TEVATRON BEAM-BEAM COMPENSATION PROJECT PROGRESS*

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Abstract

In this paper, we report the progress of the Tevatron Beam-Beam Compensation (BBC) project [1]. Proton and antiproton tuneshifts of the order of 0.009 induced by electron beam have been reported in [2], suppression of an antiproton emittance growth in the Tevatron High Energy Physics (HEP) store has been observed, too [1]. Currently, the first electron lens (TEL1) is in operational use as the Tevatron DC beam cleaner. Over the last two years, we have greatly improved its reliability. The 2nd Tevatron electron lens (TEL2) is under the final phase of development and is being prepared for installation in the Tevatron in 2005.

OPERATION AND STUDIES WITH TEL1

The TEL1 was mainly operated as a gentle remover of the Tevatron proton DC beam in the abort gaps [3], which keeps the Tevatron safe from the quench during abort. It also effectively surpresses the proton halo loss spikes which cause high background and limit the CDF detector operation. TEL1 was also instrumental for calibration of the Tevatron Abort Gap Monitors [5]. Since luminosity runs are of much higher priority, time for BBC beam studies was and is very limited.

Issues identified in previous studies

The tuneshift produced by TEL-1 did help to reduce growth of a single antiproton bunch emittance at the beginning of one HEP store (see e.g. [1]).

The effect was not repeated reqularly because of two reasons; a) in consequent stores, a global tune correction was introduced that greatly suppressed emittance growth of all antiproton bunches; b) there were difficulties with proper alignment of the electron beam w.r.t. the antiproton beam. The latter is caused by a systematic dependence of the BPM electric centers on frequency. The scale of the offset is about 1-1.5 mm (see discussion below). A mm-scale misalignment of high-current electron beam caused full-scale tuneshift error and thought to lead to a significant reduction of of antiproton lifetime.

Electron beam position scan

To quantify effects caused by transverse displacement of the electron beam we performed e-beam position scan around the proton and antiproton beams – see Fig.1. That was done at the end of HEP store #3263(March 1, 2004) when luminosity was low (12e30 cm-2s-1 vs initial 48e30 cm-2s-1), beam emittances were large (some 40 πmm mrad vs 16 πmm mrad at the beginning of the store) and bunches were some 50% longer (2.5 ns rms length vs 1.8ns at the start of the store).

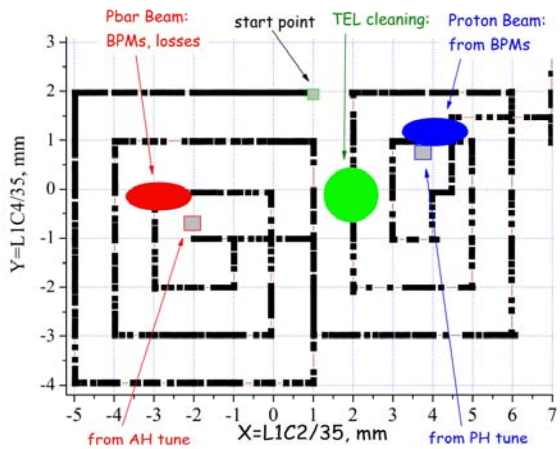

Figure 1: 2-dimensional electron beam position scan around proton and antiproton beams.

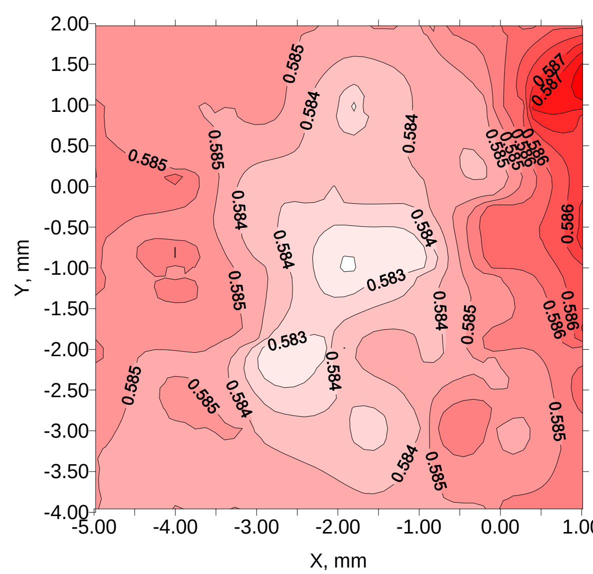

Figure 2 Horizontal tune of antiproton bunch #5 vs the electron beam position.

Electron current pulse amplitude was about 0.6A. Rms electron beam radius was 0.7mm that is smaller than the proton and antiproton horizontal rms beam sizes of 0.9 mm at the end of the store. Maximum tuneshift of the

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bunches affected by TEL (measured by 1.7GHz Schottky detector [4]) was about 0.003-0.004 (positive for protons, negative for antiprotons) – see in Fig.2. Because of (comparatively) small electron beam size, one did not expect to obtain a good lifetime even with perfect e-beam alignment. Indeed, the scan has shown that the maximum of beam losses occurred when beams collided head-on –as can be seen in Figure 3.

