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PRESSURE DISTRIBUTION ALONG THE AGS VACUUM CHAMBERS

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Abstract

The monitoring of the AGS HEBT and ring vacuum system is based on the discharge current of the magnet ion pumps, which is proportional to the vacuum level at these ion pumps. The pressure distribution along the vacuum chambers is certainly different from that of the ion pumps. This technical note demonstrates numerically the potential difference between the vacuum chamber pressure and the ion pump pressure under various conditions. Comparisons with the measured pressure, the outgassing rate, and the leak rate are also given.

1. Introduction

The AGS vacuum system includes the Linac, HEBTs, and the ring. The Linac vacuum system is locally operated/monitored and will not be the subject of this discussion. The HEBT and ring vacuum sectors are evacuated and maintained by the 140 ℓ/s magnet ion pumps. There are about 260 standard ion pumps and odd ion pumps around the ring and HEBTs grouped into 24 ring sectors and 4 HEBT sectors. The standard 140 ℓ/s ion pumps are located 100 cm away from the vacuum chambers through a 10 cm o.d. elbow. The discharge current of these ion pumps is used to monitor the pressure of the vacuum system. Due to the conductance limitation of the pump elbow and the vacuum chamber itself, substantial pressure gradient exists between the ion pumps and the chambers. The magnitude of the gradient will depend on the distance between ion pumps and the uniformity of outgassing/leak and can be derived using some fundamental vacuum equations and the measured pressure at the ion pumps.

A basic ring vacuum system is shown schematically in Figures 1(a) and 1(b). The following symbols will be used in this note to represent different parameters of the vacuum system:

C'	linear conductance of the vacuum chamber, 19,200 $\ell \cdot$ cm/s
C	the conductance of the vacuum chamber, = C'/L ℓ/s
c	the conductance of the elbow, 102 ℓ/s
S_o	the pumping speed of the ion pump, 50 ℓ/s
S	the net pumping speed at the end of the elbow, = $1/(1/S_o + 1/c)$
P_i	pressure at the ith ion pump
$P_i(0)$	pressure at the neck of the ith elbow
$P_i(x)$	pressure x cm from the neck of the ith elbow
L	average distance between ion pumps
l	length of the elbow, 100 cm
U	perimeter of the vacuum chamber, 43 cm
u	perimeter of the elbow, 31 cm
q	unit wall outgassing rate, $\sim 5 \times 10^{-11}$ Torr $\cdot$ ℓ/s $\cdot$ cm^2
Q_i	net gas flow along the chamber due to leaks
Q_i'	net gas flow toward ion pumps due to leaks

2. Pressure Distribution

In this section, three simplified scenarios will be analyzed; namely, the uniform wall outgassing with no leaks, with one large leak, and with one small leak. The pressure distribution relative to the measured pressure, therefore, will represent the extreme cases. The real life distribution should lay in between these extremes.

A. Uniform Outgassing With No Leaks

For a vacuum sector with uniform outgassing only, the pressure distribution will be repeating along the length, such that

$$Q_i = Q_i' = 0$$
$$P_1 = P_2 = P_3 \ldots$$
$$P_1(x) = P_2(x) = P_3(x) \ldots$$

If we examine a small section of the vacuum chamber from x to x + dx as shown in Figure 1(a), the flow of the gas in and out of this section will be balanced according to

$$C' \left[dP(x + dx)/dx - dP(x)/dx\right] = -q \cdot U \cdot dx$$

$$C' \, d\left[dP(x)\right]/dx^2 = -q \cdot U \qquad (1)$$

with the boundary conditions of $dP(L/2)/dx = 0$ (the net gas flow is symmetrical at $x = L/2$), and $\left[P_i(0) - P_i\right] S = 2(q \cdot U \cdot L/2)$. Integrating Eq. (1) against dx gives

$$\begin{aligned} P_i(x) &= P_i(0) + q \cdot U \cdot x \, (L - x)/2C' \\ &= P_i + q \cdot U\left[L/S + x \, (L - x)/2C'\right] \end{aligned} \qquad (2)$$

