

Pbar Note #694

Effects of Flying Wires on Beam Characteristics.

Vladimir Nagaslaev
July 19, 2004

I. Introduction.

Flying wires are the instruments routinely used in storage rings at Fermilab for beam profile measurements. The concept of this method is having a very thin wire (typically 30 μ carbon filament) pass through the beam at high speed and recording the time structure of beam losses. The shape of the losses in time is directly related to the beam profile shape. Therefore, collisions of particles with the wire material make those measurements possible. However, these collisions do disturb the beam: due to scattering beam emittance grows, those particles that lose substantial energy or acquire large enough angle, eventually leave the beam.

Because of Coulomb scattering nature, beam emittance blowup effect is small in the Tevatron and Main Injector at flattop. It should be definitely taken into consideration at 8 GeV in Main Injector, Recycler and Accumulator rings.

II. Measuring emittance change in Accumulator.

Main technique for measuring transverse emittance in Accumulator is the Shottky monitor. Using the transverse Shottky monitor we recorded emittance changes during wire flies in different locations. Example of such data is shown in Figure 1.

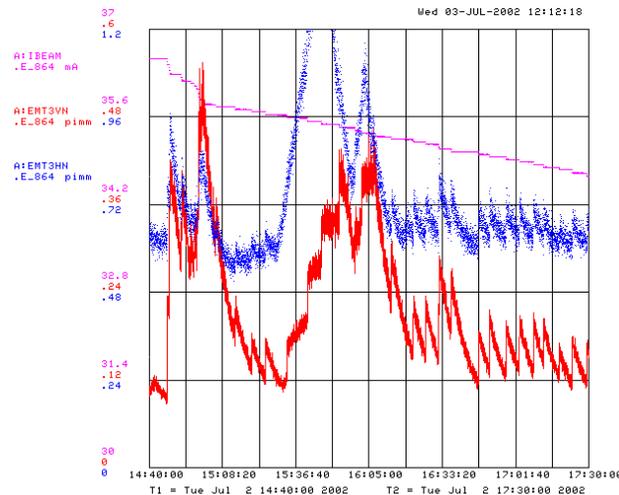


Figure 1. Vertical (red) and horizontal emittance (blue) stability curve as logged during one of the Accumulator FW studies. Beam current is shown in pink.

In order to get consistent results with flying wire profile measurements, one has to allow time to cool down beam between flies. Large emittance jumps in the beginning of the plot correspond to wire motion system initialization that required rotation of all 6 Accumulator wires. Emittance excursion in the middle of the plot is not related to flying wires. For the purpose of quantitative discussion below we will be considering relatively stable right part of this plot that corresponds to the Low Dispersion horizontal wire flies. Typical vertical emittance jump per fly here is $0.064 \pi \cdot mm \cdot mrad$.

As also can be seen in Figure 1, every fly is followed by a little step down of the beam current. For 10 flies of low dispersion wire total drop made from 35.28 to 34.92 mA, that is, there is 0.1% of beam losses per fly.

III. Scattering.

The cross section of electromagnetic single scattering is given by formula

$$\frac{d\sigma}{d\Omega} = \frac{4Z^2 e^4}{p^2 c^2 \beta^2} \frac{1}{\theta^4},$$

or

$$\frac{d\sigma}{d\theta_k} = \frac{8\pi Z^2 r_p^2}{\gamma^2 \beta^4} \frac{1}{\theta_k^3},$$

and probability of scattering at angles θ_k (k=x,y) can be represented in the form:

$$dP(\theta_k) = \theta_{\min}^2 d\left(\frac{1}{\theta_k^2}\right) \quad (1)$$

where $\theta_{\min}^2 = \frac{4\pi n a Z^2 r_p^2}{\gamma^2 \beta^4}$, in a sample with thickness a . θ_{\min} for carbon filament is

about $4 \cdot 10^{-6}$ and close to the angle of atomic screening. Most of the scattering occurs at very small angles that are negligible in terms of beam angle spread, but multiple scattering does yield noticeable angles. The distribution of multiple scattering is close to Gaussian shape with rms [1]

$$\sqrt{\langle \theta_{ms}^2 \rangle} = \frac{14 MeV}{p \beta c} \sqrt{\frac{a}{X_0} \left(1 + 0.038 \ln \left(\frac{a}{X_0} \right) \right)} \quad (2)$$

where X_0 - radiation length of wire material. Emittance growth for a single beam pass through a sample will be

$$\Delta\varepsilon = 3\beta_x \langle \theta_{ms}^2 \rangle \quad (3)$$

Adding real wire parameters and number of a single particle passes through the wire during its fly, one can rewrite

$$\Delta\varepsilon = 4.1 * 10^{-4} \frac{f_0 d^2 \beta_x}{X_0 P^2 v_w \sin(\theta)}$$

