RECENT EXPERIENCE WITH ELECTRON LENS BEAM-BEAM COMPENSATION AT THE TEVATRON*

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Abstract

Tevatron Electron Lenses (TEL) have reliably demonstrated correction of the bunch-to-bunch tune shift induced by long-range beam-beam interactions. With the commissioning of the new high voltage modulator that became operational in 2008, the electron beam can be pulsed on every bunch of the Tevatron beam. We report on the recent results of beam-beam compensation studies in the high luminosity regime.

INTRODUCTION

Electron lenses were proposed for compensation of both long-range and head-on beam-beam effects in the Tevatron collider [1]. The lens employs a low energy βe=v/c <<1 beam of electrons which collides with the high-energy bunches over ~2 m of length. The electron beam current can be adjusted between each of the bunches, equalizing the bunch-to-bunch differences (e.g. in tunes or in lifetime) [3]. Two Tevatron Electron Lenses (TELs) have been built and installed at two different locations of the Tevatron ring, A11 and F48. The high-energy protons are focused by the TEL and experience a positive betatron tune shift. A significant beam-beam compensation (BBC) effect does not typically require more than dQp=0.0015 induced by 0.6A of electron current in a 2 m long 5 kV electron beam.

All results reported in this paper were achieved with a SEFT electron gun [3]. The planned installation of the new Gaussian gun in order to be able to perform nonlinear beam-beam compensation experiments had to be postponed for the reasons of Tevatron operations.

Since the alternative approach to abort gap cleaning is still being worked on, TEL1 continued to operate for abort gap cleaning in each HEP store [4].

During the recent shutdown the new Stacked Transformer Modulator (STM) was installed [5]. The novel modulator is capable of generating complex waveforms that make equalizing the bunch-to-bunch tune differences possible [6].

Late in 2008 the Tevatron attained the record luminosity of $3.5 \cdot 10^{32}$ cm^{-2} s^{-1}. In this report the results of beam-beam tune shift compensation for the so-called pacman bunches in the high luminosity regime are presented.

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RECENT EXPERIENCE

Stacked Transformer Modulator

The major challenge while building the HV modulator to drive the TEL electron gun is to deliver a programmable, high duty factor waveform at high enough voltage with sufficiently fast rise time and keep internal power dissipation manageable. The STM takes advantage of the fact that pulse transformers are capable of producing fast enough rise times. Stacking a number of transformer secondary windings in series produces higher voltage. FET H-bridges drive the primary windings [6].

The STM consisting of 5 transformer modules was designed and built at Fermilab. It was tested on the bench with a load identical in its electrical characteristics to the electron gun anode prior to the installation in the Tevatron tunnel. The flatness of the voltage pulse flat top was found to be better than 3V/ns after a voltage transition of about 5 kV.

The built-in digital controller receives the beam clock signal and takes care of proper electron pulse timing. It provides interface for configuring the HV waveform parameters, reading back of vital device parameters (core and heat sink temperatures, average current in each transformer etc.) The STM is fully integrated into the accelerator controls system and thus all its functions can be controlled remotely.

Tune shift compensation

Though the initial and integrated luminosities were increasing throughout 2008, the beam-beam effects during the high energy physics stores were not a pressing issue due to numerous improvements in the collider complex [7]. Early in 2008 the dispersion at one of the collision points was eliminated, and later in the year the local coupling at the IPs was corrected. Together with the stable parameters of the beams delivered to the collider from the upstream machines this made it possible to find the optimal running condition that would minimize beam-beam related particle losses.

Fig. 1 shows the bunch-by-bunch non-luminous portion of the proton intensity loss during the first hour of the record initial luminosity store #6683. Contrary to the situation in 2006-2007, there is no distinct difference for the pacman bunches no. 12, 24, and 36, and the overall losses are much smaller being on average below 2%. Still, acting with the TEL2 beam on selected proton bunches would increase the available tune space and was found helpful in reducing halo loss rate which is beneficial for the quality of physics data obtained by experiments.

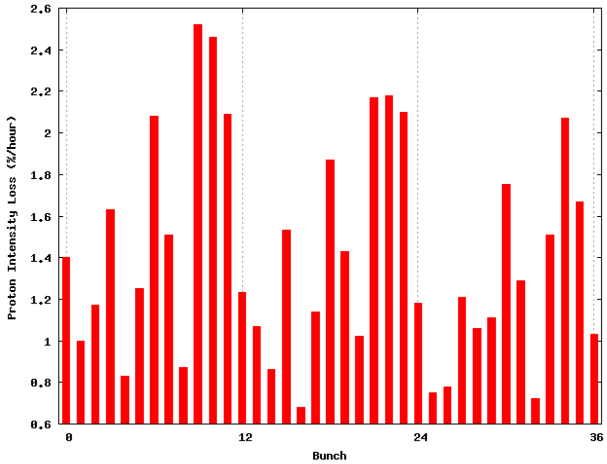

Figure 1. Bunch-by-bunch non-luminous proton intensity loss during first hour of store #6683 with initial luminosity of $3.53 \cdot 10^{32}$ cm^{-2} s^{-1}.