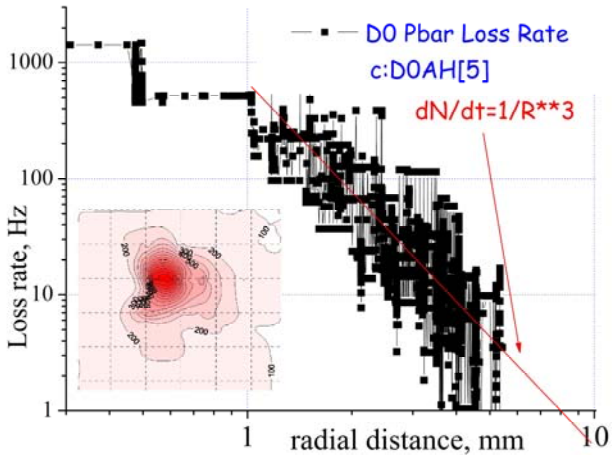

Figure 3: 2-D scan of antiproton beam loss rate vs the electron beam position (lower left corner) and $1/R^3$ fit.

The lessons of that experiment were: a) loss rates roughly scale with the displacement of the electron beam w.r.t. the proton or antiproton beam as $1/R^3$, b) a 50-100% larger size electron beam with significant area of constant current density (flat-top) is needed to accommodate all (anti)protons with a typical end-of-store emittances of about 40πmm mrad; c) there was no bad effects (no losses) on proton beam while e-beam was centered on antiprotons – and vice versa (thus, there is no need to shut off the electron beam between pbar bunches to allow proton bunches to pass through as we worried before).

DEVELOPMENT OF TEL2

Based on the successful experience of commissioning and operation of the TEL1, the 2nd Electron Lens (TEL2) was designed and the main magnets system was fabricated. There are a few major improvements over the TEL1. The TEL2 will be installed in the Tevatron A0 straight section where we have a much larger vertical function. It will allow us to do mainly vertical beam-beam tune shift compensation complementing the TEL1 which is mainly for horizontal beam-beam compensation. It is also give us a spare as Tevatron Abort Gap DC Beam Cleaner.

TEL2 magnets system

One of the main improvements of TEL2 is the less electron beam bending angle. In the TEL1, the bending angle of the electron beam is 90 degrees. Therefore, the field combinations of gun/collector solenoid and the main solenoid for electron beam to pass without scraping the walls are limited. As a result, we do not have much freedom to vary electron beam sizes to adapt to the (anti)proton beam sizes. In addition, the electron beam size is larger in the bends due to the weak magnetic fields in the bending section. The gradient of the magnetic field also causes small vertical beam orbit drift[3].

Decreasing of the electron bending angle with additional solenoids in the bending path expect to at least double the transmission region of TEL1. The magnetic field simulations show that this will allow 60% larger e-beam size variation than TEL1 system. Figure 3 shows the layout of the TEL2 with 53 degrees of bending angle. The additional solenoids in the bending section (three for gun side and three for collector side) will strengthen the magnetic field in the bends to keep the electron size smaller and the beam path more controlled.

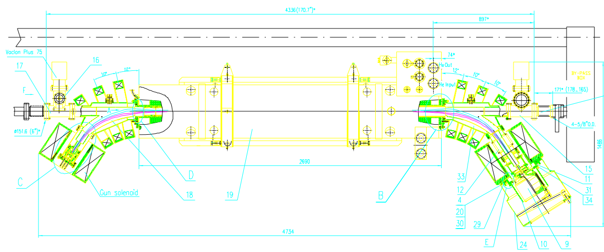

Figure 3: Layout of the TEL-2

Another improvement of the magnets design is the center tap on the superconducting coils, which do not exist in TEL1. These center taps help us to improve the precision and stability of the quench protection system detection with faster response. The TEL2 is already installed at the E4R test facility for magnetic field measurement as shown in the photo of Figure 5. We have done the 3 cycles of cooling-down and warming-up. The cool down takes about 16 hrs to 4.5K. We also ran it up to the 6.5 Tesla design value without quench and special training. At the same time, we did the initial magnetic field quality measurement. The first few measurements show the magnetic system meet our requirement.

Magnetic field measurement results

The TEL2 superconducting magnets were successfully cooled down. And we measured the magnetic field of the using the Lakeshore 460 Gaussmeter with Hall probe. A few results of the initial magnetic field measurements are shown in Figure 4 and 5.

