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THE SPECIAL APPLICATIONS OF TEVATRON ELECTRON LENS IN COLLIDER OPERATION

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Abstract

Besides the Tevatron Electron Lens(TEL) runs as a R&D project for Tevatron Beam-Beam Compensation[1], it is used daily as a Beam Abort Gap Cleaner for collider operations. It can also be served as beam exciter for beam dynamics measurements and slow proton or antiproton bunch remover. This report descibes all these applications and observations.

TEL AS DC BEAM CLEANER

DC Beam and Abort Gap Loss

Currently in the Tevatron, the protons are injected with a larger longitudinal emittance. And some of the DC beam coming from the Main Injector Coalescing Process also got injected. In addition, the protons slowly leak out of the buckets and migrate into the abort gap caused by not well-understood noise sources[4]. The DC beam is usually accumulated about 200×10^9 during injection, which were lost at the beginning of ramping, or above an amount of 6×10^9 protons and antiprotons at the end of the High Energy Physics (HEP) store, which is enough to cause Tevatron quench. When those protons lost suddenly, you will see the loss in the CDF detector spikes, which cause the CDF cannot work properly, even be damaged. And Tevatron also quenches occasionally during the high losses at abort or during ramping due to those protons.

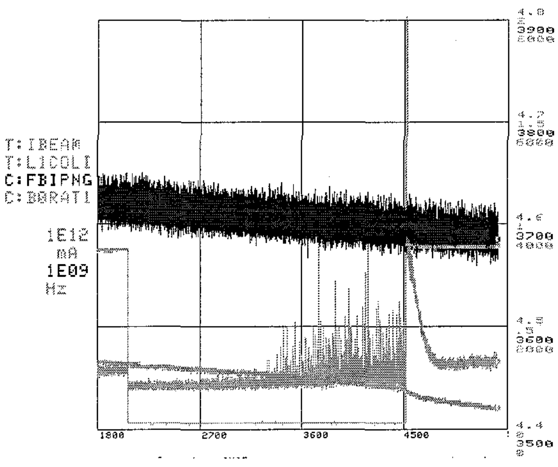


Figure 1: Beam intensity and loss during HEP store

Figure 1 shows such a typical case for High Energy Physics Store. In this figure, the T:IBEAM is the total beam current in the Tevatron, C:FBIPNG is the total bunch current, the T:L1COLI is the average current of the electron current and C:B0RATI is the abort gap loss counter from CDF detector. When the TEL was shut off (red trace), the abort gap loss started to grow after about 10min and the high spikes appeared.

DC Beam Cleaning

To clean out of the DC beam in the abort gap, the dipole beam-beam kick is used to apply to excite the multipole resonance of particle oscillation to increase its oscillation amplitude until the particle get lost by limited aperture. Therefore, when the TEL was turned on, there was a chunk of DC beam losted so that T:IEBAM had a beam loss (green curve) while the lifetime of bunch beam T: FBIPNG did not change. There was also a huge spike on the abort gap loss indicate that the DC beam in the abort gap was cleaned out by the TEL. Then the loss in the abort gap was stabilized without the loss spikes. By introducing the TEL for DC beam cleaning, we accelerating the loss of the DC beam and spread them in the warm section to eliminate the big spikes in the detector so that it is able to work properly, and we also make the beam ramping and abort much safer. Moreover, the little bit higher the baseline loss does not have any harm effect. In DC beam cleaning operation, the electron beam from TEL is placed about 2.5mm beside the proton beam orbit horizontally and 1.5mm down, which is showing in Figure 2.

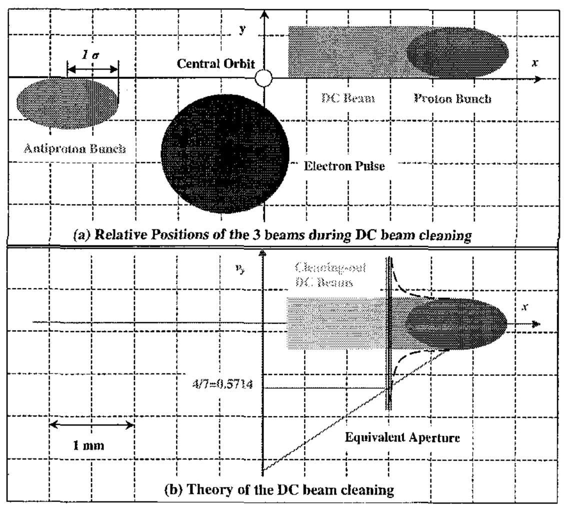


Figure 2: DC beam cleaning: (a) Beam postions (b) Physical mechanism of cleaning

In Tevatron operation, we found that the most effective beam removing by TEL is to apply the electron beam kick of the TEL in every 7th turn or 3rd turn, which excite the 4/7th order or 2/3rd order beam oscillation resonance respectively. The Figure 3 below shows the TEL is operated in Abort Gap Cleaning State with 3 electron pulses in the 3 abort gaps for every 7th turn. The blue trace was the electron gun cathode current. The pulse width is about 1µs and peak amplitude is about 400mA. The green trace was the intensity signal of the TEL BPM, where the big upright spikes were the proton bunch signals since the proton pulse was only 20ns. The pulses downward are electron pulses timed in the abort gap. The intensity of the antiproton bunches were 10 times less than that of the proton bunches, so they were barely seen as the small spikes downward beside the proton bunches. It excites the 7^{th} resonance of the protons in the abort gap and drives them out quickly.

