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ON THE LARGE LOAD CHARACTERISTICS OF VAPOUR PUMPS

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ABSTRACT. The different characteristics of vapour pumps under various leak-load and forepressure conditions are studied. The leak load position dependence of forepressure is investigated from which different conditions of critical forepressure are distinguished.

INTRODUCTION

Since the pioneer theory of Gaede (1915, 1923) and a much later attempt by Matricon (1932), on the performance of a "vapour stream pump", much work on its performance has been done to collect data in the attempts to verify the theories (Blears and Hill, 1948 ; Dayton, 1948, Ho ; 1932). Specially the influence of heater input, forepressure and load, on the performance of a pump has been much discussed. The present paper is an investigation of the vacuum characteristics of a pump in their relation to leak-load and its position.

Normally, a vapour pump is characterised by three specific factors :

1. *The ultimate vacuum* : i. e. highest vacuum reached.

2. *The speed* : i .e. average litre-micron that is handled throughout the operating range.

3. *Maximum load handling capacity* : i. e. peak load that can be tolerated by the pump before jet-breakdown.

It is well-known that backing pressure in case of a good multiple jet pump has no effect on the speed until a certain critical value, called the critical forepressure, is exceeded when the speed drops rapidly. The relation of speed to fine pressure shows (figure 1) that fine pressure falls from

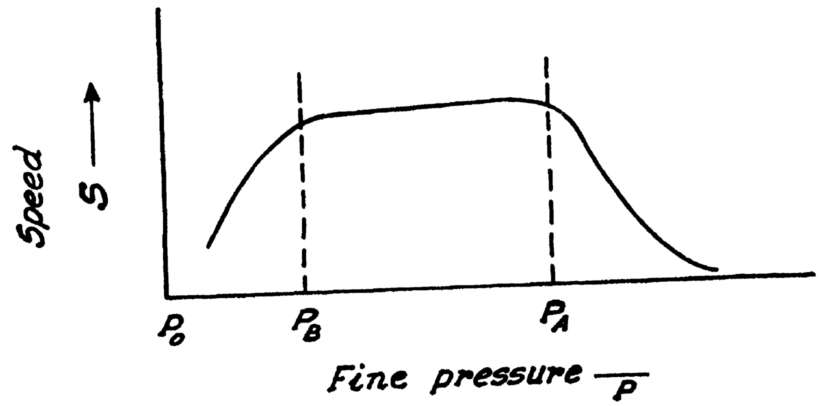

FIG. 1

the forepressure value to a value P_A when the vapour pump takes over from the backing pump. In this region the speed rises to a maximum value P_A and then remains constant upto P_B beyond which it gradually decreases until it reaches the ultimate vacuum P_0. Here the effective pump speed is zero because the real pump speed at this stage is just counter balanced by the evolution of gases and vapours from the system and operating pump fluid. It may be noted that real pumping speed is the same throughout the operating range. It is the effective pump speed which falls to zero from a maximum value. We consider a system directly connected to the vapour pump. We assume the validity of the equation of continuity in the case of the flow of air past different jets. For the sake of simplicity, we omit here the dependence of speed on the effect of back diffusion of air whose contribution to the lowering of speed is generally small for a well designed pump, specially at higher heater input. The pumping action is provided by the vapour stream of the operating fluid directed downwards by directed jets from high vacuum side to the fore vacuum side. The gas is compressed by the jets and fed to the backing pump at sufficient pressure to enable the backing pump to handle it before the jet breaks down. The pump remains in in working condition so long as this pressure gradient is maintained from high side to fore side. This power of the jets to compress the gas (i. e. the critical forepressure) is dependent on jet design, number of stages in the pump, the operating fluid and the heater input. But the maximum gas load tolerated is determined by forepressure at which it is operating at a constant heater input. So breakdown forepressure is always associated with gas load or leak in the system. As against this condition, when a leak load is placed in the forevacuum part of the system, only a very slight increase of fine pressure will result until, of course, the leak will increase the forepressure to such an extent that the jets breakdown. These two jet breakdown forepressures may be completely different.

The following cases may conveniently be classified :

1 Leak-load, introduced on the fine side, is increased till jets breakdown corresponding forepressure, fine pressure relations observed and the critical forepressure noted.