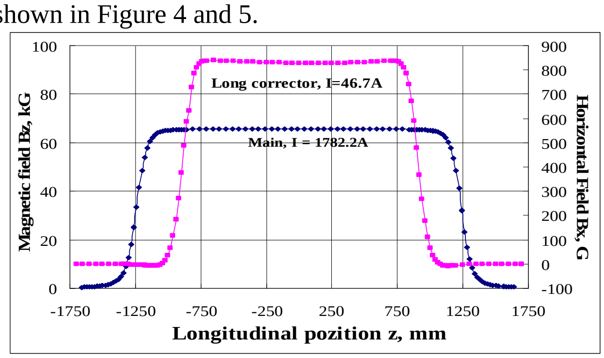

Figure 4. Magnetic field of the main solenoid and the long corrector, each powered on separately.

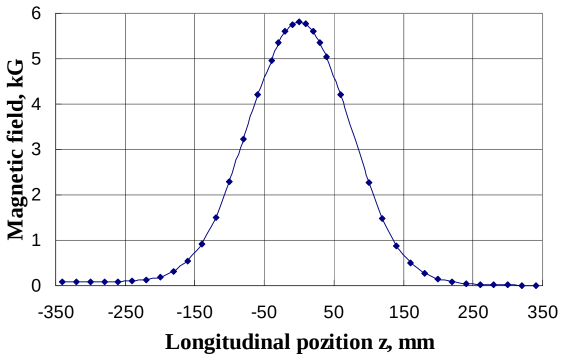

Figure 5. Magnetic field of horizontal short correctors 1

The main superconducting magnet have one main solenoid coil for beam focusing and 2 long corrector coils for electron beam angle adjustment and 2 short corrector coils at the each end for beam position adjustment. The initial results show the maximum fields and linearity of the fields versus the exciting currents met our requirement. The detailed field quality measurements and error analysis will be carried out soon.

OTHER DESIGN IMPROVEMENTS

BPM upgrades

As we noted above, electric centers of the TEL-1 BPMs are frequency dependent and may vary by 1-1.5 mm between proton and electron-like signals which have durations of few ns and almost 1 microsecond correspondingly. We plan to overcome this deficiency by calibrating TEL-1 BPMs *in situ* with few ns electron pulses (corresponding HV pulse generator is currently under design) which will mimic short (anti)proton pulses. We have also redesigned the BPM pickups which we plan to employ in the TEL-2 system. The new pickups two-dimensional and have four parallel plates, while TEL1 BPM pickups are a diagonally cut cylinders. The new BPM pickups are more compact and have built-in electromagnetic shields between neighboring plates to minimize cross-talk. First prototype measurements show that electric center offset between short (anti)proton –like pulses and long electron pulses is less than 0.1 mm.

Current and position fluctuation DAQ

As we have found experimentally, 3.5 mA of high frequency (noise) fluctuations of the TEL-1 electron current lead to the growth of transverse emittance of the 980 GeV Tevatron beams with rate of 0.1 πmm mrad/hr (95% normalized). For comparison, natural emittance growth rates are about 0.5-1 πmm mrad/hr. Turn-by-turn transverse electron beam position fluctuations can lead to the emittance blowup as well. In order to be able to measure the amplitude of oscillations, we have developed a segmented memory scope with 15 bit ADC. Measured high-frequency current fluctuations were found to be ($\delta J/J$)~ (4-10)e-4 for pulses of current $J \approx 0.3$-0.5A. Beam position stability was estimated to be better than 10 μm.

Electron gun with smooth edge

From our beam studies we learned that a flat-top current density distribution gun with a sharp edges produces strong nonlinear force, which acts as a soft collimator and causes the high loss and shorter lifetime for the (anti)proton bunch being compensated. The Gaussian gun greatly reduced the nonlinearity, so the proton losses were much lower and the lifetimes were much longer for the same tune shift. Drawbacks of the Gaussian beam gun are a) lower peak electron current density due to the smaller micro-perveance, and b) the rms size of the electron beam has become comparable to the (anti)proton transverse beam size instead of being larger as desired. To overcome these issues, we have designed (using SuperSAM code) and manufactured an electron gun which has a flat distribution in center and smooth edges similar to the Gaussian distribution.

Modulator Upgrade

The modulator in operation now is based on the RF amplifier design using high power tetrode. It is able to produce 7~9KV pulse with rising time of over 300ns and repetition rate of 50kHz. It is not up to final specs for full-scale beam-beam compensation (100-400ns 10-12kV pulses every 400 ns). We expect a substantial progress with a HV modulator based on Marxx generator technique. A corresponding order for a 14kV pulser has been placed with Stangenes Industries (CA) with expected delivery in Summer 2005.

Improvement of Tune Diagnostics

Tune diagnostics of great importance for the BBC project. In order to be able to berform single-bunch experiments during Tevatron HEP store, we need to have a non-destructive monitor which reports individual antiproton bunch tunes every second or so with relative accuracy of (2-4)e-4. So far the most suitable diagnostics is 1.7Ghz Schottky monitor which can report bunch tunes with accuracy of about 0.001 but the measurement takes some 20 minutes for 36 bunches and 2 minutes for three bunches[6]. We are also exploring two other approaches to the “base-band” tune line detection (at frequencies below revolution frequency of 47.7 kHz) [4].

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