Here d is wire diameter, θ - angle between the wire trajectory and the beam, v_w - linear wire velocity, f_0 - revolution frequency, P - beam momentum in GeV. Logarithmic factor is included here in the constant. For the Accumulator, this yields numbers: $\Delta\varepsilon_v = 0.055 \pi \cdot mm \cdot mrad$ and $\Delta\varepsilon_h = 0.67 \pi \cdot mm \cdot mrad$. Measured numbers are $\Delta\varepsilon_v = 0.065 \pi \cdot mm \cdot mrad$ and $\Delta\varepsilon_h = 0.80 \pi \cdot mm \cdot mrad$. It should be noted here that calculations may be affected by inaccurate knowledge of beta-functions. However main reason for discrepancy is that expression (2) underestimates contribution of scattering, as it assumes Gaussian distribution. Real distribution has tails that fall slower than Gaussian due to single scattering at large angles. One may calculate rms angle for single scattering according to Eq. (1), but it is inappropriate to add those contributions directly as soon as single scattering is already included in part in Eq. (2).

Note that emittance growth does not depend on the initial beam emittance.

Figure 2 shows the result of beam size growing simulation. Simulation assumed Gaussian multiple scattering only, but took into account betatron motion in the beam and finite wire speed.

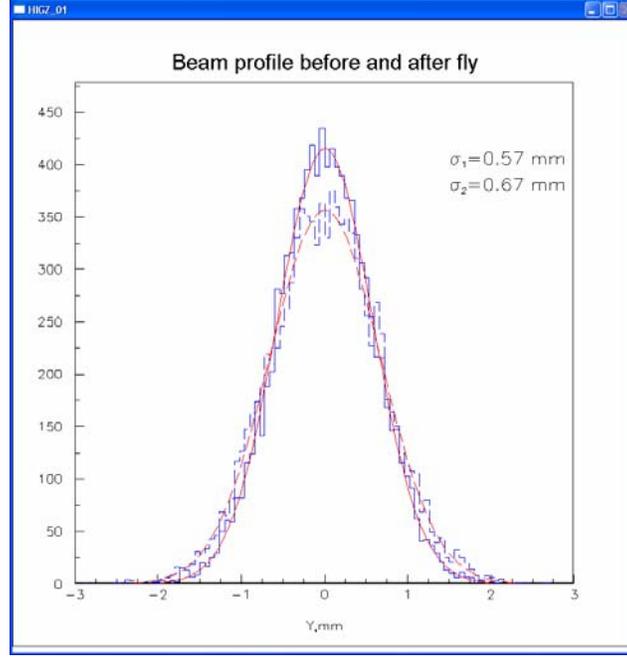


Figure 2. Vertical beam profile before and after Accumulator Low Dispersion Wire fly.

IV. Beam losses.

In order to estimate beam losses we consider two effects: single Coulomb scattering and nuclear scattering. The first one is obtained by integrating (1) over angles beyond Accumulator aperture:

$$P = \frac{\theta_{\min}^2}{\theta_{x,admit}^2} + \frac{\theta_{\min}^2}{\theta_{y,admit}^2} = \theta_{\min}^2 \left(\frac{\beta_x}{\varepsilon_x} + \frac{\beta_y}{\varepsilon_y} \right),$$

and therefore fraction of beam lost as a result of a wire fly is

$$P_s = \frac{\pi^2 n Z^2 r_p^2}{\gamma^2 \beta^2} \frac{d^2 f_0}{v_w \sin(\theta)} \left(\frac{\beta_x}{\varepsilon_x} + \frac{\beta_y}{\varepsilon_y} \right),$$

where $\varepsilon_{x,y}$ - horizontal and vertical Accumulator admittances. This expression takes into account the fact that wire actually passes the beam twice during its fly. Using admittance $\varepsilon_{x,y} = 8\pi \cdot mm \cdot mrad$, $\beta_x=19.9m$ and $\beta_y=16.2 m$, one obtains from this formula losses of $5.5 \cdot 10^{-4}$ per a fly due to single scattering.

Assuming that every act of nuclear scattering effectively kicks out a particle from the beam, beam losses due to this process per wire fly would be

$$P_{nuc} = \frac{\pi d^2 f_0}{2\lambda_{nuc} v_w \sin(\theta)} = 7 \cdot 10^{-4}$$

together with single Coulomb scattering this makes $12.5 \cdot 10^{-4}$ which is pretty close to the observed 0.1% losses per fly.

IV. Conclusion.

We considered mechanisms of emittance growth and beam losses caused by the flying wires at 8Gev proton and antiproton beams. Formulae are presented that can be used in Accumulator, Main Injector and Recycler rings. Simple calculations show reasonable agreement with data measured with Accumulator Flying wires. Numbers to remember for Accumulator are: less than 0.1π emittance growth and 0.1% beam losses per wire fly. Possible way to further reduce those numbers would be using thinner filaments. Two 7 micron filaments are currently installed in Accumulator injection orbit flying wire stations.

References:

1. Particle Data Group, Review of Particle Physics, Phys. Lett. B592 (2004)