2. Leak-load introduced in the fore side, the fine side of course, is considered to be leak-free.

3. Leak-load introduced in the fine side is kept at a certain level at a constant heat input. Additional leak-load introduced in the foreside is progressively increased till jets breakdown.

In each of the above cases, heat input is varied.

It is evident from the foregoing classification, the forepump used should be sufficiently large and the heat input in the vapour pumps should be set at an optimum value depending on the gas handling capacity. Also a series of values have been taken at different leak rates, so that the curves can be plotted over the entire range.

EXPERIMENTAL ARRANGEMENTS

In our experimental set up, the vapour pump used is a three stage 4″ diameter pump of our own make. It is backed by a mechanical pump of Leybold's type XI of pumping speed 0.5 litres/sec at 10^{-3} mm. The forepump connection is short and of sufficiently large diameter so as to have little influence on the forepump speed and its measurements. There is a valve in between the mechanical and vapour pump, and leak valve is also connected there with a ballast. This leak valve is capable of controlling leak of the order of 2 lit-micron. There is the usual arrangements for measuring pressure by means of Pirani gauge (checked at interval against a Mcleod gauge), ion gauge etc. A test dome is used for gauge housing and leak entries. The diameter of this test dome is larger than the m.p.f. of the molecules of the vapour and the leak is introduced in such a way as to eliminate any directional characteristic due to beaming. The speed measuring apparatus is a constant pressure type and is a modification of Howard's (1935) apparatus. The essential alteration is an arrangement for keeping the pressure inside the measuring apparatus constant and entire elimination of the capillary system which is substituted by a precision leak valve. The actual experimental arrangement is shown in figure 2. The leak in the fine side is also controlled by a precision leak valve of the same type as that used in the fore vacuum part of the system. The pressure is measured by means of an ion gauge connected to the dome through a liquid air trap. A Mcleod type gauge is used for frequent checking.