The average pressure inside the vacuum chamber can be obtained by integrating $P_i(x)$ versus x from 0 to L/2

$$\overline{P_i(x)} = P_i + q \cdot U\left[L/S + L^2/12C'\right] \qquad (3)$$

The total outgassing of each vacuum chamber is equal to $q \cdot U \cdot L + q \cdot u \cdot 1 = P_i$. So, then the ratios between $P_i(x)$, $\overline{P_i(x)}$, and P_i can be obtained without knowing q, such that

$$P_i(x)/P_i = 1 + U \cdot S_o\left[L/S + x(L - x)/2C'\right]/(U \cdot L + u \cdot 1) \qquad (4)$$

$$\overline{P_i(x)}/P_i = 1 + U \cdot L(1/S + L/12C')S_o/(U \cdot L + u \cdot 1) \qquad (5)$$

The outgassing rate can also be derived from the measured P_i by

$$q = P_i \cdot S_o/(U \cdot L + u \cdot 1) \qquad (6)$$

Figure 2(a) shows the pressure distribution along the vacuum chamber as compared to the ion pump pressure P_i with curves (1), (2), and (3) representing, respectively, 100%, 50%, and 20% ion pumps in operation. The nominal pumping speed of the ion pumps varies with the condition of the ion pumps and the pressure at the pumps, which in turn will affect the pressure distribution, as illustrated in Figure 2(b) with S_o varying from 50 ℓ/s to 10 or 100 ℓ/s. In all, the ratios between the average pressure and the measured pressure could be up to three times in the worst cases.

The average pressure of most ring vacuum sectors is larger than 2 x 10^{-8} Torr, which gives a unit outgassing rate of ~ 5 x 10^{-11} Torr • ℓ/s • cm^2 according to Eq. (6). An outgassing measurement done on a spare vacuum chamber gives the same value after several weeks of pumping.

B. One Large Leak

To simplify the analysis, we will assume the gas leak located midway between the ion pumps, and the normal wall outgassing Q_w is negligible compared with the size of the leak $2Q_1$. The gas flow Q_i' to the ith elbow (see Fig. 1(b)) becomes

$$Q_i' = P_i \cdot S_o = (P_i(0) - P_i) \cdot S$$

$$P_i(0) = P_i\ (1 + S_o/S) = P_i \cdot K \qquad \text{if } K = 1 + S_o/S$$

$$Q_i = [P_{i-1}\ (0) - P_i(0)] \cdot C \qquad \text{except for } Q_1$$
$$= (P_{i-1} - P_i) \cdot K \cdot C \tag{7}$$

$$Q_1 = Q_1' + Q_2 = P_1 \cdot S_o + (P_1 - P_2) \cdot K \cdot C \tag{8}$$

$$P_i(x) = P_i(0) + Q_i/C(x) \qquad \text{here } C(x) = C \cdot L/x$$
$$= P_i \cdot K + K \cdot (P_{i-1} - P_i) \cdot x/L \tag{9}$$

$$\overline{P_i(x)} = (1/L) \int_0^L P_i(x) \qquad \text{except for } P_1(x)$$

$$= K \cdot (P_{i-1} + P_i)/2 \tag{10}$$

$$P_1(x) = P_1(0) + Q_1/C(x)$$
$$= P_1 \cdot K + [P_1 \cdot S_o/C + (P_1 - P_2)\ K] \cdot x/L$$

The average pressure at the chamber with the leak is given by integrating $P_1(x)$ versus x from 0 to L/2

$$\overline{P_1(x)} = P_1 \cdot S_o/4C + K \cdot (5P_1 - P_2)/4 \tag{11}$$

and the pressure at the leak will be

$$P_1(L/2) = P_1 \cdot S_o/2C + K \cdot (3P_1 - P_2)/2 \tag{12}$$

The different between the real pressure and the measured reading at ion pumps can only be derived numerically. An example is given in Figure 3(a), which showed the ion pump current of F sector with the presence of a large leak at F5 kicker magnet. The pressure distribution $P_i(x)$, the average pressure between the ion pumps, as calculated by Eqs. (9) and (10), respectively, and the pressure at the ion pumps are plotted in Figure 3(b). The ratios between the average pressures and the ion pump pressures are about 3.5. The total leak rate given by Eq. (8) is 3×10^{-3} Torr • ℓ/sec which is consistent with the full scale leak measured by leak detector.

C. One Small Leak and Uniform Wall Outgassing

The pressure profile along the vacuum chamber in this case will be a complex function of the location and size of the leak and cannot be solved easily in general formulae. However, some specific cases can be derived using the principle of pressure superposition, namely, the pressure gradients created by the wall outgassing and by the leak can be treated independently (this is true as long as the gas flow stays in the molecular flow region) and added up to give the pressure difference between any two points.

