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:

$$\theta_s^2 = \frac{10^{-6}\varepsilon}{6\gamma}\left(\frac{1+\alpha^2}{\beta}\right) \Rightarrow \varepsilon_2 = \varepsilon_1 + \left(\frac{3\beta}{1+\alpha^2}\right)10^6\gamma \langle \theta_s^2 \rangle$$

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:

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

There are ten titanium vacuum windows in the pbar transport lines. Most are believed to be .002 inches thick, but a window that failed at the end of the AP-2 line was replaced with one that was .003 inches thick. The 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	T (inch)	χ_0 (Ti) inch	β_x m	β_y m	α_x	α_y	$\Delta\varepsilon_{x,y}$ (π mm-mrad)
AP-1 DS	8	9.5	.002	1.412	10	11	.5	1	0.4, 0.3
AP-1 DS	120	128	.002	1.412	73	10	16	4	0.003, 0.002
AP-2 US	8	9.5	.002	1.412	32	51	-3	-6	0.2, 0.1
IC728 (2)	8	9.5	.002	1.412	45	164	1	-4	1.2, 0.5
AP-2 DS	8	9.5	.003	1.412	63	2	-4	-2	0.3, 0.03
AP-2 DS	8	9.5	.002	1.412	63	2	-4	-2	0.2, 0.02
D/A US (2)	8	9.5	.002	1.412	6	12	.1	-1	0.3, 0.3
D/A DS (2)	8	9.5	.002	1.412	10	7	.1	.4	0.5, 0.3

Table 1

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 <u>normalized</u> emittances and emittance growths in the pbar are shown in Table 2.

Beamline	Typical Emittance (π mm-mrad)	Emittance growth x,y (π mm-mrad)	Average Increase (%)
AP-1 (8 GeV)	10-20	0.4, 0.3	2-4
AP-1 (120 GeV)	15-25	.003, .002	.01-.02
AP-2	200-300	3.1, 1.15	0.7-1.0
D/A	30-40	1.6, 1.2	3.0-5.3

Table 2