FERMILAB-CONF-07-229

EXPERIMENTAL AND SIMULATION STUDIES OF BEAM-BEAM COMPENSATION WITH TEVATRON ELECTRON LENSES*

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Abstract

Initially the Tevatron Electron Lenses (TELs) were intended for compensation of the beam-beam effect on the antiproton beam [1]. Owing to recent increase in the number of antiprotons and reduction in their emittance, it is the proton beam now that suffers most from the beam-beam effect [2]. We present results of beam studies, compare them with the results of computer simulations using LIFETRAC code and discuss possibilities of further improvements of the Beam-Beam Compensation efficiency in the Tevatron.

TEVATRON ELECTRON LENSES

Three types of electron guns were developed for beam-beam compensation (BBC). Currently, both electron lenses [3] are equipped with electron guns utilizing smooth-edge-flat-top (SEFT) transverse current density distribution. Fig.1 shows all three distributions. All experimental and computer simulation results presented in this paper were obtained with SEFT profiles.

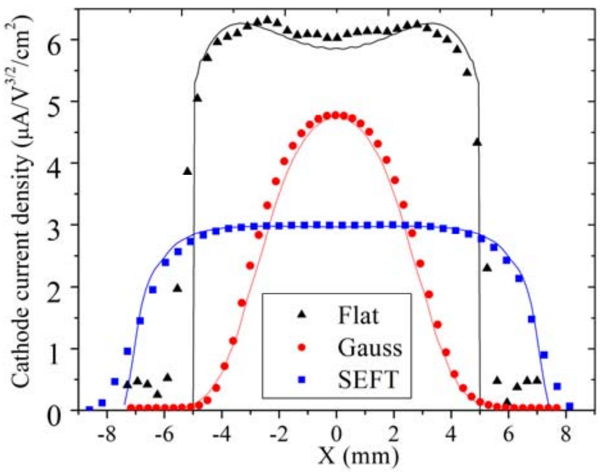

Figure 1: Transverse current density distribution generated by three types of electron guns.

Accurate longitudinal and transverse electron beam alignment is crucial for successful beam-beam compensation. Figure 2 shows how TEL2 was timed for the beam-beam compensation experiments on proton bunch #12. The cathode and collector current transformers (CT), report electron current leaving the cathode and the one arriving on the collector. The flat top of the collector signal is distorted by waves caused by a proton bunch (P12) passing through the electron beam. This feature is often used for alignment optimization. The pickup signal (see Fig.2) featuring proton and antiproton bunches as well as the ac component of the electron pulse provides valuable information for longitudinal alignment. One can see that at TEL2 location the time separation of the counter rotating proton and antiproton bunches is less than 100 ns. However, the transverse proton-antiproton separation (see Fig. 3) allows performing beam-beam compensation of one species without affecting another.

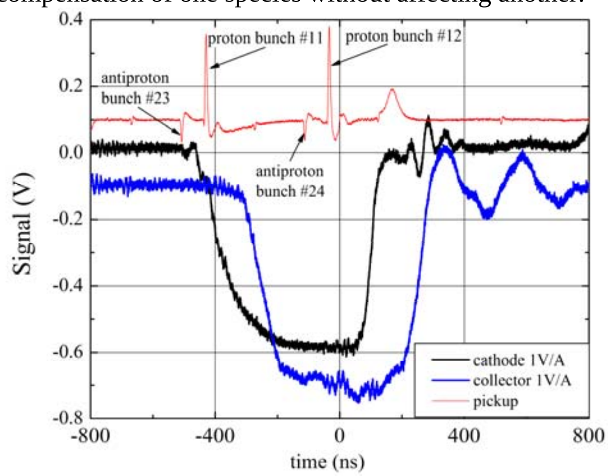

Figure 2: TEL2 timing and longitudinal waves in the electron beam detected by the collector CT. The pickup bandwidth is limited to 20MHz to reduce the bunch signal amplitude.

Transverse alignment of all three beams in TEL2 is shown in Fig. 3. One can see that the proton and antiproton beams are separated both in horizontal and in vertical planes. All the protons, even those with very large betatron amplitudes pass through the electron beam and thus experience the same tune shift.

