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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]. Electron beam induced proton and antiproton tuneshifts have been reported in [2], suppression of an antiproton emittance growth has been observed, too [1]. Currently, the first electron lens (TEL1) is in operational use as the Tevatron DC beam cleaner. We have made a lot of the upgrades to improve its stability[3]. The 2nd Tevatron electron lens (TEL2) is under the final phase of development and preparation for installation in the Tevatron..

OPERATION OF THE TEL1

The TEL1 was mainly operated as a Tevatron DC beam cleaner[4], which keep the Tevatron safe from the quench by the DC beam during abort. It also effectively surpresses the proton halo loss spikes which cause high background and limit the CDF detector operation. Since the first priority for the Tevatron is the luminosity run, we only had a few chances to do the studies on Beam-beam Compensation[1]. We expected more the machine study time in the future. Besides all above function, the TEL was also served as the beam diagnostic tools such as beam tickler and beam remover[4]. In following sections, we will describe the Beam-beam Compensation results and the use of TEL to calibrate the Tevatron abort gap DC beam monitor.

Beam-beam Compensation Studies

The TEL1 was tried to compensate the “scallops” phenomena at the beginning of the store[5]. The “scallops” is the scallop shaped emittance growth along the antiproton train of the 12 bunches, which is caused by the beam-beam effects when the antiproton tune is not optimized at Tevatron. When this happened, the emittances of the antiproton bunches in the middle of 12-bunch train grow much faster than the rest of bunches in the both ends to form a scallop. It is usually happens first 10 minutes into the beam collision stage.

To suppress the emittance of the antiproton emittance, the electron pulse was used to act on the selected bunches in the middle of one antiproton train. The other 2 trains of the antiproton train were left intact. In one successful attempt, the antiproton emittance growth was greatly suppressed with electron beam compensated, while the antiproton bunches at the same position in the other two trains were growing fast to form the scallop. The growth of the beam size was measured by the synchrotron light monitor for three antiproton bunches. They are at the same position in their relative bunch trains. Among them, only the antiproton bunch A33 was compensated by the electron beams (the purple lines). Its emittance growth rate was about 1π mm•mrad/hr, the other two are 4.1π mm•mrad/hr for A9 (green line) and 2.2π mm•mrad/hr for A21 (cyan line). It shows the TEL did compensate the beam-beam effect for A33 and decreased the emittance growth by the factor of two at least.

It was difficult to do the beam-beam compensation using TEL1, since it’s very hard to align of the electron beam to the antiproton beam. That is because the BPM system tend to report the antiproton beam position and electron position differently due to the different beam spectrum[3]. We expected the new upgraded BPM system for TEL2 will help up to mitigate this problem.

By any means, the successful of the one initial beam-beam compensation is very encouraging. Since in the RUNII plan of the Tevatron, the antiproton intensity will be tripled in the future to 12e10 per antiproton bunch, the beam-beam effect will be much stronger. We hope the beam-beam compensation will help then.

Electron beam position scan

To find the effects of the electron beam when it is electron beam is displaced transversely, we did the beam position scan of the electron beam around the proton and antiproton beams. The main purpose was to simulate the wire compensation purposed for LHC[6] and Tevatron[7]. The results are shown in Figure 1.

In Figure 1, the proton and antiproton beam are located in the red hot spots. We see the loss are roughly scaled with $1/R^3$, where R is the distance between the electron beam and the proton or antiproton beam. When the electron beam is 1mm away from (anti)proton beam, the loss is very small and can be neglected. It’s also show that there were almost no the effects of electron beam on proton beam when electron beam is compensating the antiproton beam at Tevatron for the helix orbit size is larger than 3mm at the TEL1 location. So we do not need to shut off the electron beam between the successive proton bunches arrives as we worried before.

Figure 1 (Anti)proton beam loss effects of versus the electron beam position.

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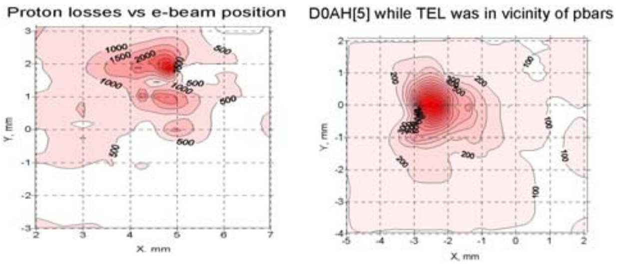

Calibration of the abort gap monitor

There three abort gap DC beam monitors in the Tevatron. They are using the existing synchrotron light monitor gated at the different part of the abort gap. These abort gap monitors are essential to the Tevatron operation. There are not only set the abort criteria, but also are the indicators for the longitudinal instabilities and background issues of the CDF and D0 physics detector. To calibrate these monitors, the TEL was used to clear the DC beam which was accumulated when the TEL was intentionally turned off. From the amount of the total beam lost when the TEL was turned back on. We can calibrate the abort gap monitors by this way against the most accurate Tevatron beam current monitor. Figure 2 shows one of the calibration processes.

