GEM TN-93-290

Calculation of Pressure Distribution of Vacuum System for GEM Detector

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Pressure distribution of GEM beam Pipe, including synchrotron radiation desorption, has been calculated with a deducted fomular for GEM tapered pipe, a discussion of the calculation method and the less perfect outgassing rate in this calculation is given.

Vacuum Group

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Abstracts

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References:

1. C.M. Van Atta, Vacuum Science and Engineering, 2-9, McGraw-Hill Book Company, 1965

2. D.A. Cragg, The Effect of Outgassing on the Vacuum Pressure in the SSC Beam Pipe System, Rutherford Appleton Laboratory, Oxfordshire, U.K. 1993

3. A.W. Maschke, Synchrotron Radiation in the IR's, Memo to Gerry Chapman, SSC

Distributions:

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I. GEM Beamline and Desired Vacuum

Figure 1 shows GEM beam pipe and associated hardware from the IP to +31 m. The total length of the beam pipe between the Collider Collimators is 62 m: ±31 m from the IP. It consists of a central section of Beryllium pipe, diameter 80 mm, running through the Central Tracker coupled to successive lengths of EC and FC Stainless Steel that vary in diameter. In the forward region the beam pipe is conical in section and lies just outside a cone of 0.50 degree from the interaction point and is therefore entirely in the shadow of the Forward Calorimeter.

In order to minimize gas background to interesting physics events, the system is designed to achieve a pressure in the ultra high vacuum system of 10^{-9} torr under optimum condition. Therefore, the interested flow process in GEM detector vacuum system is molecular flow.

The pressure distribution of GEM vacuum system was determined mainly by the following factors:
1. the geometry of the beam pipe sections; 2. the location of pumps and their effective pumping speed at the beam pipe; 3. The distributed gassing load including stimulated outgassing by photon bombardment from collider synchrotron radiation.

II. Deduction of the Calculation Formulae

Consider a long pipe whose cross-section might be circular or any other shape, as long as its lateral dimensions are much smaller than the length. It can be shown[1] that the throughput across any cross element of the pipe is related to the pressure gradient by the formula:

$$Q_x = \frac{8}{3\pi^{1/2}}\left(\frac{2kT}{m}\right)^{1/2}\frac{A^2}{s}\frac{dP}{dx} \tag{1}$$

where k: Boltzmann constant
T: Temperature in K
m: mass of molecule
A: Area of cross section
s : Perimeter of the pipe element

Q_x: Throughput across the pipe element
dP/dx : Pressure gradient at the pipe element

In case of GEM detector vacuum system, the cross-section of beam pipe is circular

$$A = \frac{\pi D^2}{4}$$

$$s = \pi D$$

Generally, the diameter of the pipe D is a function of x: D=D(x), so equation (1) can be written as

$$Q_x = \frac{8}{3\pi^{1/2}}\left(\frac{2kT}{m}\right)^{1/2}\frac{\pi D^3(x)}{16}\frac{dP}{dx}$$

$$= 3.81\left(\frac{T}{M}\right)^{1/2} D^3(x)\frac{dP}{dx} \qquad (2)$$

$$= \alpha D^3(x)\frac{dP}{dx}$$

where M: Molecular weight of the gas
$\alpha = 3.81(T/M)^{1/2}$

The throughput Q_x consists of outgassing from the wall of beam pipe Q_w, Stimulated desorption outgassing Qs and external gas load Qe:

$$Q_x = Q_w + Q_s + Q_e \qquad (3)$$

1. Pressure distribution along an uniform cross section beam pipe
For a uniform cross-section beam pipe shown in Figure 2

D(x) = D is a constant, and

$$Q_w = \pi q_w D(L-x) \qquad (4)$$

where q_w: The rate of outgassing from the wall of pipe
L : Length of the pipe section

