TEVATRON ADMITTANCE MEASUREMENT*

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Abstract

We measured the Tevatron beam admittance by the means of exciting the beam with noise and causing emittance growth. The noise power was about 3W with a bandwidth of 100Hz and centered either in the horizontal betatron frequency or vertical betatron frequency. We were able to controllably blow the beam emittance up quickly. From the point where the beam emittance stopped growing, we measured the beam acceptance of the Tevatron.

EMITTANCE GROWTH WITH NOISE EXCITATION AND THE ADMITTANCE

Beam Emittance Growth with Noise Excitation

The emittance growth for an open loop beam feedback system is:

$$\left\langle y^2 \right\rangle = \int_{-\infty}^{\infty} d\omega \left| \int_0^t d\tau \bar{h}(\tau) e^{i\omega\tau} \right|^2 \left| G(\omega) \right|^2 S(\omega)$$

where y is the transverse beam particle coordinate, *h(t)* the beam frequency response function, *G(ω)* the gain of the system and *S(ω)* the spectral density function.[1]

For the Tevatron, the beam emittance growth by a noise powered stripline kicker is related to the noise power by the following empirical formula: 19.8π(mm•mrad•hr^{-1})/(W/kHz), where W is the noise power within the given bandwidth, i.e. to blow up the emittance to 100π aperture, we need about 15 minutes at 2W noise with 100Hz bandwidth.

Beam Scrapped by the Limited Aperture

Assuming that the initial beam distribution is Gaussian, the number of protons within the boundary of *dr* is[2]:

$$dN(r) = \frac{N_0}{\sigma^2} e^{-r^2/2\sigma^2} r dr$$

where $r^2 = x^2 + (\alpha x + \beta x')^2$, σ is the beam size, x the transverse coordinator and α, β the beam Twiss parameters.

The emittance of the beam can be expressed simply as the area of the ellipse in x-x' phase space. Particles in the beam circle around the elliptical orbit. When it receives a kick towards the outside, it follows a larger ellipse until it reaches the aperture and is eventually lost. So the beam admittance is defined by the maximum area of the ellipse in Figure 1. When you excite the beam to fill the entire aperture, the admittance will be equal to the emittance of the beam. Therefore, we can measure the admittance by blowing up beam emittance in a controlled fashion until it stops growing.

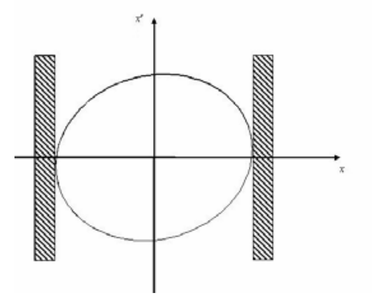

Figure 1. The emittance is simply the area of the ellipse of the phase plot, which is limited by the aperture.

ADMITTANCE MEASUREMENT

The Setup of the Measurement System

The setup for measuring the Tevatron beam admittance by blowing up one coalesced proton bunch is shown in the Figure 2. The vector signal analyzer (VSA) was used to generate white noise signal within the bandwidth we interested and also control the gain of the signal to the power amplifier. Then the noise signal was up-converted to the bunched beam signal of 53MHz. Finally the amplified noise power was used to excite the beam via stripline kicker. The system can also be synchrtronized with the beam. And the emittance grows linearly with noise power we applied to the stripline kicker.

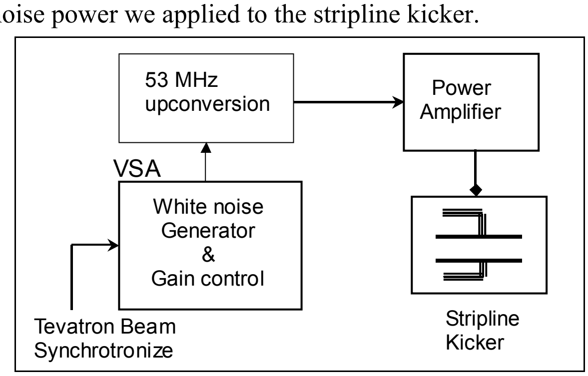

Figure 2: Noise excitation scheme.

When the beam emittance reaches the acceptance of the beam aperture, the emittance we measured will not grow any more as the beam particles are scraped away by the limited beam aperture. To measure the emittance of the beam, the Tevatron flying wire was used during this study. In addition, we also need to keep the beam loss rate under control in order to avoid quenching the Tevatron. Therefore, the proton loss rate C:LOSTP measured by the CDF detector was kept under 40KHz.

In order to do the measurement fast, we used a very narrow bandwidth limited noise centered on the betatron tune. A single coalesced proton bunch of 2e11 protons was injected into Tevatron. The measured fractional Tevatron tune is 0.575 for vertical and 0.583 for

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horizontal, which corresponds to a frequency of 27.4344 kHz and 27.813 kHz respectively because the Tevatron revolution frequency is 47.713 kHz. The noise bandwidth chosen was 200Hz centered on either the vertical or horizontal betatron frequencies and with the power amplifier set to about 2W. So we expected the beam to fill up the aperture in less than 20min. The bandwidth of noise is only 200Hz and so the measurement of the tune and center our noise kicker on them is very important, or else the noise will not be anywhere near the tune and the beam emittance growth will be quite slow. These measurements were all done at the Tevatron injection energy for convenience and safety.

