BTeV Pixel Detector – 10% Model Outgassing Test

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Purpose:

The BTeV Pixel Detector will reside in a vacuum chamber. The current design specifies that if the gas load of the detector due to the outgassing rate and virtual leaks is 0.1 torr-L/sec, the vacuum pressure will be around 10^{-4} torr [1,2]. The gas load is an estimate based on research of previous measurements of similar materials that will make up the detector. However, the experimental procedures, the test setup, the manufacturing process of the sample, the storage of the sample, and the surface treatment of the sample vary greatly, resulting in a wide range of measurements for any single material [3,4]. Further, as noted in O'Halon [4], the reported measurements are the net outgassing rates, not necessarily the true outgassing rates. Due to the non-zero pressure inside the vacuum vessel, there is a flux incident on the sample surface. The total or true specific outgassing rate is the sum of the net outgassing rate plus the incident molecules flux times their sticking coefficient on the sample surface. While the actual numbers are not important to specify, it is important to note the distinction.

An assembly of the Pixel Detector that contains 10% of the material by volume will be built. The gas load of the model will be measured. Based on the measurements of the gas load at a vacuum pressure between 10^{-3} and 10^{-6} torr, the gas load of the entire detector at 10^{-7} torr can be extrapolated. The measurements will be taken at room temperature and at cryogenic temperatures. The conductance method, also known as the throughput method, will be followed. The method will include taking measurements at different conductances and is similar to the throughput method with variable conductance described in Elsey [2]. To confirm the accuracy of the measurements taken using the variable conductance method, the gas load will also be measured using the rate-of-rise method. The test setup and theory will be explained in detail in this note.

Basic Test Setup:

A stainless steel tank with inner diameter 19.5 inches and length 66 inches will be used as the test chamber. It will be divided into two volumes, as shown in Figure 1.

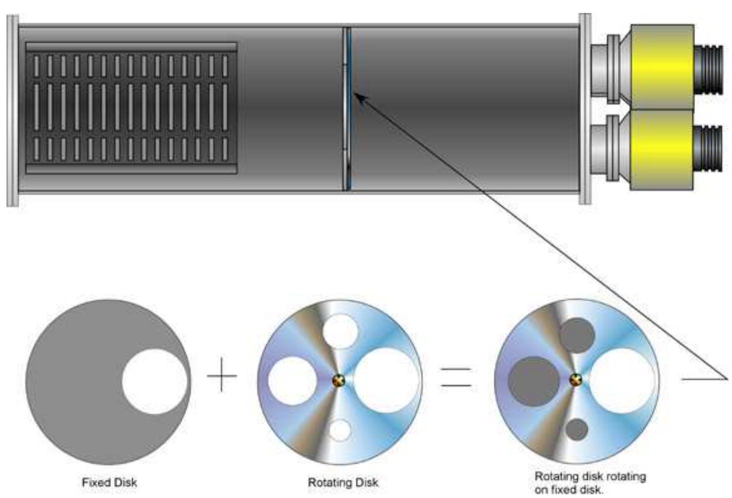

Figure 1 – Schematic of Test Chamber

A fixed disk with one hole is welded in place inside the surface of the tank. A disk with different sized orifices is attached to the fixed disk and is allowed to rotate. The rotating disk allows for various conductances from one volume to the other.

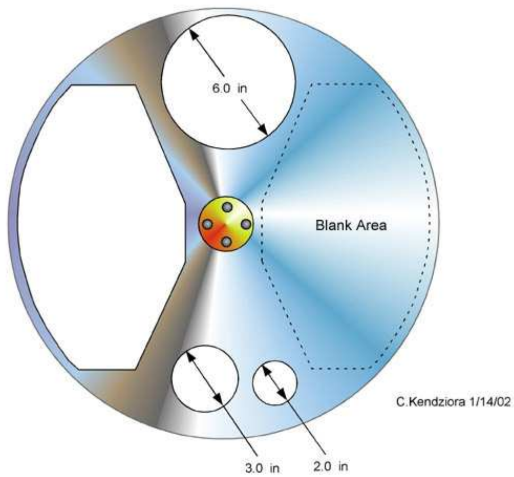

Figure 2 – Rotating Disk with Various Sized Orifices

The disk can be set at the following orifice sizes: 2 inch diameter, a combination of the 2 and 3 inch diameters, 6 inch diameter, and the largest hole, which has a cross sectional area of about 500 cm^2. When the disk is set at the blank area, the conductance between the volumes comes only from the small leak between the dividing disks. There are no seals between the disks.

