Estimate of emittance growth from Pbar vacuum windows

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Recently it was found that two vacuum windows in the P1/P2 line caused 8 GeV protons to experience significant emittance growth. Mike Church calculated that the beryllium windows caused about a 6 π mm-mrad increase in normalized emittance for an 8 GeV beam. Because there are a number of vacuum windows in the Pbar transport lines, I made similar calculations in an attempt to quantify the severity of the emittance growth.

Beam scattering when passing through a thin window can be described by the following equations. The change in angle due to scattering can be described as:

$$\langle\theta_2^2\rangle = \langle\theta_1^2\rangle + \tfrac{1}{2}\langle\theta_s^2\rangle$$

The scattering angle θ_s is related to the beam γ, the normalized beam emittance ε and lattice parameters β and α through the formula:

$$\theta_s^2 = \frac{10^{-6}\varepsilon}{6\gamma}\beta \quad \Rightarrow \varepsilon_2 = \varepsilon_1 + 3\beta(10^6)\gamma\langle\theta_s^2\rangle$$

ε is in units of π mm-mrad, β is in meters

From the Particle Data Book comes the following expression:

$$\theta_s^2 = \left[\left(\frac{13.6}{938}\right)\left(\frac{1}{\gamma}\right)\sqrt{\frac{t}{\chi_0}}\left(1+.038\ln\left(\frac{t}{\chi_0}\right)\right)\right]^2$$

t is the window thickness, χ_0 the radiation length of the material.

Therefore, the emittance growth for protons or antiprotons passing through a thin vacuum window can be expressed as:

$$\Delta\varepsilon = 3\beta(10^6)\gamma\left[\left(\frac{13.6}{938}\right)\left(\frac{1}{\gamma}\right)\sqrt{\frac{t}{\chi_0}}\left(1+.038\ln\left(\frac{t}{\chi_0}\right)\right)\right]^2$$

There are 14 vacuum windows in the pbar transport lines. Most are titanium and approximately .002 inches thick, but the AP-2 line windows near VT702 and the window upstream of IC728 are .003 inches thick titanium. Also, the window at the end of the AP-1 line is .010 inch thick and made of beryllium. Table 1 summarizes the calculations for each vacuum window (note that the beam energy can be either 8 GeV or 120 GeV on the AP-1 window):

Location	E (GeV)	γ	Material	T (inch)	χ_0 inch	β_x m	β_y m	$\Delta\varepsilon_{x,y}$ (π mm-mrad)
AP-1 near EB6 (2)	8	9.5	Titanium	.002	1.4	170	140	9.0, 7.4
Associated air gap	8	9.5	Air	9.0	11,955	170	140	4.5, 3.7
AP-1 near EB6 (2)	120	128	Titanium	.002	1.4	170	140	0.7, 0.6
Associated air gap	120	128	Air	9.0	11,955	170	140	0.3, 0.3
AP-1 DS	8	9.5	Beryllium	.010	13.9	4	3	0.1, 0.1
AP-1 to target	8	9.5	Air	100	11,955	2.5	2.5	0.9, 0.9
AP-1 DS	120	128	Beryllium	.010	13.9	4	3	0.01, 0.01
AP-1 to target	120	128	Air	100	11,955	2.5	2.5	0.07, 0.07
Target to AP-2	8	9.5	Air	197	11,955	6	6	4.7, 4.7
AP-2 US (BSC700)	8	9.5	Titanium	.002	1.4	9	9	0.6, 0.7
AP-2, VT702 (2)	8	9.5	Titanium	.002	1.4	10	64	0.8, 5.3
IC728 US	8	9.5	Titanium	.003	1.4	35	42	2.9, 3.5
Ion Chamber	8	9.5	Kapton, Al	.003	7.4, 3.5	35	42	0.8, 1.0
IC728 DS	8	9.5	Titanium	.002	1.4	35	42	2.0, 2.2
AP-2 DS (2)	8	9.5	Titanium	.002	1.4	14	4.5	0.3, 0.03
D/A US (2)	8	9.5	Titanium	.002	1.4	6	12	0.3, 0.3
D/A DS (2)	8	9.5	Titanium	.002	1.4	10	7	0.5, 0.3

The total emittance growth due to the vacuum windows is generally quite small. Recall that emittance and admittance quoted in the pbar source are usually absolute and must be multiplied by γ to be normalized. Typical normalized emittances and emittance growths in the pbar are shown in Table 2.

There will also be losses due to elastic scattering of the beam. This is a much smaller effect than the losses due to emittance growth. Table 2 includes beam loss due to elastic scattering.

Beamline	Typical emittance (π mm-mrad)	Emittance growth x,y (π mm-mrad)	Average increase In emittance (%)	Beam loss due to elastic scattering (%)
AP-1 (8 GeV)	12	23.5, 20.5	183	0.5
AP-1 (120 GeV)	20	1.8, 1.0	7.2	0.5
AP-2	250	13.2, 22.8	6.8	0.9
D/A	20	1.6, 1.2	7.0	0.04

Table 2