The Measurement Results

First we start to excite beam vertically on the central beam orbit of the Tevatron. The entire process is shown in Figure 3. The green curve in the figure is the total beam in the Tevatron for a single coalesced proton bunch(T:BEAM), the red curve is the bunched beam length measured by the wall current monitor(T:SBDPSS). The cyan curve (T:FWVEMI) and the purple curve (T:FWHEMI) are the vertical and horizontal beam emittances measured by the flying wires respectively. As the noise excitation keeps going, the beam loss becomes greater and bunch length decreases. The horizontal emittance begins to stop growing at about 100-104π, while the vertical emittance continues growing to over than 207π. Since the beam loss rate was faster now, we decided that we should stop here and conclude that the beam acceptance is about 100π in the horizontal and well beyond 200π in the vertical. The losses were located near F2 and a few other places.

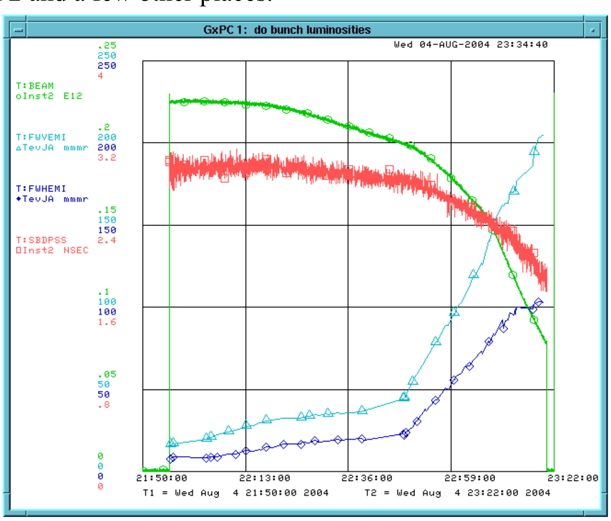

Figure 3: Central Orbit, emittance growth.

The emittance growth at the beginning is slower because we used 200 Hz bandwidth and about 2W noise power. The center frequency is also 50Hz lower than the beam betatron frequency. When we re-centered the noise generator to the betatron frequency and narrowed the band width, the beam emittance grew much faster. The fast decrease of the bunch length also indicates that longitudinal shaving was the major cause of the beam loss, which showed that the horizontal dynamic aperture is the main aperture limitation in the Tevatron on the central orbit.

The measurements were also done on both proton and antiproton helices. The result for the proton helix is shown in Figure 4. The excitation was still in the vertical plane. From the point where the emittance starts to roll off, we estimated the beam acceptance to be about 75π in the horizontal plane and 85π in vertical plane on the proton helix. But we also observed the bunch length was not decreasing. This shows that the major aperture on the proton helix is the physical aperture in both transverse planes and that the horizontal aperture is smaller.

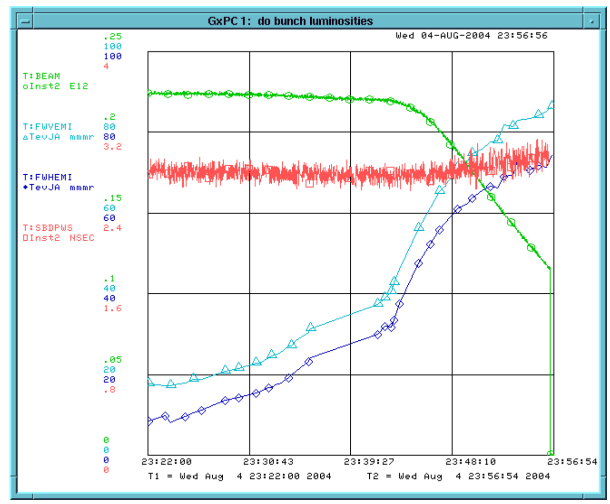

Figure 4: Proton helix, emittance growth.

In the antiproton helix, the measurement is shown in Figure 5. From the point where the emittance starts to roll off, we estimate the beam admittance is 67π in the vertical plane on the antiproton helix, while the beam emittance on the horizontal plane did not grow much. The excitation is still in vertical plane.

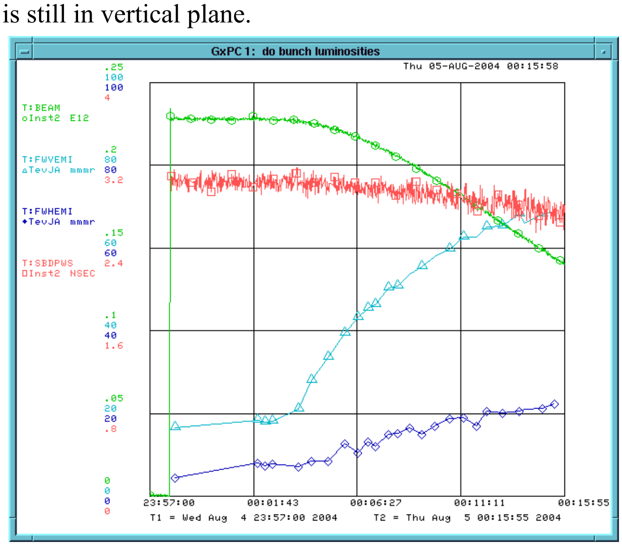

Figure 5: Vertical emittance blowup on pbar helix.