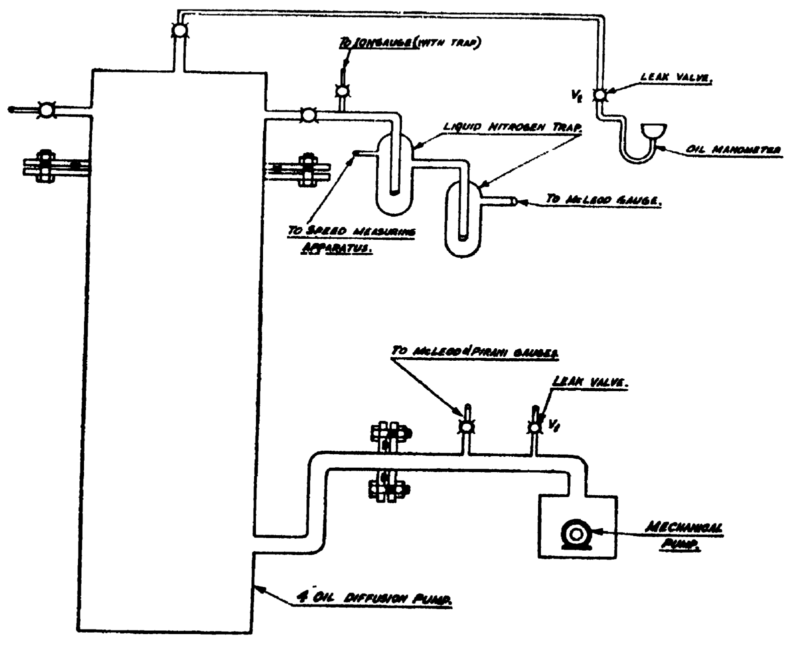

FIG. 2

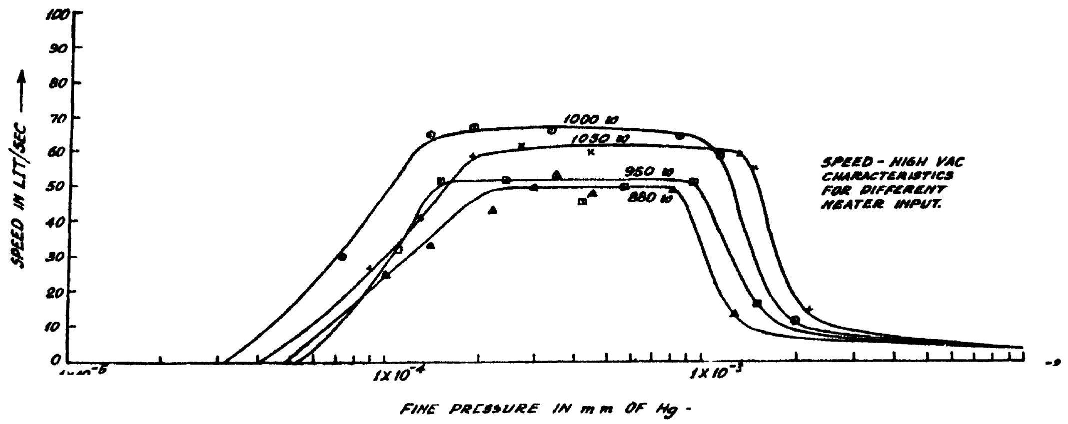
SPEED IN LIT/SEC
FINE PRESSURE IN mm OF Hg
1000 w
1050 w
950 w
880 w
SPEED - HIGH VAC CHARACTERISTICS FOR DIFFERENT HEATER INPUT.
1X10^{-4}
1X10^{-3}

FIG. 3

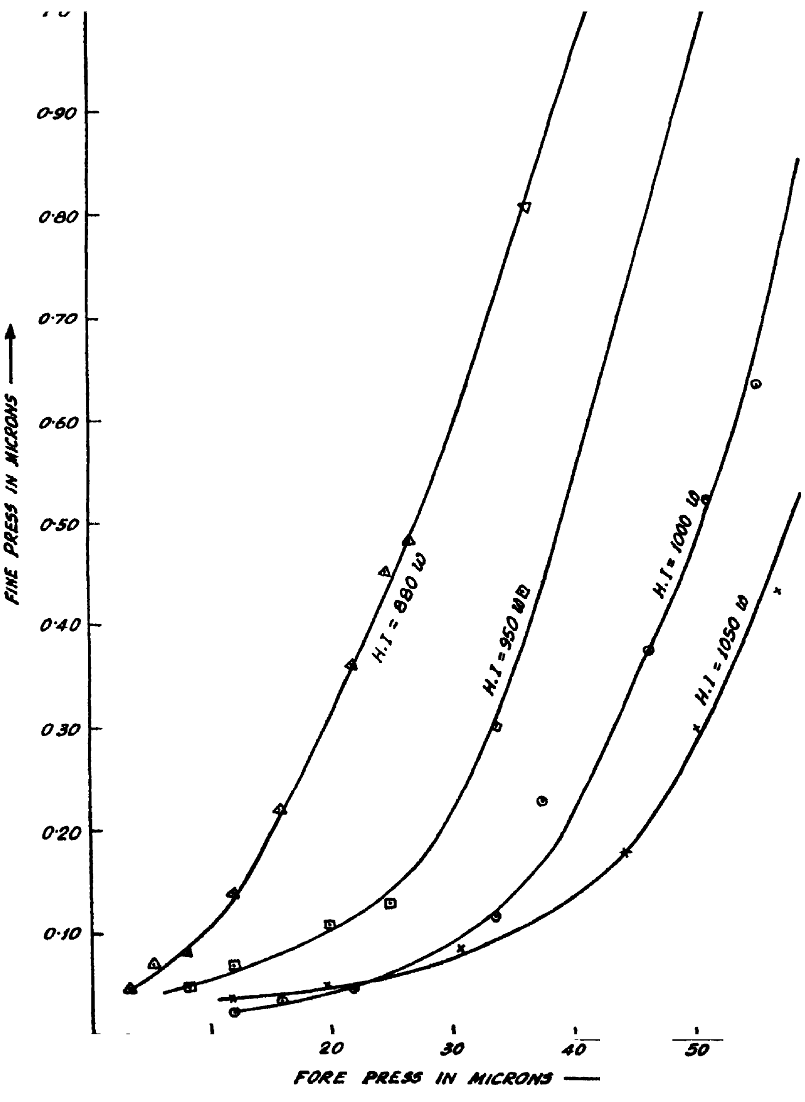
FINE PRESS IN MICRONS
FORE PRESS IN MICRONS
H.I = 880 W
H.I = 950 W
H.I = 1000 W
H.I = 1050 W
0·90
0·80
0·70
0·60
0·50
0·40
0·30
0·20
0·10
20
30
40
50