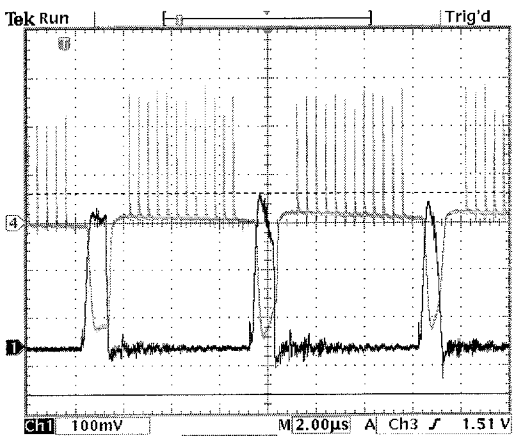


Figure 3: TEL for DC beam cleaning at 3-pulse every 7th turn

Mechanism of DC Beam Cleaning

For normal Tevatron operation, the fractional part of tune was chosen as 0.583 for horizontal and 0.575 for vertical. The most harmful resonance lines for Tevatron are $4/7^{th}$=0.5714 and $2/3^{rd}$=0.667. When the particles in the DC beam lose energy by synchrotron radiation and their also transverse oscillation amplitude increase, their tune changes and finally fall into the resonance band and their oscillation amplitude get larger and larger and finally hit the aperture and lost. Usually it takes about 40min for them to get lost with collimator pull out. With the collimators in and the aperture restricted, it takes about 15min. If with TEL excitation, this process takes about 20sec. With TEL on, the tune of the DC beam particles is roughly follow the formula (1) below:

$$\nu = \nu_0 + C_V \frac{x}{D_x} + \Delta\nu(x^2) + \Delta\nu_{TEL} \qquad (1)$$

where ν_0 and ν are the tune of the on momentum particles and DC beam particles respectively; $\Delta\nu_{TEL}$ the DC beam particle tune changes due to the electron beam. The tune also varies with the beam orbit[5], and $\Delta\nu(x^2)$ is the tune changes due to the particle orbit x; Cv is the vertical chromaticity and D_x the dispersion function at TEL location which indicates the tune variations with particle momentum.

The DC beam clean mechanism is also shown in Figure 2(b). As the electron beam kicks the DC beam particles, their betatron oscillation amplitude increases. The tune changes linearly with the particle position due to the chromaticity and quadratically due to high order field errors of the Tevatron. When the tune falls into the $4/7^{th}$ resonance, their oscillation amplitude increased very fast until it hit the aperture and get lost. The equivalent aperture is the smallest aperture restricted by the collimation system transferred to the TEL location which is about 3mm from helix beam orbit. Figure 4 shows the simulation results of the maximum particle oscillation amplitude for the linear lattice. The maximum amplitude is determined by the nonlinear force of the electron beam. Normally there are about 1/3 of the DC beam is cleaned out of the abort gap since the electron beam roughly occupies 1/3 of the beam abort gap.

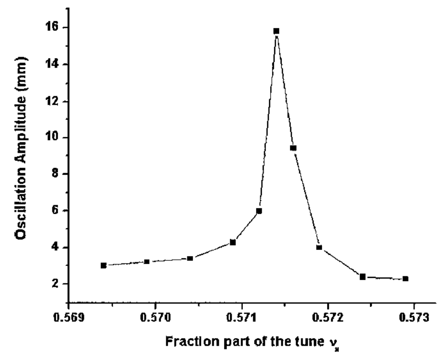


Figure 4: The oscillatin amplitude of the particles near 4/7th resonance line

AS BEAM TICKLER

The electron beam of the TEL can also be used as the beam tickler to measure the beam dynamics. To do so, we only need to modulate the electron beam current or position to produce the dipole kicks which we want and measure the beam response. The Figure 5 below show the method which we modulated the electron current by the white noise and timed to the specific pbar bunches to measure their tunes and emittance growth versus the noise strength.

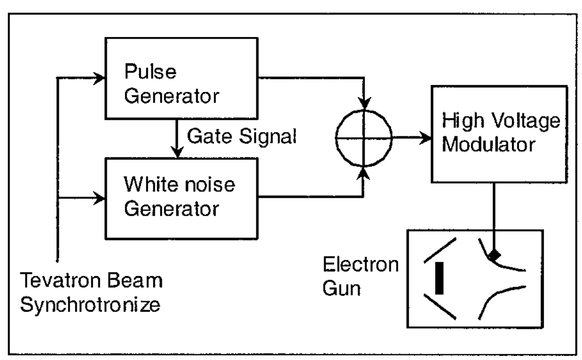


Figure 5: The scheme of the modulation of TEL electron current

The Figure 6 shows the wave form of electron current modulated by the white noise. The modulation depth was

70%. This modulation was used for antiproton bunch by bunch tune measurement.