A vacuum sector (having 10 ion pumps) with a small leak $2Q_1$ located at the center of the sector as shown in Figure 1(b) will be discussed here. The pressure difference between two points will be the sum of the gradient dP_w (Eq. (2)) from wall outgassing and the gradient dP_1 (Eq. (9)) from the leak such that

$$P_i(0) - P_i = (q \cdot U \cdot L + Q_i')/S$$

here $Q_i' = P_i \cdot S_o - q \cdot U \cdot L - q \cdot u \cdot 1$, and

$$P_i(x) - P_i(0) = q \cdot U \cdot x(L-x)/2C' + Q_i \cdot x/C \cdot L$$

$$P_i(x) = P_i + q \cdot U \left[L/S + x(L - x)/2C'\right] + Q_i'/S + Q_i \cdot x/C \cdot L \qquad (13)$$

Integrating $P_i(x)$ versus x from 0 to L for leak and 0 to L/2 for wall outgassing will give average pressure in ith chamber as

$$\overline{P_i(x)} = P_i + q \cdot U(L/S + L^2/12C') + Q_i'/S + Q_i/2C \qquad (14)$$

with the last term equal to $Q_1/4C$ for $\overline{P_1(x)}$ instead. Q_i can be solved

if we put in the boundary condition for half vacuum sector such that $Q_5 = Q_5'$; then $Q_4 = Q_4' + Q_5'$; $Q_3 = Q_3' + Q_4' + Q_5'$ ....

An example of calculating $P_i(x)$ and $\overline{P_i(x)}$ from the measured P_i is demonstrated in Figure 4, where a 10^{-5} Torr • ℓ/s leak (as measured by leak detector later) at B17 has caused a local pressure rise. The ratio between the average pressure and the measured ion pump pressure is about 2.7. The calculated leak rate $2Q_1$ is about 6 x 10^{-5} Torr • ℓ/s.

Conclusion

The pressure distribution along the AGS ring vacuum chamber has been analyzed numerically using the known geometry and pumping speed for three different cases, uniform outgassing, large leaks, and small leaks.

For uniform outgassing, the ratio between the average pressure and the measured pressure would be less than 3 even if 80% ion pumps are out of service. The ratio between the cold cathode gauge (usually located at x = L/6) reading and the pressure of the nearest ion pump should be less than 2.5.

The difference between the real pressure along the vacuum chamber and the measured pressure in the presence of the leaks are demonstrated for two cases at BC and F sectors. The ratios are slightly higher than those for uniform outgassing. The calculated leak rates from the ion pump pressures are consistent with those obtained during leak checking.

The feasibility of calculating the real pressure from the measured ion pump pressure has been demonstrated here. Other factors will certainly alter the accuracy of the measurement/calculation, such as the calibration of the ion pump current (leakage current), the type and size of the ion pumps, the variation of pumping speed with operating pressure, and the effect of non-uniform outgassing. Some of these factors will be addressed in a forthcoming technical note.

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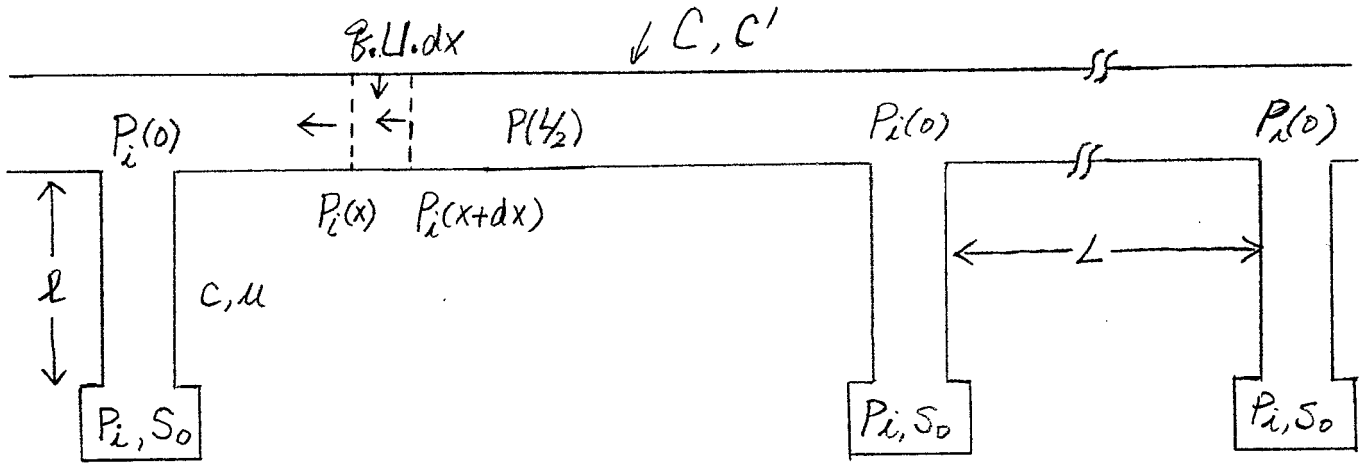