FIG. 4

EXPERIMENTAL RESULTS

Using the method outlined above, speed and pressure measurements were made under conditions given below :

The usual fine pressure-speed characteristics of the pump at different heat inputs are shown in figure 3.

1. *Fine side leak : forepressure :*

The leak was introduced on the fine side by means of leak valve V_2. The forepressure at which the jets just break down was noted in each case of a particular heater input (figure 4). This jet breakdown is indicated by the sudden start of continuously increasing pressure in the ion gauge reading and the ultimate swing towards foreside pressure. The heat input variation ranges between 880 W-1050 W.

2. *Foreside leak : fine pressure :*

Quite distinct from the previous case, are the cases where the leak was introduced in the foreside (figure 5). The curves represent cases of different

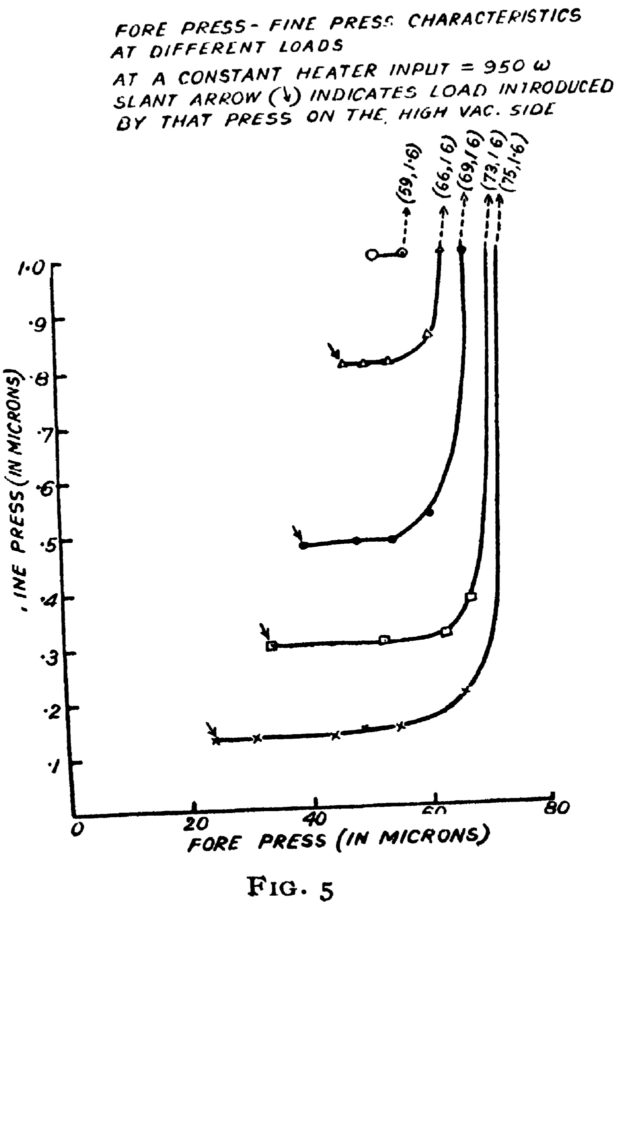

FIG. 5

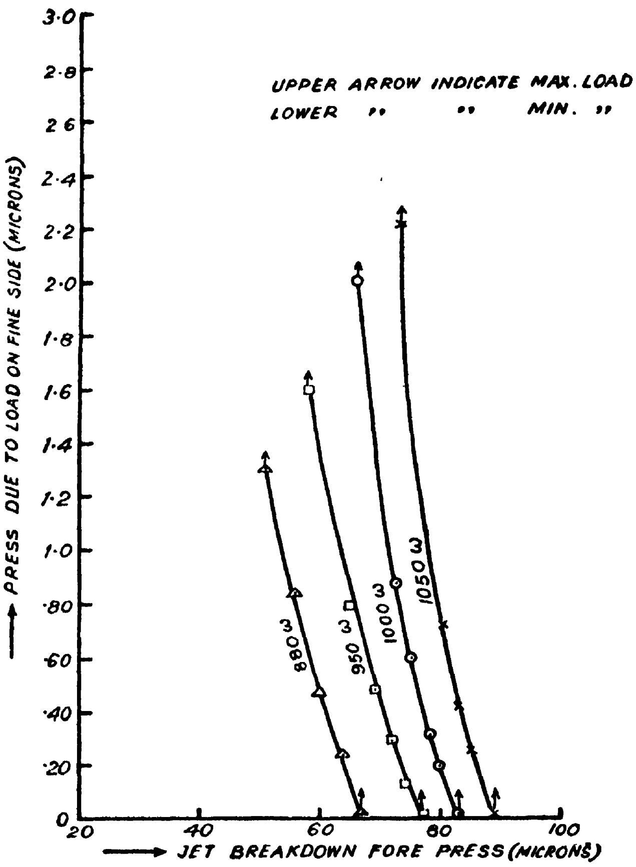
UPPER ARROW INDICATE MAX. LOAD
LOWER ,, ,, MIN. ,,
PRESS DUE TO LOAD ON FINE SIDE (MICRONS)
JET BREAKDOWN FORE PRESS (MICRONS)
880 ω
950 ω
1000 ω
1050 ω
3·0
2·8
2·6
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