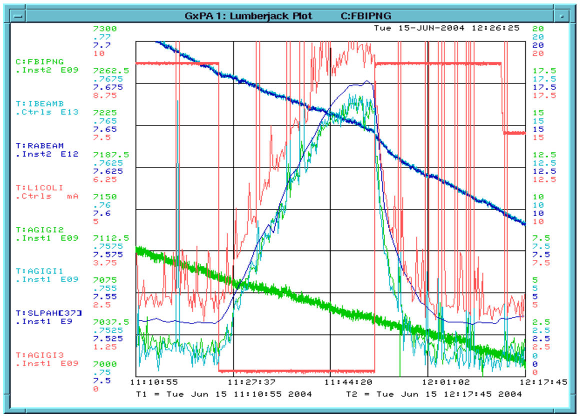

Figure 2: Datalogger plot of the beam intensity, loss and abort gap monitor

In Figure 2, the devices of T:AGIGI[1,2,3] and T:SLPAH[37] are the synchrotron light abort beam gap monitor being calibrated. The green line of C:FBIPNG is the total bunched proton intensity and the T:RABEAM and T:IBEAMB are different devices for the total beam intensities in the Tevatron. When TEL was turned off (TEL current T:L1COLI became zero), we see the beam in the abort gap start to accumulate. As soon as TEL turned back on, the beam in the abort gap was clearing out. So from the total beam loss during this time, we can calibrate the abort gap beam monitor and tune their sensitivities.

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.

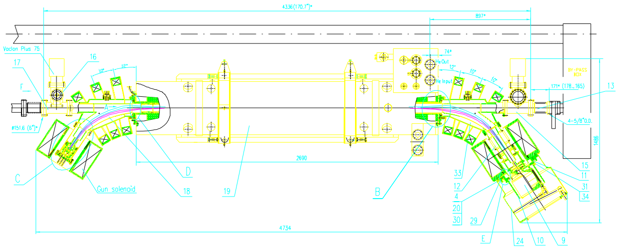

Figure 3: New layout of the TEL

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.

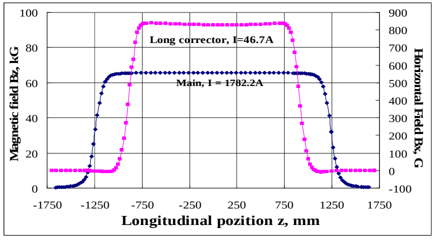

Figure 4. Magnetic field of the main solenoid and the long corrector, each powered on separately.

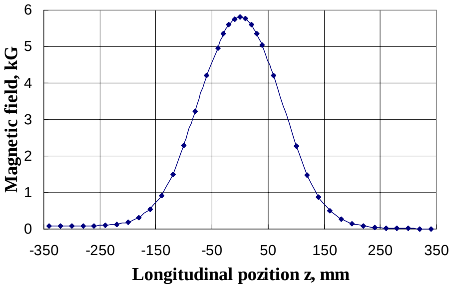

Figure 5. Magnetic field of horizontal short correctors 1

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

Besides the magnetic system upgrades in TEL2, the BPM pickups are redesigned. The new BPM system pickup has four plates as shown in left of Figure 8 left, while TEL1 BPM pickups are a diagonally cut cylinder. The new BPM pickups are more compact and have built-in electromagnetic shields between neighboring plates to minimize crosstalk. The measured response versus the signal frequency for this BPM is shown in Figure 7. This kind of BPM has a offset of only 0.065mm between short (anti)proton bunches and long electron pulse, which is significant better than the 1mm measured for the old BPM[3].

Electron gun with smooth edge

Our study showed that the flat-distribution gun with a sharp edge distribution produces a large nonlinear force, which acts as a soft collimator and causes the high loss and shorter lifetime for the (anti)proton beam being compensated[3]. 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. But the peak electron current was much lower due to the small micro-perveance. Therefore another new gun was designed and under manufacture, which will have a flat distribution in center but with a smooth edge similar to Gaussian distribution. As the result we will be able to have the benefits of a higher peak electron current with reduced nonlinearity.

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[3]. It is not up to our final goal of beam-beam compensation. We need a modulator with 14KV amplitude and fast repetition rate. The 3 new modulator designs are under study[6]: a wider band amplifier, a PFN based or an multimode oscillating network modulator. The last one seems more promising to achieve the high voltage and repetition frequency. The challenging part is it consists of over a thousands of FETs and almost 5 hundreds of IGBTs[8].

SUMMARY

The TEL1 is operating successfully for daily operation of Tevatron as an irreplaceable Abort Gap DC Beam Cleaner. It also showed it's potential on Beam-beam Compensation. It can also be a complimentary beam diagnostic tool. Based on the experience of R7D of TEL1, the TEL2 was made on upgraded design and currently under testing. It will be installed in the Tevatron late this year. It is expect to bring the full potential of Beam-beam Compensation in the future.

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REFERENCES

[1] V. Shiltsev,*et.al*, AIP Conf. Proc. **693**(2004), p.256
[2] K.Bishofberger *et al*. Proc. PAC2003, pp. 57
[3] X. Zhang *et al*. Proc. PAC2003, pp. 1781
[4] X. Zhang *et al*. Proc. PAC2003, pp. 1778.
[6] L.Jin and J.Shi, *et al.* Proc. EPAC2002, pp. 1299
[7] T. Sen, *et al* , Fermilab Beams-doc-1111, Mar. 2004
[8] I. Terechkine, Fermilab Internal Review on TEL R&D, Nov. 10, 2004