Fig. 1(a). Schematics of AGS Ring Vacuum Chamber w/ uniform outgassing

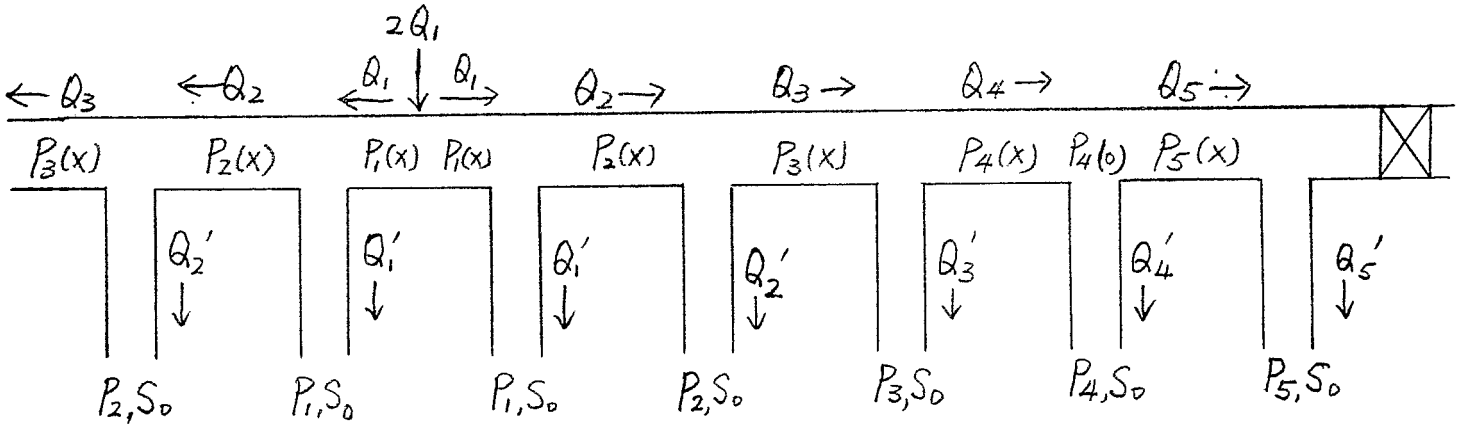


Fig. 1(b) Uniform outgassing and single leak $2Q_1$

Fig. 2(a)