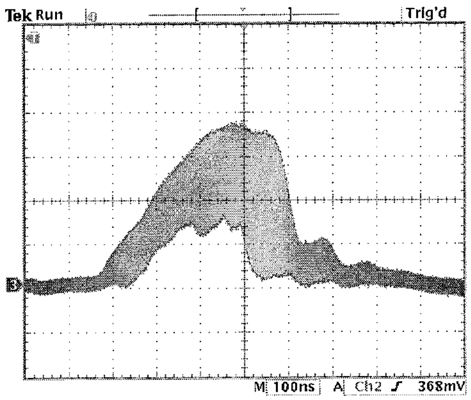


Figure 6: The wave form of the white noise modulated electron current

The emittance growth due to the noise modulated electron beam kick was also observed[1]. It exhibits a quadratic relation which agrees with the theoretic prediction.

Pbar Tune Measurement

During the High Energy Physics store of Tevatron operation, normally the proton intensity is over ten times of the pbar intensity. The Schottky signal, which we are using now for tune measurement, was dominated by the proton signal. In order to see the tune of the individual pbar bunches, we have to tickle the pbar beam harder.

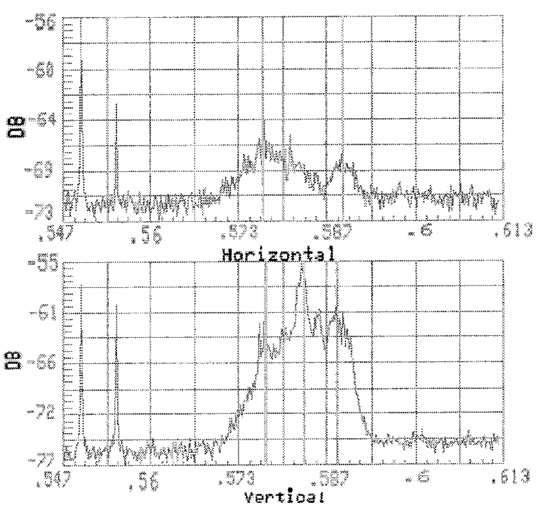
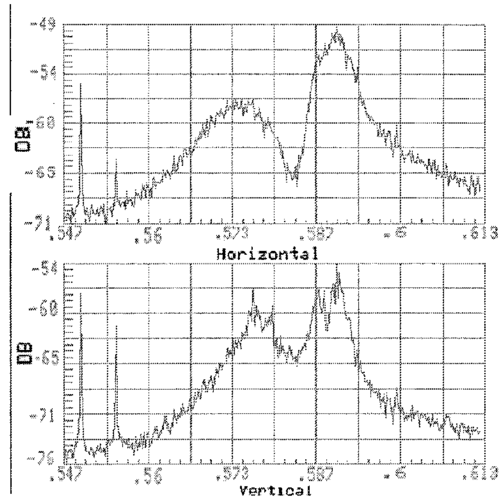


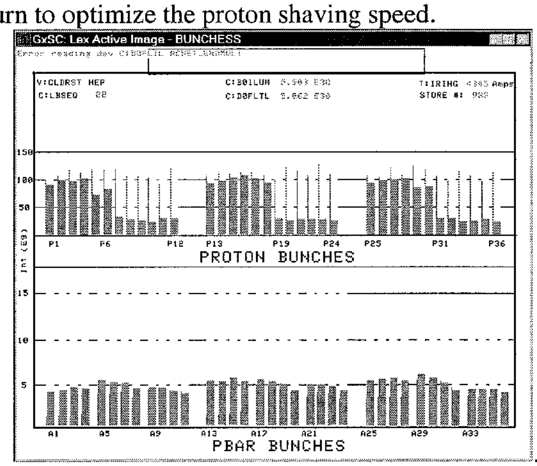
Figure 7: Tune signal from Schottky spectrm detector

Figure 7 shows the Schottky spectrum of the beam. It mainly shows the coalesced proton tune signal, which is about 0.575 in vertical and 0.59 in horizontal. But in figure 8 the antiproton beam is excited by the TEL and we can see the antiproton signal from the split peaks. For this measurement, we have control the modulation strength carefully not to blowup the pbar emittance too fast.



AS BEAM REMOVER

Electron acted as a controllable proton beam remover as shown in left graph. We can remove the unwanted proton bunches one by one in a controlled way that the loss in the Tevatron were kept below the dangerous level. During this operation, the electron beam was operated every 3rd or 7th turn to optimize the proton shaving speed.



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REFERENCES

[1] K. Bishofberger et al., this conference, TPPB083 and MOPA011

[2] X. Zhang et al., Beam Instrumentation Workshop 02, pp. 483-490

[3] V. Shiltsev et al., Phys. Rev. ST Accel. Beams **2**, 071001 (1999)

[4] Alvin Tollestrup et al., this conference, WPPB040

[5] Mike Martens et al., this conference, FPAB031