·80
·60
·40
·20
0
20
40
60
80
100

FIG. 6

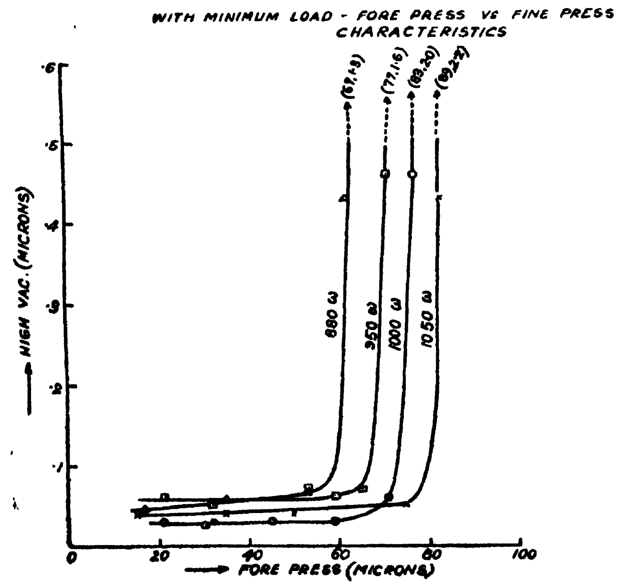
WITH MINIMUM LOAD - FORE PRESS VS FINE PRESS CHARACTERISTICS
HIGH VAC. (MICRONS)
FORE PRESS (MICRONS)
880 ω
950 ω
1000 ω
1050 ω
·6
·5
·4
·3
·2
·1
0
20
40
60
80
100

FIG. 7

heater inputs, the fine side is, of course, kept load free. The figures within bracket give the forepressure and fine pressure respectively recorded just when the jet breaks down.

3. *Fore pressure: fine pressure of different load* :

Figure 5 indicates the effects of additional leaks on the foreside till jets break down ; the fine side pressure in this case is kept at definite levels by means of leaks on fine side; the heat input is, of course, kept constant. The jet breakdown points are indicated by fine side pressure which means that up to that fine pressure can be measured after which jet breaks down.

Curves of figure 6 give the relation between jet breakdown forepressures with the fine side pressure due to leakload on that side at different heat-input. Figures 8 and 9 represent cases where relation of forepressure with speed is calculated for different fixed loads on the fine-side.