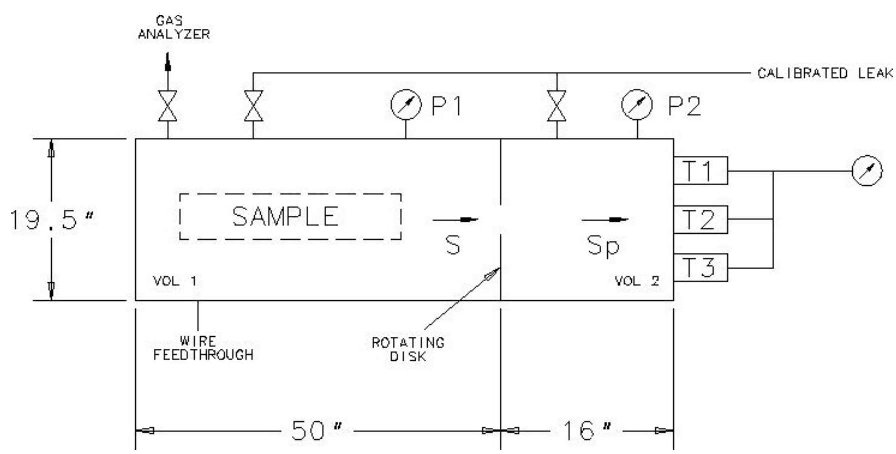

Figure 3 – Piping Diagram of Test Setup

Figure 3 shows a piping diagram of the test setup. Each volume will have its own pressure gauge. Three turbomolecular pumps (T1, T2, T3) are placed in parallel at the end of one volume (Volume 2). The three pumps results in a total pumping speed of 2500 L/sec. The sample is placed in the other volume (Volume 1). The different pumping speeds S from the low vacuum side to the high volume side will be measured by the calibrated leak. The pumping speed S_{pump} in the high vacuum side will also be checked by the calibrated leak. A residual gas analyzer is take readings of Volume 1 during the test. An electrical feedthrough in the wall of Volume 1 will allow the reading and recording of the sample temperature. Using liquid or cold gas nitrogen, the sample temperature can also be lowered. Piping will be built in to allow for a calibrated leak. The rotating disk divides the chamber so that Volume 1 will be 50 inches in length and Volume 2 will be 16 inches in length.

Theory of Throughput Method using Variable Conductance:

To understand how the gas load is measured using the throughput method with variable conductance with the previously described setup, let the following variables be defined:

S_{pump} = total pumping speed of the three turbos in parallel = **2500** L/sec
P_2 = pressure in the high vacuum side of the test chamber (where the turbos are located) (torr)
P_1 = pressure in the low vacuum side (where the sample resides) (torr)
A = area of orifice (cm^2)
Q = net outgassing from the sample (torr-L/sec-cm^2)
C = conductance of the orifice (L/sec) = (11 L/sec-cm^2)*A for air at room temperature
S = pumping speed in the low vacuum side (Volume 1) (L/sec)

For the throughput method,

$$Q = P_1 * S = P_2 * S_{pump} \tag{1}$$

and

$$\frac{1}{S} = \frac{1}{C} + \frac{1}{S_{pump}} \tag{2}$$

There are several assumptions that are made for the test. For one, the vessel outgassing rate is negligible compared to the outgassing rate of the sample. This will be confirmed by measuring the gas load of the empty chamber. Another assumption is that the flow through the two volumes is air at room temperature. Again, this will be confirmed by measuring the gas partial pressure and temperature inside Volume 1. Also, it is assumed that the outgassing rate of the model changes with varying pumping speed in the Volume 1. The reason for this assumption is that the outgassing rate of the sample is the net result of the sample desorption rate n_d and the adsorption rate n_a. In other words:

$$Q = n_d - n_a \tag{3}$$

When the orifice size changes, the pressure around the sample changes. As a result, the gas density around the sample changes. Note that when the pressure in the volume is zero, $n_a = 0$ and $Q = n_d$.

Thus, measurements of the gas load and the pressure around the sample P_1 will be taken for each orifice size. Measuring the values of Q for different P_1, the value of Q at lower pressures like 10^{-7} torr can be extrapolated. When varying the orifice size, the pumping speed around the sample varies according to equation 2. The pumping speed will be measured by a calibrated leak of the appropriate gas. Thus, measurements of the pressure around the sample P_1 will be taken for each orifice size. The net gas load is then calculated using equation 1. Knowing the values of Q for different P_1, the value of Q at lower pressures like 10^{-7} torr can be extrapolated.

In an exercise to estimate the values of P_1 and P_2, assume that the outgassing rate of the sample is constant, or independent of P_1. Let the gas load be 0.01 torr-L/sec and the sample surface area be 3 m^2. Table 1 shows the relationship of orifice size, pressure in the low vacuum volume, and the ratio of the sample surface area to the effective area of the pumping orifice:

Table 1 – Varying Pumping Speed by Varying Orifice Size
With Sample Surface Area 3 m^2 and Q = 10^{-2} torr-L/sec

d (inch)	d (cm)	A (cm^2)	C (L/sec)	S (L/sec)	Ratio	P_1 (x 10^{-6} torr)
blank	blank		~10	~10	30,000	1000
2	5.08	20.3	235	215	1600	47.0
2+3		65.9	770	590	590	17.0
6	15.2	182.0	2120	1160	300	8.7
large			~5000	~1700	200	5.9

The gas load of a smaller sample can be measured with a simple modification of the rotating disk. Table 2 shows the results assuming smaller orifices. The 2 inch and 3 inch holes can be reduced to 1 inch and 2 inch holes, respectively, by obstructions. The analysis also assumes a reduced surface area of 0.3 m^2 and a reduced gas load of 10^{-3} torr-L/sec. The gas load of the empty vacuum vessel is still expected to be negligible compared to a smaller sample. The minimum expected pressure P_1 is more than a factor ten higher than the expected limit pressure of the empty vacuum vessel.