At present time, only synchrotron radiation induced outgassing is taken into account of the stimulated outgassing. As a simple model, the synchrotron radiation desorption can been expressed as

$$Q_s = q_s(L-x) \qquad (5)$$

where q_s: The rate of synchrotron radiation desorption

From the equation (2) to (5)

$$dP=\frac{(\pi Dq_w+q_s)(L-x)+Qe}{\alpha D^3}dx$$

After a simple integral, the pressure difference is given

$$\Delta P(x)=P(x)-P(0)=\int_0^x dP=\int_0^x \frac{(\pi Dq_w+q_s)(L-z)+Q_e}{\alpha D^3}dz$$

$$=\frac{(\pi q_w D+q_s)(Lx-x^2/2)+Q_e x}{\alpha D^3}$$

substitute $\alpha D^3=CL$ and P(0)=P0 , the pressure distribution if given

$$P(x)=P_0+\frac{(pq_w D+q_s)(Lx-x^2/2)+Q_e x}{CL} \qquad (6)$$

Where P0: Pressure at the inlet of the pump
C: Conductance of the pipe

2. Pressure distribution along a tapered beam pipe section

For a tapered pipe section, a simple geometric relation was shown in Figure 3. From equation (2) and (3)

$$dP=\frac{Q_x}{\alpha D^3(x)}dx=\frac{Q_w+Q_s+Q_e}{\alpha D^3(x)}dx$$

$$\Delta P(x)=P(x)-P(0)=\int_0^x \frac{Q_w+Q_s+Q_e}{\alpha D^3(z)}dz \qquad (7)$$

Where

$$D(x)=2(\frac{b-a}{L}x+a)$$

$$Q_w=\pi q_w l_x[b+D(x)/2]$$

$$=\frac{\pi q_w\sqrt{(b-a)^2+L^2}}{L}(L-x)(b+a+\frac{b-a}{L}x)$$

$$Q_s=q_s(L-x)$$

Q_e: External gas load

a,b,L and l_x: Geometric parameters as in the Figure 3

Carrying out the integrals in the equation (7) give

$$\int_0^x \frac{Q_w}{\alpha D^3(z)}dz = -\frac{\beta}{B^2}[\ln(Bx+a) - \ln a] - \frac{\beta M}{2B}[\frac{1}{(Bx+a)^2} - \frac{1}{a^2}]$$

$$\int_0^x \frac{Q_s}{\alpha D^3(z)}dz = \frac{q_s}{8\alpha B^2}[\frac{1}{(Bx+a)} - \frac{1}{a}] - (\frac{q_s LB + q_s a}{16\alpha B^2})[\frac{1}{(Bx+a)^2} - \frac{1}{a^2}] \tag{8}$$

$$\int_0^x \frac{Q_e}{\alpha D^3(z)}dz = -\frac{Q_e}{16\alpha B}[\frac{1}{(Bx+a)^2} - \frac{1}{a^2}]$$

Where the coefficient representation are:

$$\beta = \frac{\pi q_w \sqrt{(b-a)^2 + L^2}}{8\alpha L}$$

$$B = (b-a)/L$$

$$M = a^2/B + L(a+b)$$

Substituting equations (8) and boundary condition in equation (7) gives

$$P(x) = P_0 + \frac{\beta}{B^2}[\ln a - la(Bx+a)] + [\frac{\beta M}{2B} + \frac{Q_e + q_s(L + a/B)}{16\alpha B}]X$$
$$(\frac{1}{a^2} - \frac{1}{(Bx+a)^2}) - \frac{q_s}{8\alpha B^2}(\frac{1}{a} - \frac{1}{Bx+a}) \tag{9}$$

III. Calculation Method

1. The Beam Pipe of GEM detector is symmetry about the I.P., it is necessary to calculate only half of the whole system: that is from I.P. to the distance of 31m. In order to obtain the designed goal of average pressure of about 10^{-9} torr for the beam pipe vacuum system, the trial and error method was used to determine pumping the position of pumps as shown in Figure1. The pumping speed of the NEG pump is designed 300 l/s and located at 3.5m to IP, the pumping speed of Ion pump plus NEG or sublimation source is about 500 l/s or 1000 l/s at the beam pipe with location of 9.0m, 25.5m, 28.0m and 30.0m to IP.