PRESSURE ALONG RING VACUUM CHAMBER

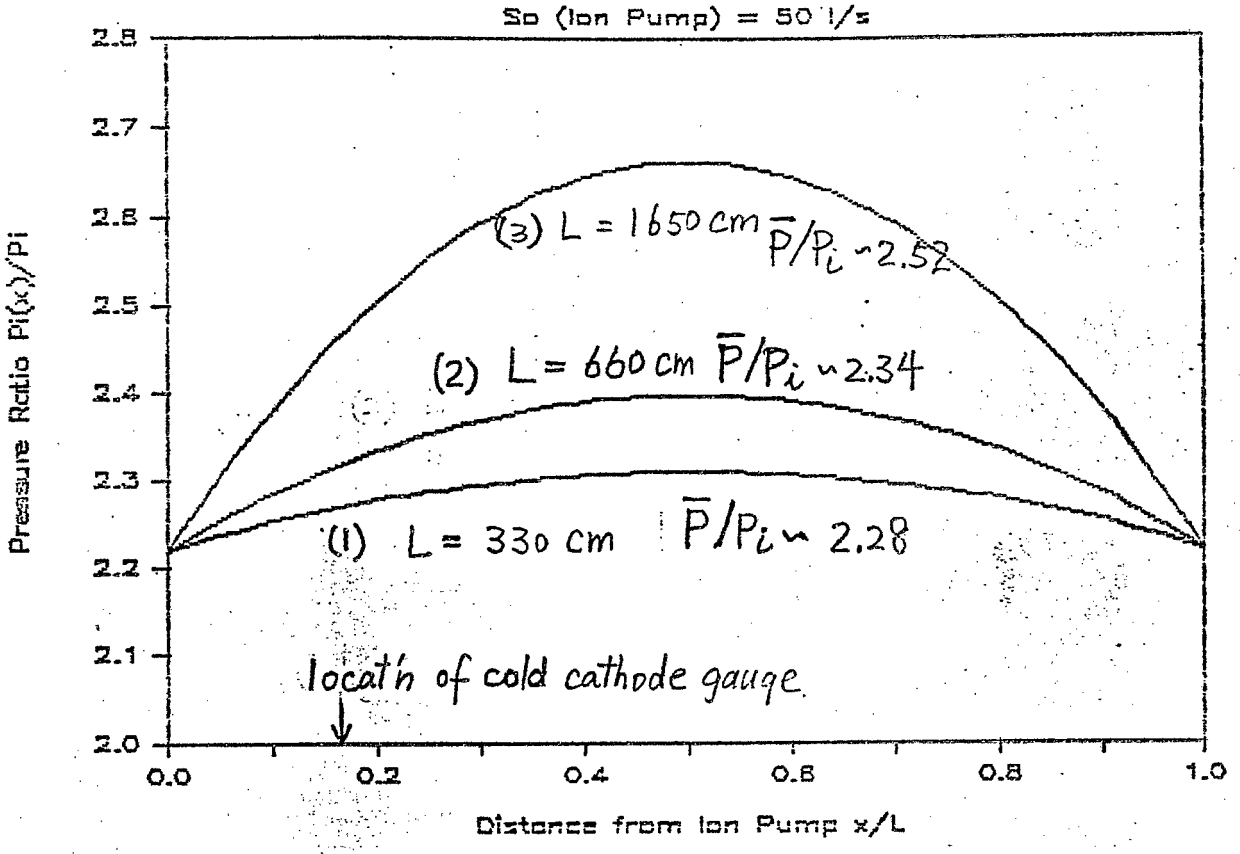