TEL - a tune space exploration tool

Before TEL2 with the new modulator could be employed in beam studies in high luminosity regime, a series of tests were run in order to establish the proper tuning of the lens and ensure safety of its operation. In Fig. 2 the Shottky spectra with TEL2 acting on 3 bunches on each turn is shown in comparison with the electron beam off mode at the end of store #6555. No increase in the Shottky power is observed, which is the sign of a well aligned and stable electron beam.

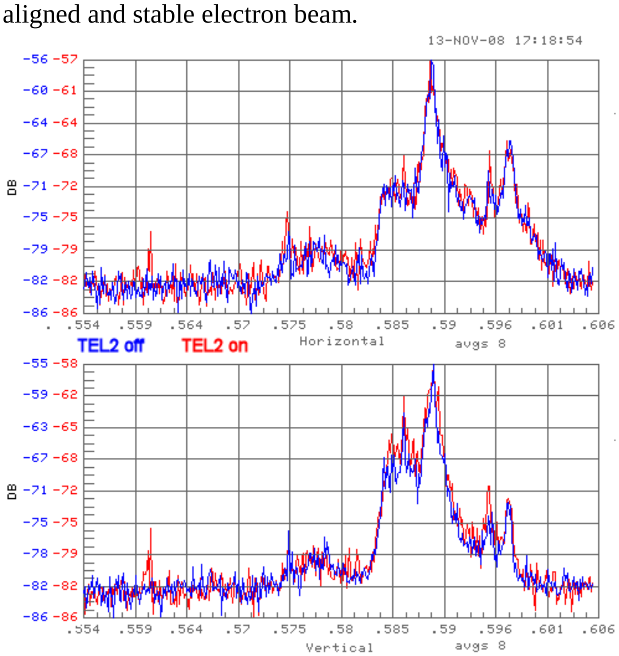

Figure 2: 21 MHz Schottky spectra recorded at the end of store #6555. TEL2 is acting on proton bunches 12, 24, 36 with 0.4 A of peak electron current (red trace); TEL2 electron beam is off (blue trace).

During TEL2 studies in 2006 it was observed that the action of the electron beam on the pacman bunches 12, 24, and 36 was not equivalent to the change of the vertical tune. This is no longer the case after the changes of the Tevatron optics. In Fig. 3 one can see that the effect of the negative vertical tune change is completely eliminated by the positive tune shift of the TEL2 e-beam acting on bunch 12 and vice versa.

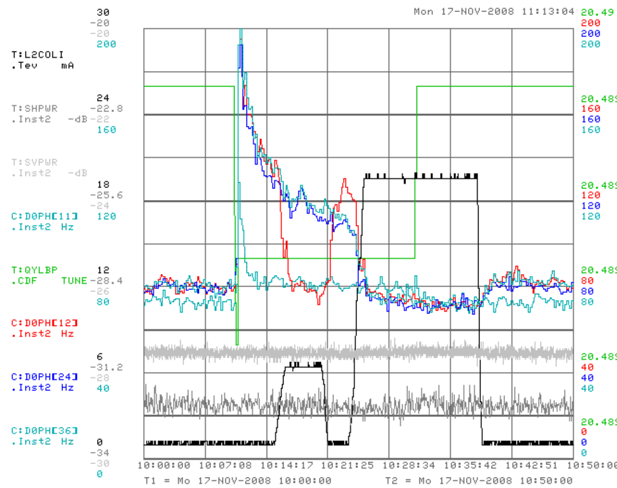

Figure 3: Results of the TEL2 beam study in the middle of store #6566. Plotted are the parameters logged via the accelerator controls network ACNET. T:L2COLI – TEL2 average electron current, T:SHPWR, T:SVPWR – horizontal and vertical Schottky power, C:D0PH[xx] – proton halo loss rates of individual proton bunches reported by the D0 experiment, T:QYLBP – set vertical proton tune.

In this study the TEL2 electron current was turned on twice - first time acting on proton bunch 12 and the second time on all three pacman bunches.

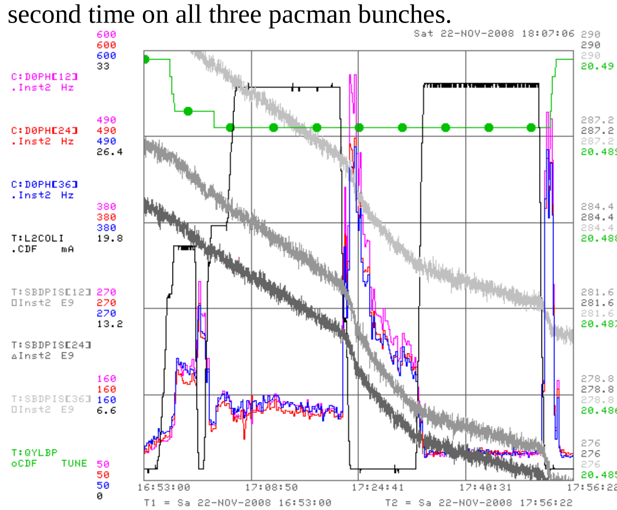

Figure 4: Results of the beginning of store #6587 beam study using TEL2. C:D0PH[xx] – halo loss rates of individual proton bunches reported by the D0 experiment, T:SBDPIS[xx] – intensities of individual proton bunches, T:QYLBP – set vertical proton tune.