2. Spreadsheet techniques were used to calculate the pressure profile of GEM detector vacuum system based on the deduced formulae in section II. The whole vacuum system can be divided into five subsystem at points where the pressure is at a maximum value[2]. Each subsystem has a pressure minimum value at the pump inlet. The geometric parameters used in this calculation are list below

Pipe Section	Location(mm)	Length(mm)	Diameter(mm)
Central Tracker Beryllium Pipe	IP to 2000	2000	80
EC Calorimeter SS Pipe	2000 to 3500	1500	200
FC Calorimeter SS Pipe	3500 to 8512	5012	80
FFS Tapered SS Pipe	8512 to 31000	22488	134-518

3. An *in situ* bake-out of the beam pipe appears to be possible in certain area of the experiment and impossible for the Central Tracker pipe and NEG pump. When calculated the eventual pressure distribution of the beam pipe, a less perfect condition has to be taken. The out-gassing rate in the calculation, in contrast with perfect conditions, are as follows:

Material	**Out-gassing rate**	**(torr.liter/sec.cm^2)**
	In this calculation	Perfect condition
Beryllium	5.0×10^{-11}	7.0×10^{-14}
Stainless Steel	5.0×10^{-11}	2.0×10^{-13}

Meanwhile this calculation was carried out for air at room temperature. The corresponding parameter is:

$\alpha = 12.1$ for air at room temperature

4. Stimulated outgassing of vacuum pipe wall can be induced by 1) synchrotron radiation; 2) interaction of the cutoff protons in collimator with the beam pipe; 3) radiation of p-p collision in the IP region; 4) ion stimulated desorption. In this calculation, only synchrotron radiation induced outgassing has been taken in account. In the worst case, the rate was estimated as $q_s = 2.0 \times 10^{-10}$ torr. liter/s. cm according to the estimating of photon flux of A. W. Maschke[3] based on a simple "uniform" model.

IV. Results and Discussion

1. The calculated pressure distribution of GEM beam pipe vacuum system is shown in Figure 4. The calculation was carried out for air at room temperature. The average pressure has been calculated using formula

$$P_{av} = \frac{\int_0^l P_x dx}{\int_0^l dx} \tag{10}$$

to obtain $P_{av.} = 7.06 \times 10^{-9}$ torr, with a Non-Evaporable Getter pump (300 l/s) and four ion pumps plus NEG or sublimation source(500 l/s for the ion pump before FFS and 1000 l/s for the other ion pumps).

2. In the previous calculation of pressure distribution, the long tapered pipe had been approximately treated as several pieces of cylindrical pipe, with different diameter, connected in series. The results in both calculations showed that the agreement is fairly good for the 0.50 degree tapered pipe of GEM detector. The comparison of both calculation is shown in Figure 5. Without taking the effect of synchrotron radiation desorption, this calculation gave a value of average pressure for an option of six ion pumps 6.81×10^{-9} torr while the approximation calculation gave a value of 6.91×10^{-9} torr for the same option.

3. In order to calculate the pressure distribution with the better accuracy under collider operation i.e. dynamic pressure, it is necessary to have better understanding of stimulated outgassing. The "uniform" model of synchrotron radiation desorption may need to be modified according to theoretical and experimental results.. The interaction of the cutout beam protons in collimator with the vacuum pipe, the radiation under P-P collision in the IP and ion-stimulated desorption also need more work to be taken in account.