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When we tried to excite the beam horizontally, the excitation blowup the horizontal emittance faster, but it still led to much faster vertical emittance growth as shown in Figure 6.

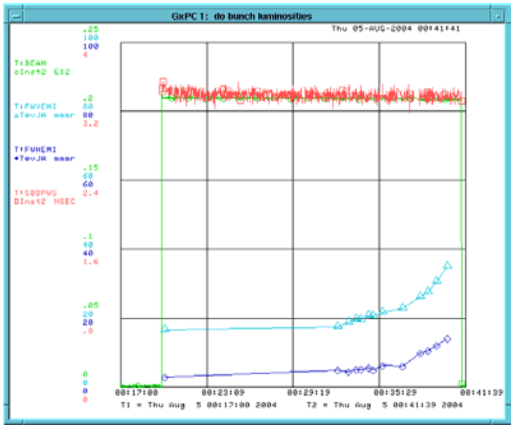

Figure 6: Vertical emittance blowup on pbar helix, horizontal excitation

We were not sure what caused this. We think that it was due to coupling, because the Tevatron is a strongly coupled machine, especially from the strong local coupling at the location of the excitation kicker. We stopped here as we needed to understand why the horizontal emittance did not grow faster than the vertical one.

After the long shutdown work which began in August 2004, the Tevatron dipole coils were re-shimmed to compensate for the coils having sunk. This was the major contributor to the Tevatron systematic coupling effect. A few misalignments were also corrected. We did the same admittance measurements again. The results are shown in Figure 7 and 8. On the antiproton helix, the vertical admittance is about 65π and the horizontal admittance is greater than 55π. But now, the admittance comes from the limitation physical aperture, because the bunch length did not decrease as shown in Figure 7, which was different from the measurement before shutdown.

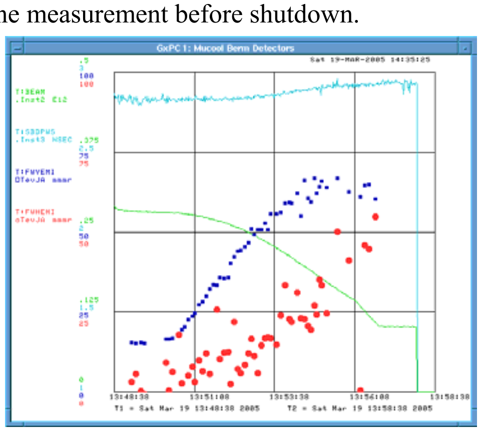

Figure 7: Admittances measurements at 150GeV on antiproton helix after shutdown work

But on the proton helix, the admittances were estimated to be about 82π in horizontal plan and 66π in vertical plane. The main cause of the admittance is from the dynamic aperture. This is also different from the pre-shutdown results.

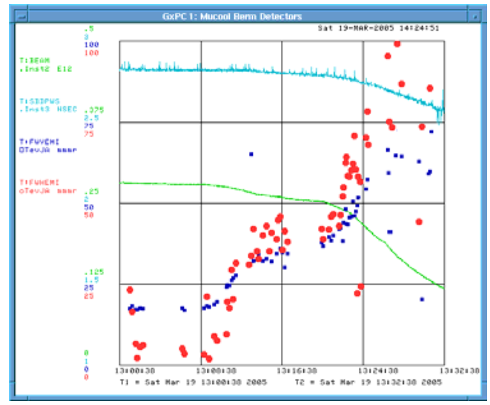

Figure 8: Admittances measurements at 150GeV on proton helix after shutdown work

SUMMARY

We applied a few watts of noise source in 200Hz bandwidth centered on either the vertical or horizontal tune lines to excite emittance growth and determine the Tevatron admittances at 150 GeV. We were able to excite fast beam emittance growth successfully.

The admittances determined when the value at which the emittances level off is about 104π in the horizontal plane and greater than 200π in vertical plane on the central orbit. The dynamic aperture is the major limitation on the central orbit. At the helices, the admittances are 75π/85π in the horizontal and the vertical planes respectively on the proton helix; on antiproton helix, the admittance is 67π in the vertical plane and greater than 25π in the horizontal plane. Also the locations of beam loss can be determined from ring-wide losses from where the aperture restriction might be. We also able to put the losses under control to avoid quench.

Comparing the admittances before and after the shut down, we observed different behaviors before and after shutdown work, which may indicate that the main shutdown improvements which are the residual uncorrected elements played a different role as opposed the pre-shutdown situation. And we have not observed any big improvements or huge deteriorations. But due to software problems of the Tevatron flying wire systems, the spread of the data were larger. These problems will be addressed in the future improvement of the flying wire system.

ACKNOWLEDGEMENTS

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