Similar result was achieved during a study at the very beginning of a high luminosity store as depicted in Fig. 4. In this case the vertical tune had to be lowered in order to enhance the long-range beam-beam effect for the pacman bunches, and it was then compensated by the pulsed TEL2 beam.

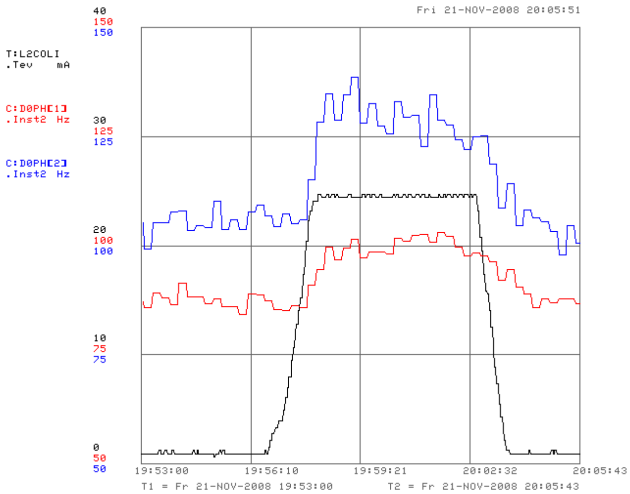

Figure 5: TEL2 affecting the proton halo loss rates of proton bunches 1 and 2 in the beginning of store #6584. T:L2COLI – TEL2 average electron current corresponding to 0.7A of peak electron current, C:D0PH[xx] – halo loss rates of individual proton bunches reported by the D0 experiment.

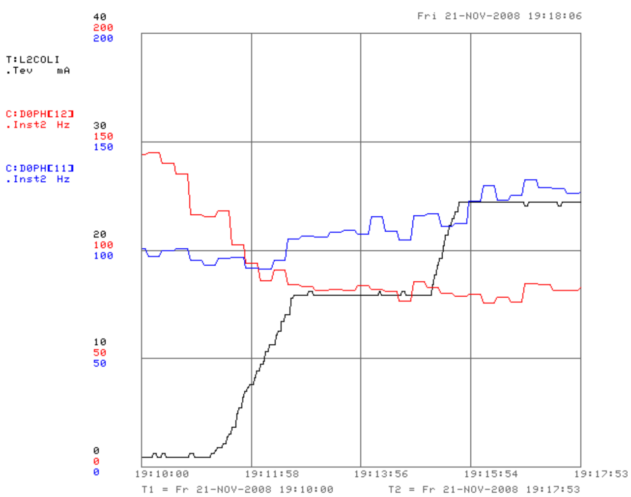

Figure 6: TEL2 affecting the proton halo loss rates of proton bunches 12 and 11 in the beginning of store #6584. T:L2COLI – TEL2 average electron current correspondding to 0.7A of peak electron current, C:D0PH[xx] – halo loss rates of individual proton bunches reported by the D0 experiment.

The capability of TEL2 to act on individual bunches during a high luminosity store is a valuable tool for exploration of the available tune space and for determination of the optimal tune working point. It provides a safe method of scanning the tune using only one or few bunches at a time, as opposed to the regular tune knob. Fig. 5 and fig. 6 demonstrate an example of such non-destructive study in store #6584.

The vertical tunes of P1 through P12 were increased by about the same amount 0.001-0.0015 (TEL2 peak e-current ~0.7A). There was no effect on P11, and increase of losses for P1, and P2. This behaviour is consistent with the calculated beam-beam tune shift of the bunches.

SUMMARY

The newly installed HV modulator allowed much greater flexibility in electron gun driving schemes. Therefore, a very wide selection of possible electron beam settings (pulse amplitude and timing) has become available. Due to faster pulse rise and fall times of the new HV modulator the TEL2 became a much more accurate instrument.

Numerous beam studies were performed using TEL2 in the middle and the beginning of HEP stores. The study results were in good agreement with theoretical expectations. Though significant luminosity improvements could not be achieved due to the absence of strong long-range beam-beam effects in the Tevatron at the time, TEL2 operated safely and reliably and was found fully compatible with HEP operation.

TEL2 in its current configuration can be used for experimental exploration of the available tune space by shifting vertical tunes of individual bunches one or some at a time. This may contribute to better understanding of bunch-by-bunch beam-beam effects in multi-bunch colliders.

TELs are also used for the experimental studies of electron columns [8].

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