V. References

1. C. M. Van Atta, Vacuum Science and Engineering, 2-9, McGraw-Hill Book Company, 1965

2. D. A. Cragg, The Effect of Outgassing on the Vacuum Pressure in the SSC Beam Pipe System, Rutherford Appleton Laboratory, Oxfordshire, U.K. 1993

3. A. W. Maschke, Synchrotron Radiation in the IR's. Memo to Gerry Chapman, SSC USA, 1992

VI. Figures

Figure 1: Beam Pipe System in the Entire Interaction Region

Figure 2: Schematic Diagram of A Cylindrical Pipe

Figure 3: Schematic Diagram of A Tapered Pipe

Figure 4: Pressure Distribution in the Entire Interaction Region

Figure 5: Comparison of Conical Formula vs. Approximation

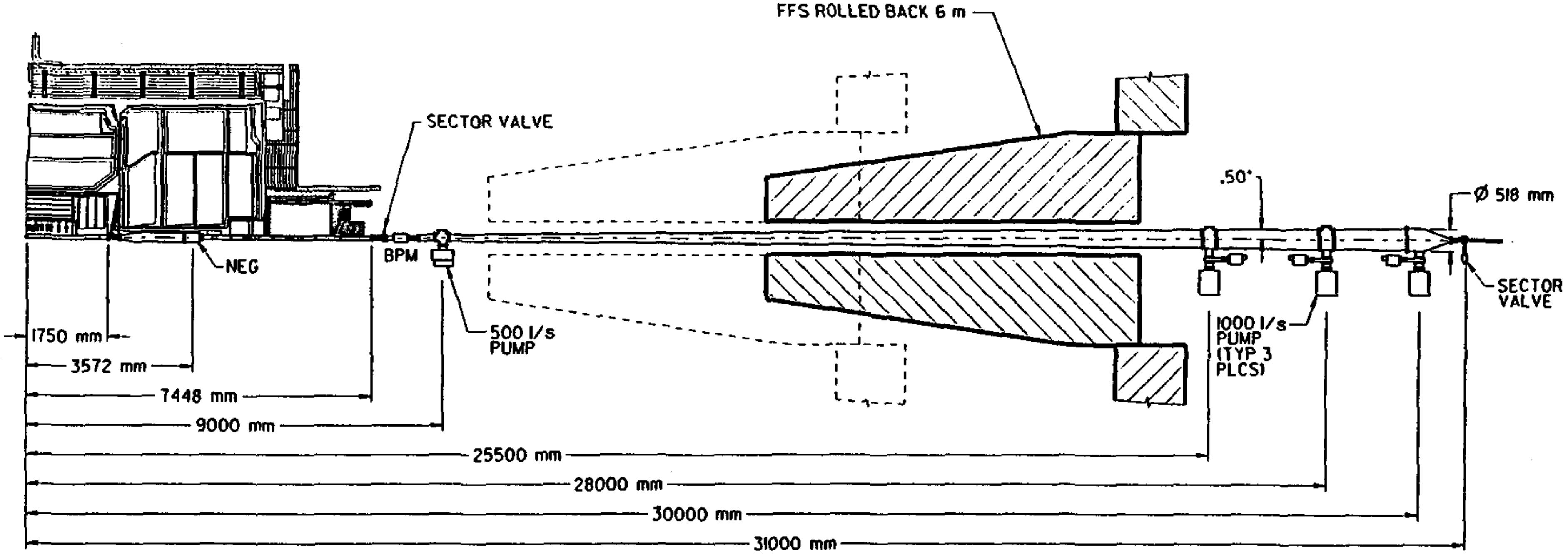


Figure 1

Beam Pipe In The Entire Interaction Region

Figure 2
Cylindrical Pipe

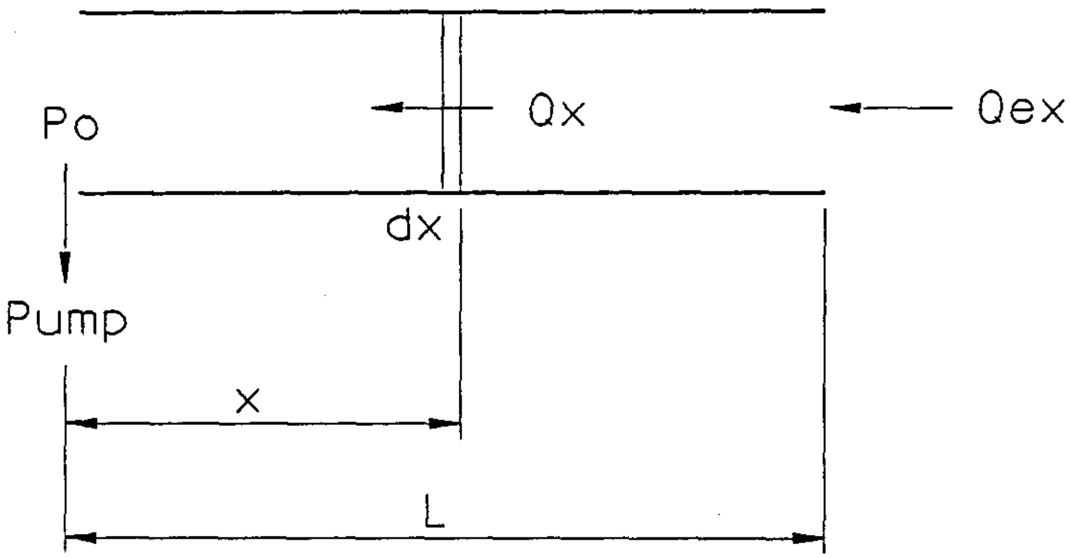
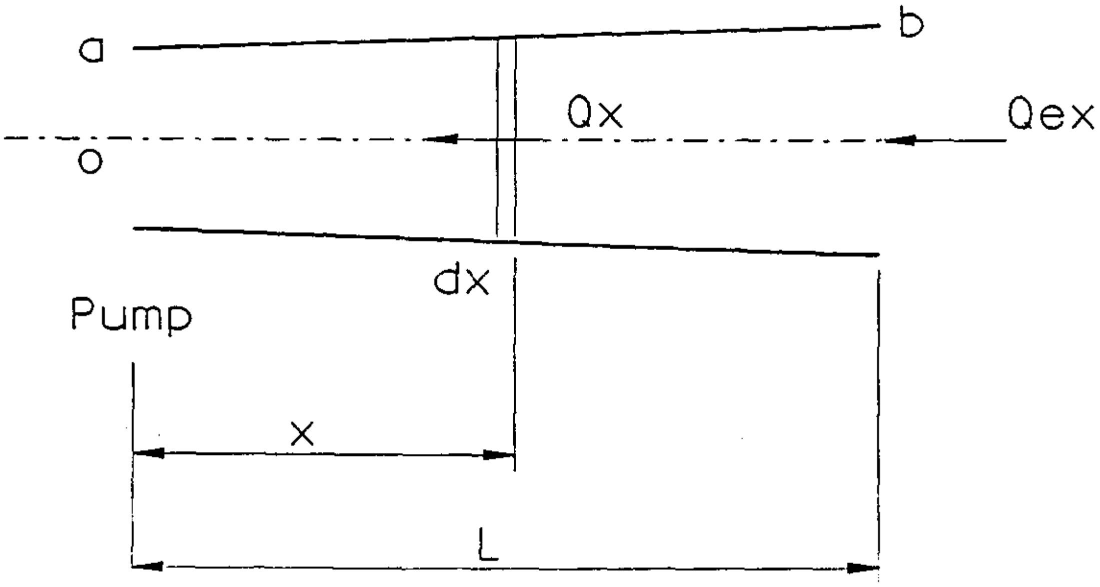
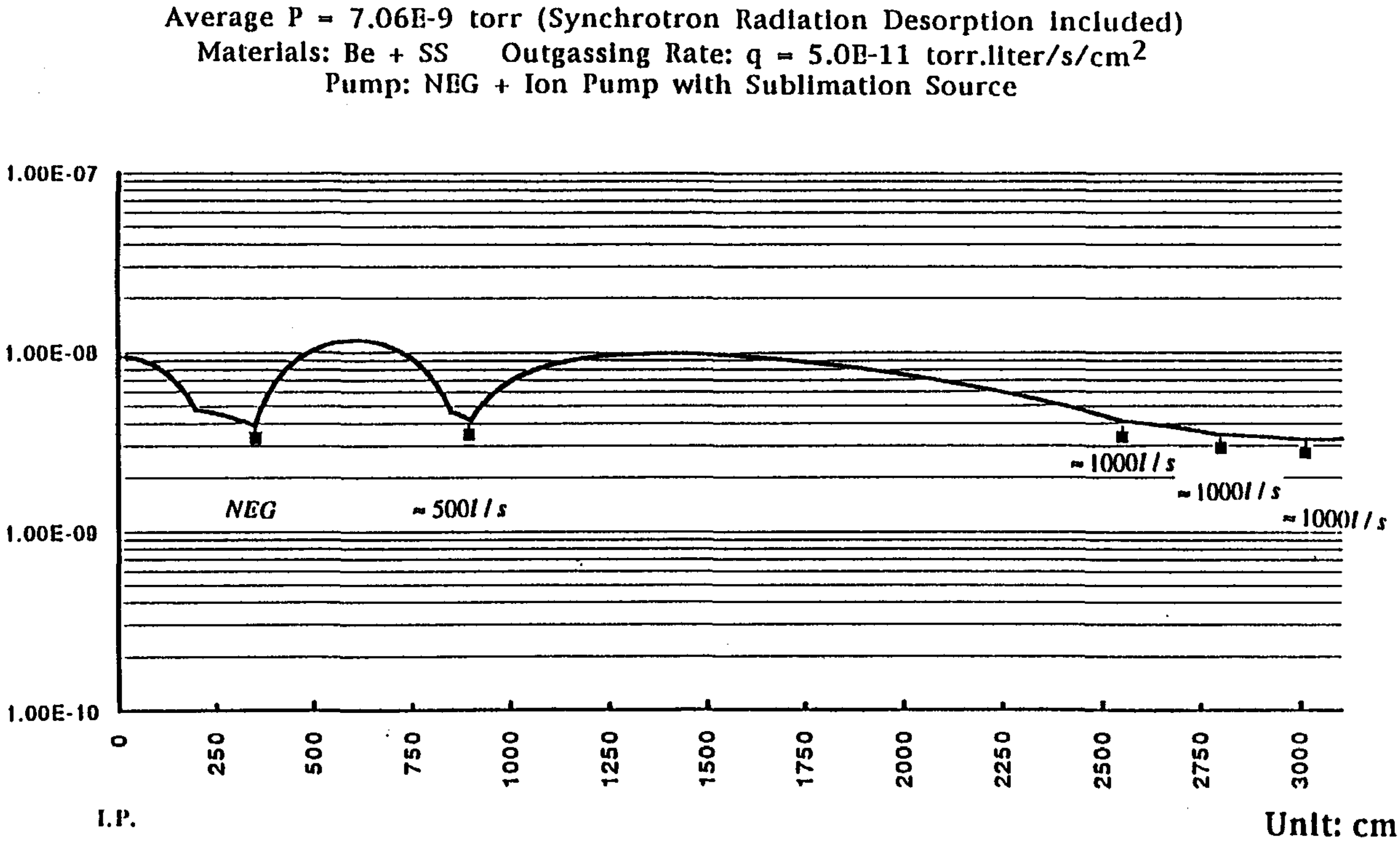