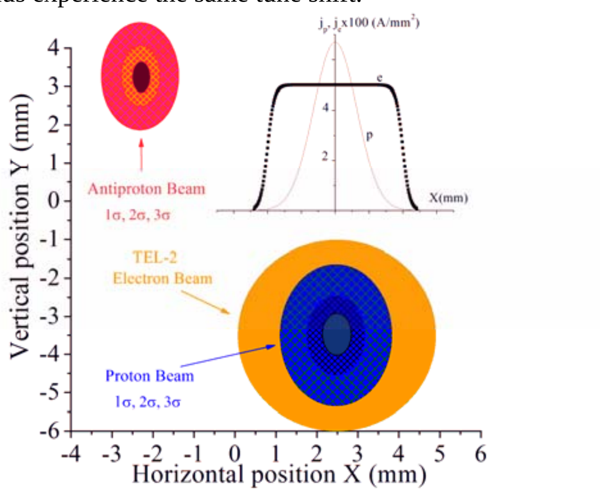

Figure 3: Transverse alignment of proton, antiproton and electron beams in TEL2 during proton BBC.

* Work supported by the U.S. Department of Energy under contract No. DE-AC02-07CH11359
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EXPERIMENTAL RESULTS

After a few end of store beam studies aimed at optimization of electron beam alignment on protons we moved on to the beginning of store studies since the beam-beam effects are much more pronounced at high beam intensities.

The 36 proton bunches in the Tevatron are arranged in 3 trains with abort gaps between them (same is true for antiproton bunches) [4]. The first and the last bunches in each train experience different long range interaction pattern as compared to all other bunches (in the middle of the trains). The last proton bunches in each train typically have the lowest vertical tune, while the first ones exhibit the lowest horizontal tune. Therefore, TEL2, being the vertical beam-beam compensation device, was set to affect the proton bunch #12 (P12).

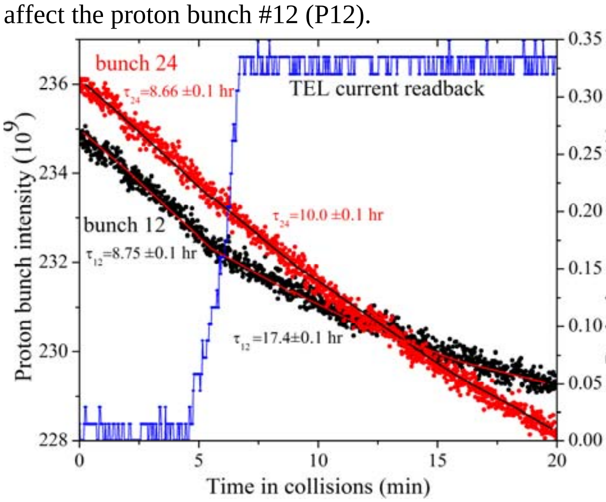

Figure 4: Effect of TEL2 on proton intensity decay.

As soon as TEL2 electron current was turned on a significant change of slope of P12 intensity decay was observed (see Fig. 4). This change corresponds to a lifetime improvement of about 100%. This result has been confirmed in several beam studies. Such an effect can be explained by a positive tune shift introduced by the TEL (tune shift of about 0.0014 at J_e^{pk}=0.6 A has been confirmed [3]) pushing the P12 tune away from the resonance. However, it is not yet clear whether it is the only mechanism responsible for the significant lifetime improvement.

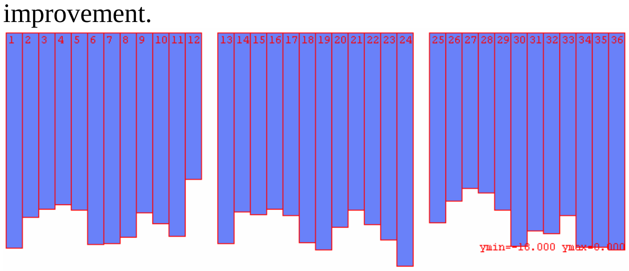

Figure 5: Decrease of bunch intensity as reported by T:SBDPIS for the first 1.5 hours of a store. TEL2 was acting on proton bunch #12, J_e^{pk} = 0.3 A. Scale: 0 – -18e9 protons.

Furthermore, another beam study with TEL2 at J_e^{pk} = 0.3 A on P12 showed that this bunch experienced the smallest decrease of intensity than any other proton bunch (see Fig. 5). The tune shift caused by such a moderate electron current is not sufficient for P12 to reach the average tune value. Nevertheless, P12 had the best lifetime among all proton bunches. This single result is not fully understood yet.

