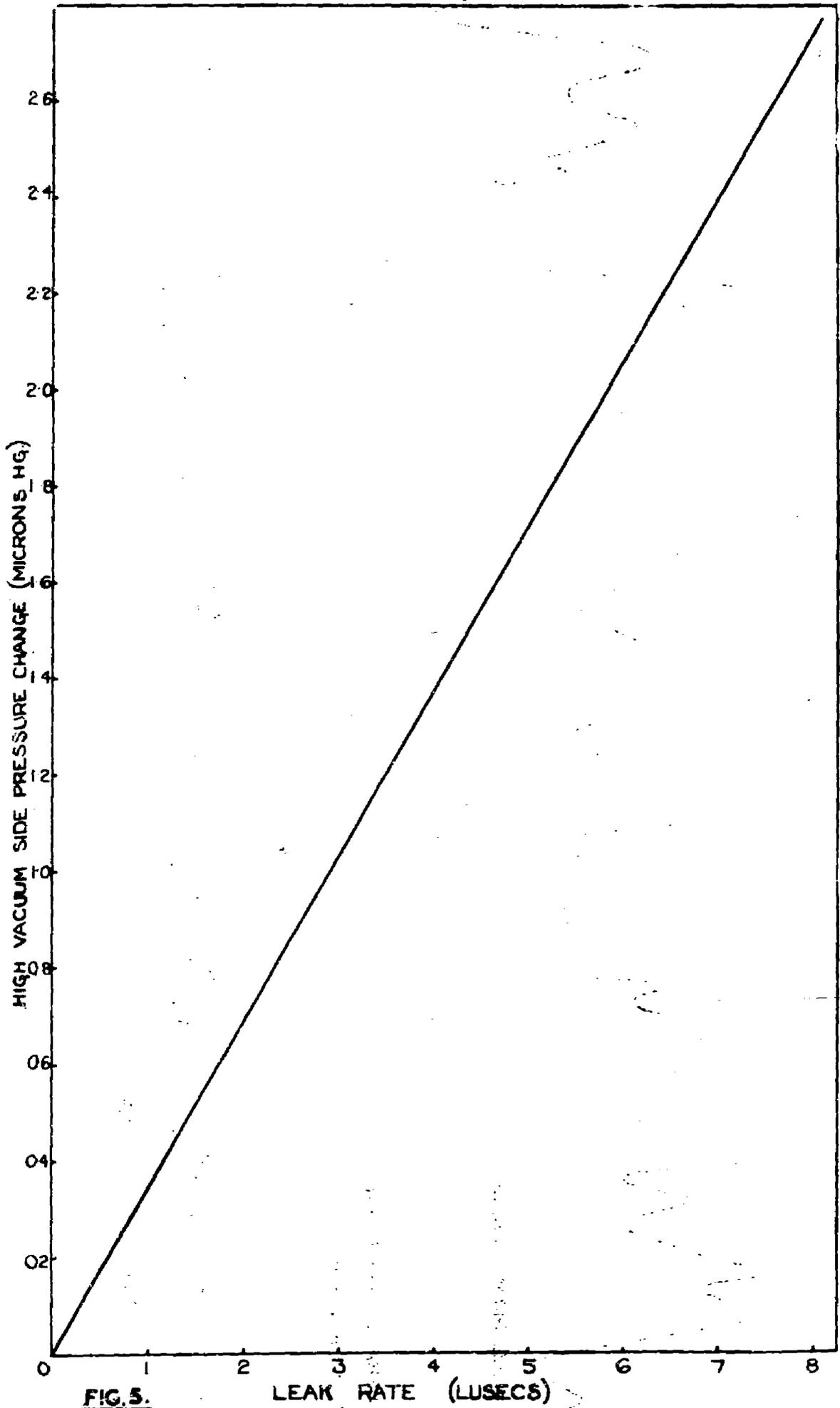
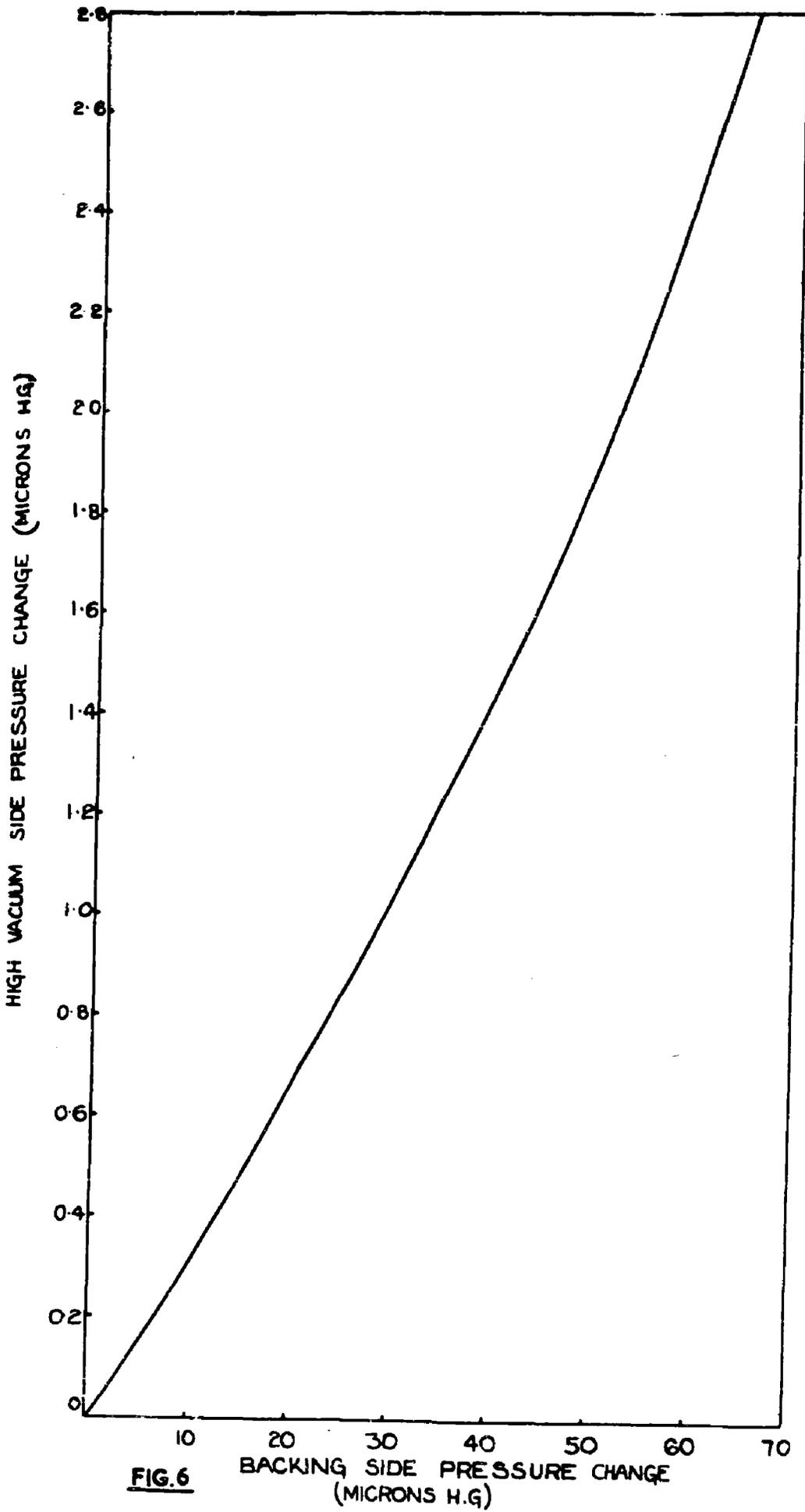


FIG. 5.

LEAK RATE (LUSECS)

**FIG. 6.**

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**FIG. 6**



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