Figure 3
Tapered Pipe





Average P = 7.06E-9 torr (Synchrotron Radiation Desorption Included)
Materials: Be + SS Outgassing Rate: q = 5.0E-11 torr.liter/s/cm^2
Pump: NEG + Ion Pump with Sublimation Source

Figure 4: Pressure Distribution in the Entire Interaction Region

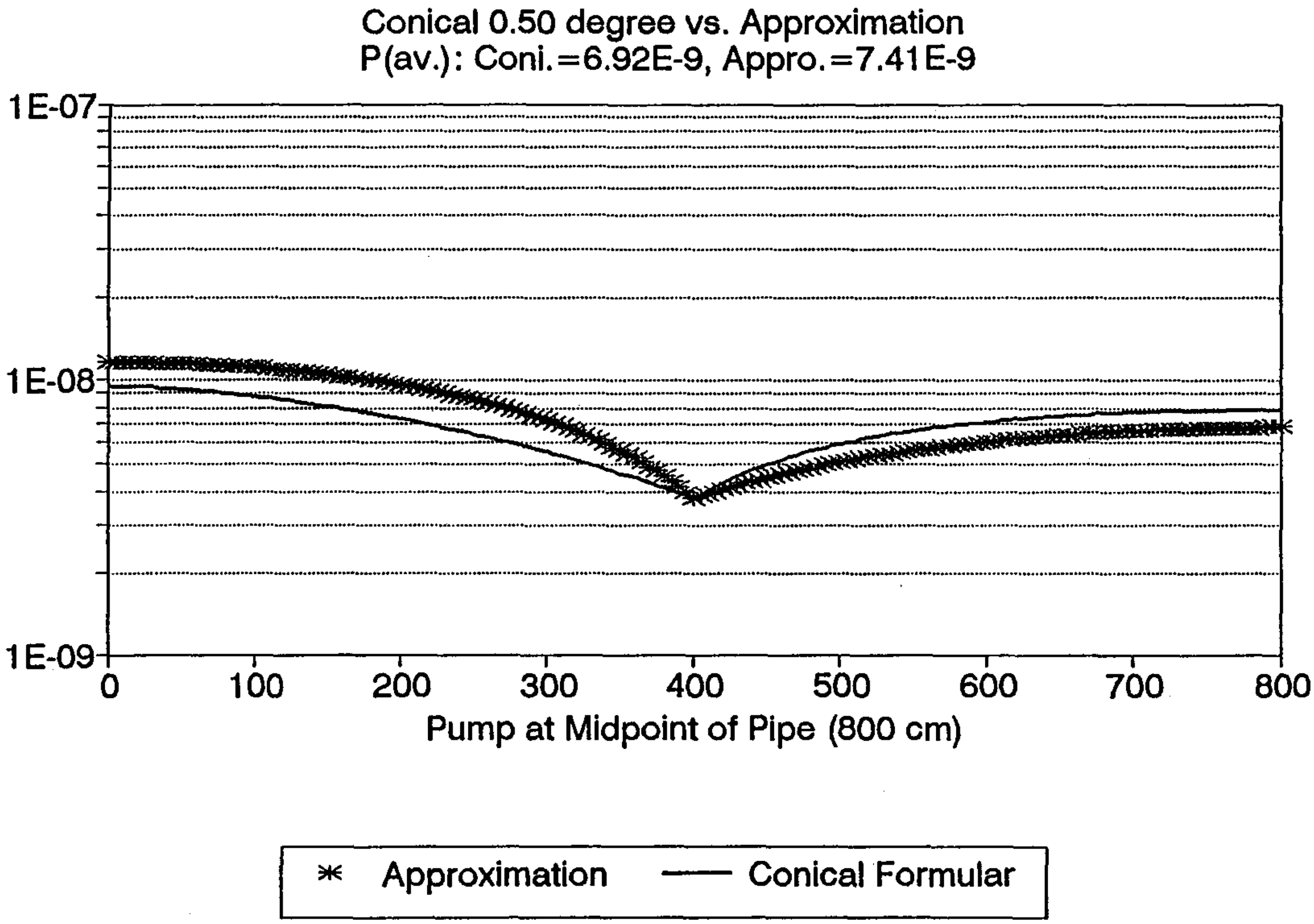


Figure 5: Comparison of Conical Formula with Approximation