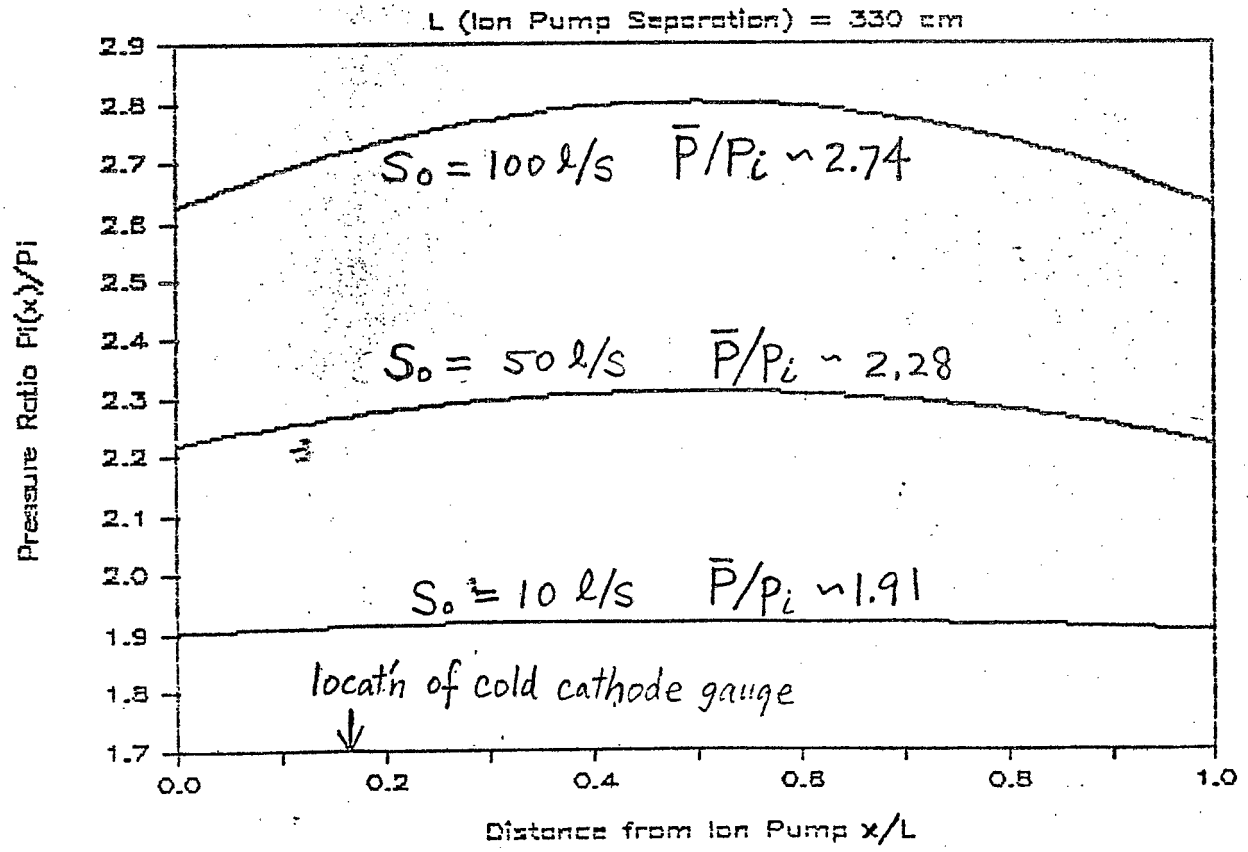