HIGH VACUUM PRESS ($= 4 \times 10^{-4}$ mm Hg)

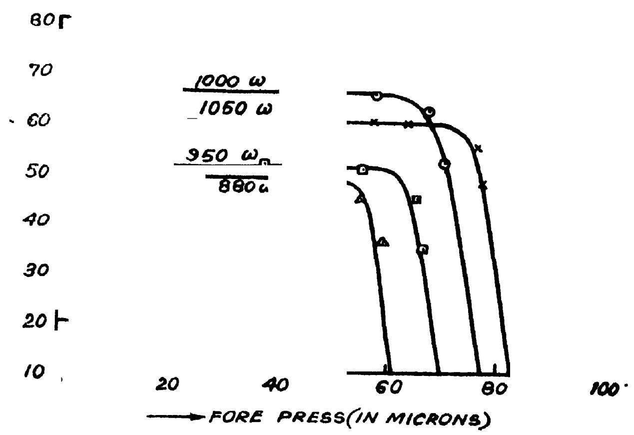

FIG. 8

(HIGH VACUUM SIDE PRESS $= 2 \times 10^{-4}$ mm Hg)

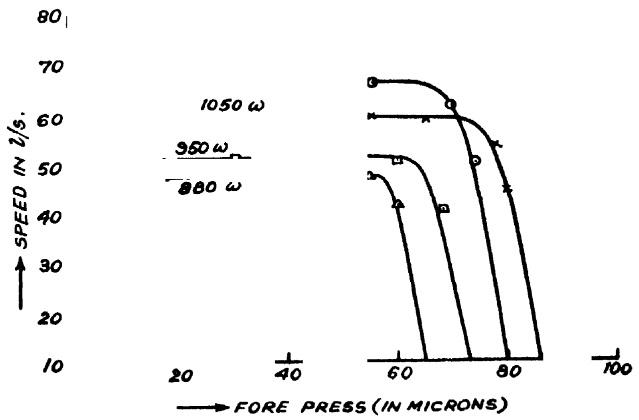

FIG. 9

DISCUSSION

It is noteworthy that the effect of a small leak load on the ultimate vacuum produced will be small or pronounced according as it is situated on the fore or the fine side. This is amply borne out by the curves in figures. 7 and 8. The very sharp critical forepressure is to be noticed, particularly in the case when the leak is introduced in the fore side. Quite different is the case when the leak is introduced in the fine side. Any rise in the forepressure is not reflected in the fine pressure until the critical forepressure is reached. The explanation is obvious from the working of the vapour pump. So long as the jets are able to maintain an effective seal between the two sides, any leak in the forepressure side will have little effect on the ultimate vacuum produced. Less heating than the rated minimum value may mean that the jets are not dense enough to stand a comparatively large pressure differential. On the other hand, when the rate of heating is too large, vapour molecules are imperfectly condensed on the pump walls, resulting in increased back-diffusion which will lead to reduction in speed and ultimate vacuum, (figure 4, curve-II. I. 1050). Another explanation offered by some authors is that at higher heat-inputs, a temporary cracking of fluid may take place giving off higher vapour pressure components, with consequent worsening of ultimate vacuum, which may take place concurrently with the first effect at higher heat inputs.

In our experiment we did not study individual jet breakdowns, but by jet breakdown the breakdown of all the jets is meant, as a result of which the vapourpump ceased functioning.

It is evident from the foregoing discussions that a knowledge of these characteristic curves under leak load should be very helpful particularly when used with kinetic systems with heavy loads. For example, in the case of vacuum smelting of magnesium, or similar other large kinetic systems used in industries, these pump characteristics are essential to choose proper types of pumping systems to be used.

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REFERENCES

Blears J. and Hill, R. W., 1948, *Rev. Sci. Inst.*, **10**, 847.
Dayton B. B., 1948, *Rev Sci. Instr.*, **10**,
Gaede. W. 1915, *Ann. d. Physik.*, **46**, 337.
Gaede, W. 1923, *Zeits. f. Tech. Physik* , **10**, 337.
Ho, T L. 1932, *Physics.*, **2**, 386.
How H. C. ard, 1935, *Rev. Sci. Instr.*, **6**, 327.
Matricon, S M. 1932, *J. de. Phys. et Rad.*, **3**, 127.