Table 2 – Varying Pumping Speed by Varying Orifice Size
With Sample Surface Area 0.3 m^2 and Q = 10^{-3} torr-L/sec

d (inch)	d (cm)	A (cm^2)	C (L/sec)	S (L/sec)	Ratio	P_1 (x 10^{-6} torr)
blank	blank		~10	~10	3000	100
1	2.54	5.07	69	67	1550	15.0
2+1		54.4	300	268	130	3.7
6	15.2	182.0	2100	1150	30	0.9
large			~5000	~1700	20	0.6

So, when varying the orifice size by rotating the moveable disk, the pumping speed in the low vacuum side of the vessel changes by a factor of 170.

Theory of Rate-of-Rise Method

Using the same setup for the conductance method, it is possible to measure the outgassing rate of the 10% model by the rate-of-rise method. When the rotating disk is first set at an orifice size, the pressure P_1 in the low volume side, where the sample resides, will change with time according to the following equation:

$$Q(t) = S * P_1(t) + V_1 * \frac{dP_1}{dt} \tag{4}$$

where Q(t) = the net gas load in the low vacuum volume
$S*P_1(t)$ = the gas load being pumped out of the low vacuum volume
$V_1 * \frac{dP_1}{dt}$ = the gas load stored inside the low vacuum volume **per unit time**
V_1 = volume 1 = 250 L

For each orifice setting, there is a time constant that represents the time scale for the pressure in the low side volume to settle at a steady-state condition. The time constant τ is calculated using equation 5:

$$\tau = \frac{V_1}{S} \tag{5}$$

Rearranging equation 4:

$$P_1(t) + \tau\frac{dP_1}{dt} = \frac{Q}{S} \tag{6}$$

Note that at steady-state, (dP1/dt) = 0 and:

$$P_1(t) = \frac{Q}{S} \tag{7}$$

To illustrate how the equations can be applied, assume, as for the throughput method, that the outgassing rate of the sample is at a constant 0.01 torr-L/sec-cm^2, regardless of the pressure in volume 1. Let the rotating disk be set at the largest orifice (see Figure 2), which has a cross-sectional area of 500 cm^2. As noted in Table 1, the largest orifice corresponds to a conductance for air at room temperature of about 5000 L/sec and a pumping speed of 1700 L/sec. At steady-state, following equation 7, the pressure in the low vacuum volume is 5.9x10^{-6} torr. Now, let the rotating disk be set at a smaller orifice of diameter 0.5 inch (by adding a restriction on the 2 inch orifice). The pressure P_1 increases from its initial 5.9x10^{-6} torr to the new steady state value of 6.6x10^{-4} torr. It will take 17 seconds to reach this pressure.

At the very beginning of this transient, when $t \cong 0$ seconds and P_1 is still in the 10^{-6} torr scale, in equation 4, P_1 can be neglected. The outgassing rate can be obtained using the rate-of-rise measurement:

$$\frac{Q}{S} = \tau\frac{dP_1}{dt}$$

$$Q = V_1\frac{dP_1}{dt}$$

Because of the time required to rotate the disk from the largest to the smallest orifice, and because of the response time of the electronics of the ion gauge, it is practical to increase the value of the time constant as much as physically possible. By looking at the calculations above, the time constant can be increased by decreasing the pumping speed. For instance, the orifice size can be decreased to 0.1 inch to 0.2 inch in diameter. Another alternative is to use the leak between the rotating and fixed disks when the rotating disk is in the blank position. By the calibrated leak that was previously measured, the pumping speed with the disk in the blank position can be measured.

At this point, it is noted the minimum expected pressure in the low vacuum side occurs with the largest orifice setting. The minimum pressure is still higher than the specified 10^{-7} torr in the pixel detector's beam line area. However the outgassing rate measurement taken with the rate-of-rise method is a good cross-check of the measurement taken using the throughput method.

References

1. BTeV Pixel Detector – Mechanical, Cooling & Vacuum Group Presentations, 17 December 2001.
2. Howell, J., et al. "Analysis of the BTeV Vertex Detector Vacuum System," 21 November 2001.
3. Elsey, R.J. "Outgassing of vacuum materials II." Vacuum, Volume 25, Number 8, Pergamon Press, 1975.
4. O'Hanlon, J.F. A User's Guide to Vacuum Technology. Second Edition. John Wiley and Sons, 1989.