Fig. 2(b)

PRESSURE ALONG RING VACUUM CHAMBER



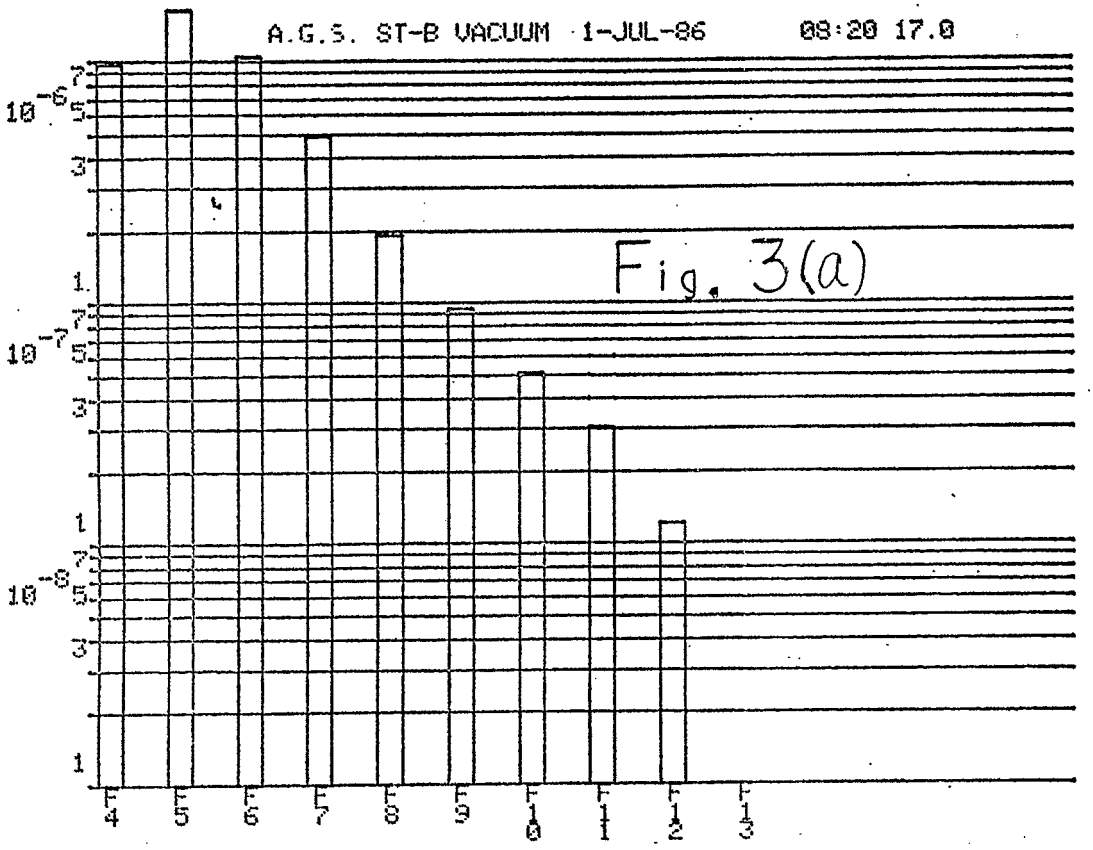
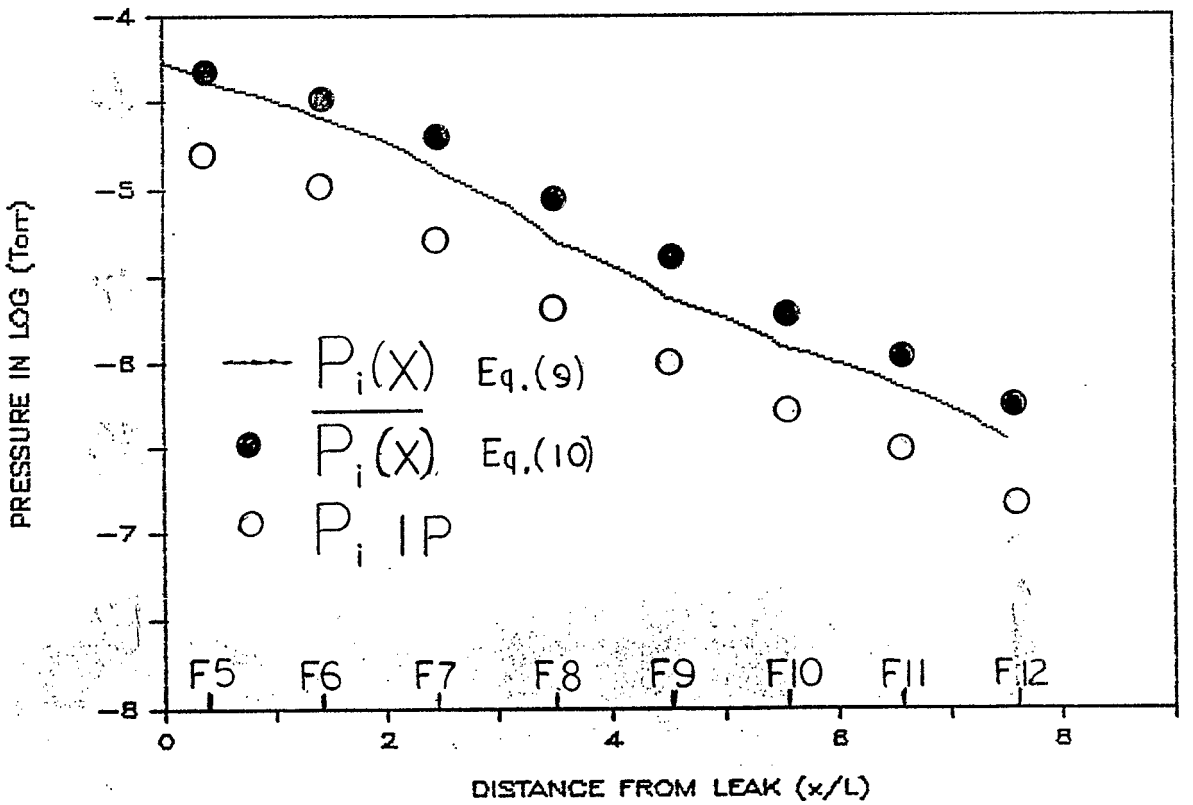


Fig. 3(b): Pi(x) D/S OF F5 LEAK



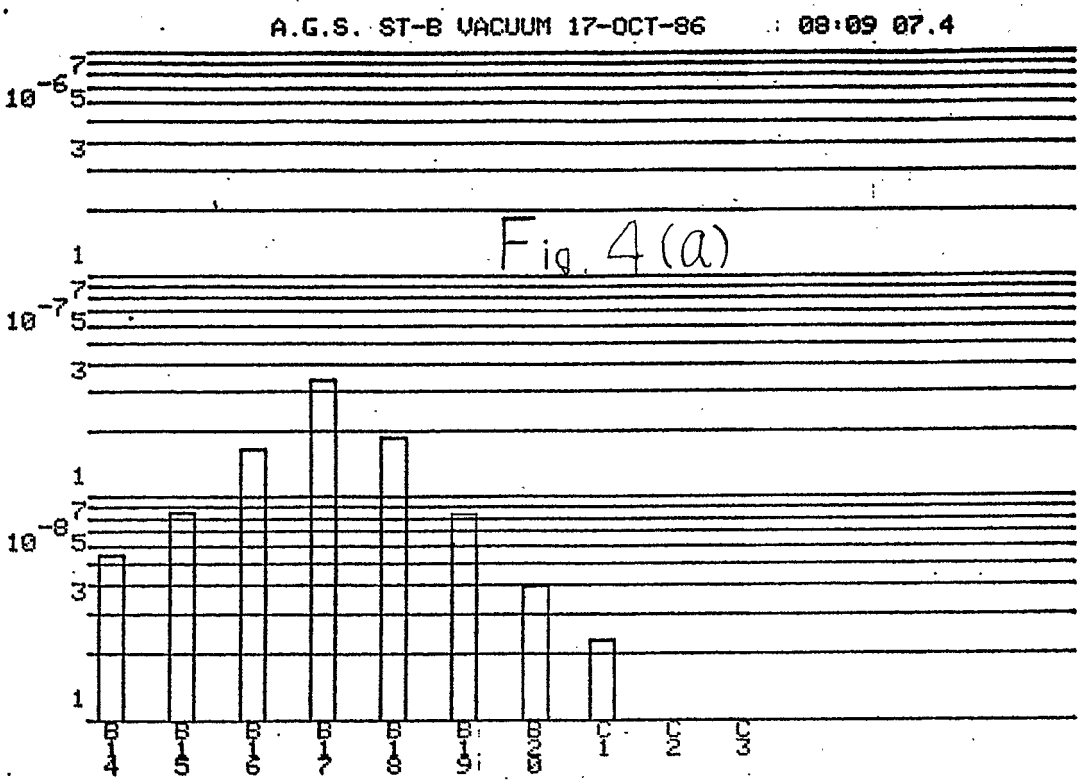


Fig. 4(a)

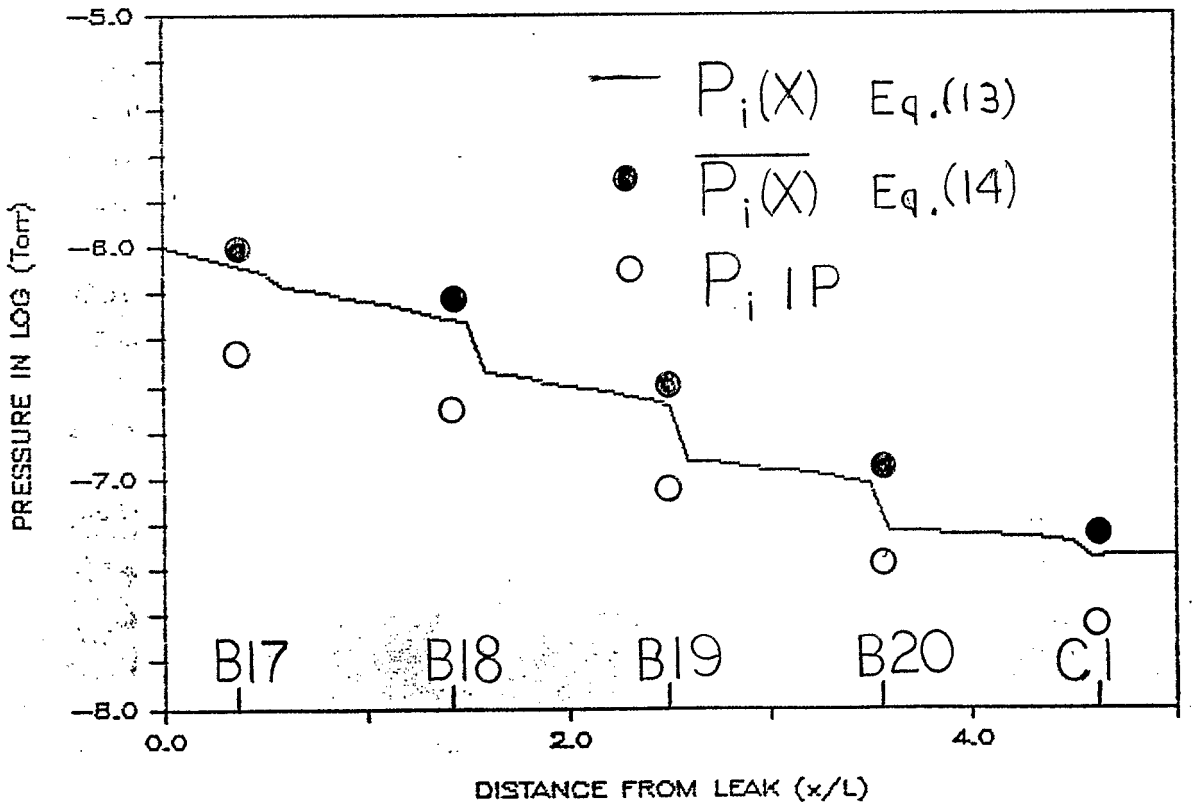



Fig. 4(b): Pi(x) D/S OF B17 LEAK