Another way to look at the same phenomena is to measure the effect of the TEL on proton loss rate. Both HEP experiments D0 and CDF routinely measure loss rates (halos) around their detectors on a bunch-by-bunch basis. Figure 6 shows the dependence of D0 proton loss rate on TEL1 electron current. In this experiment TEL1 was acting on P13 only. P14 was chosen as a reference bunch because its behavior in terms of halo and lifetime is very similar to P13. The loss rate of P13 dropped by about 35% once the electron current was turned on, while P14 rate stayed unaffected (TEL1 is not acting on P14). The P13 loss rate actually became smaller before the final e-current value (0.6 A peak, 19mA AVG) was reached. After about 12 min the e-current was turned off which made P13 loss rate return to the reference level.

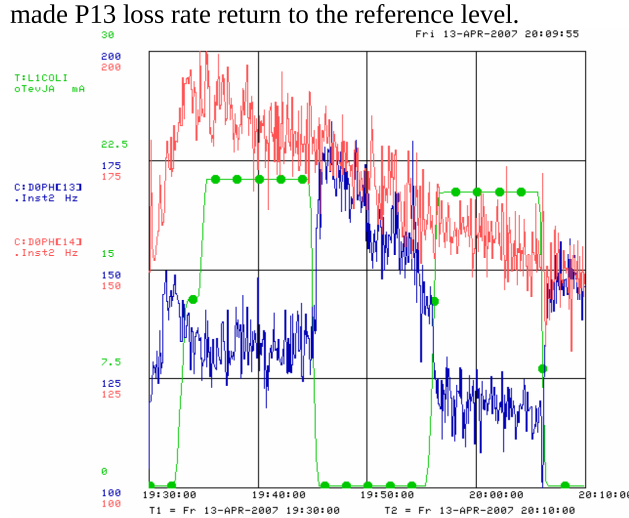

Figure 6: Dependence of proton loss rate of proton bunch #13 (C:D0PH[13]) and #14 (C:D0PH[13]) on TEL1 electron current (T:L1COLI).

This result has been confirmed in several beam studies.

LIFETRAC SIMULATION RESULTS

To simulate the effect of the TEL on dynamics of the proton beam we used the weak-strong code LIFETRAC [5] which has been extensively used to study beam-beam effects in the Tevatron [6]. This is a multi-particle simulation code where a single bunch of particles is tracked through a sequence of linear maps and points of beam-beam interaction reproducing the real pattern of collisions in the machine. The code makes full advantage of the current knowledge of the Tevatron optics by using the measured beta-functions and helical orbits in order to compute the transfer maps for tracking particles between the IPs and to calculate the beam-beam kick.

In the simulation, the TEL was represented by a thin kick generated by the electron beam with the transverse density distribution described by the formula

$$\rho(r) = \rho_0 \left(1 + (r / r_0)^8\right)^{-1}$$

Particle diffusion in the Tevatron is dominated by the intrabeam scattering which however may be enhanced significantly by the beam-beam effects, especially when the betatron tune is close to the strong 4/7th or 3/5th resonances. Still, the strength of the random noise can be used to set the time scale for tracking simulations. With the present computing capacity it is possible to track a bunch of 10,000 macro particles for up to 10^6 turns. With the real Tevatron revolution frequency this corresponds to roughly 2 minutes. By artificially increasing the IBS diffusion rate we are stretching this time to about 2 hours. Hence, calculating the number of particles lost from the beam during the time of simulation can be used to estimate the non-luminous beam lifetime. Although this method does not give a very accurate absolute result it is quite effective for relative comparison of various conditions.

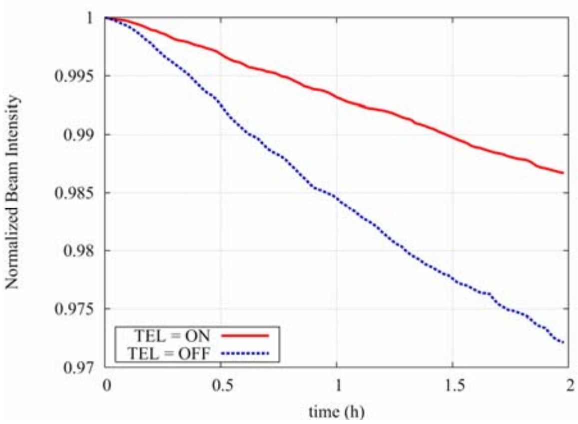

Figure 7: Normalized proton beam intensity, first two hours of an HEP store, simulated with LIFETRAC code.

This approach has been applied to the beam-beam compensation with the TELs. Fig. 7 shows the evolution of intensity of a single proton bunch with and without the TELs acting on it.

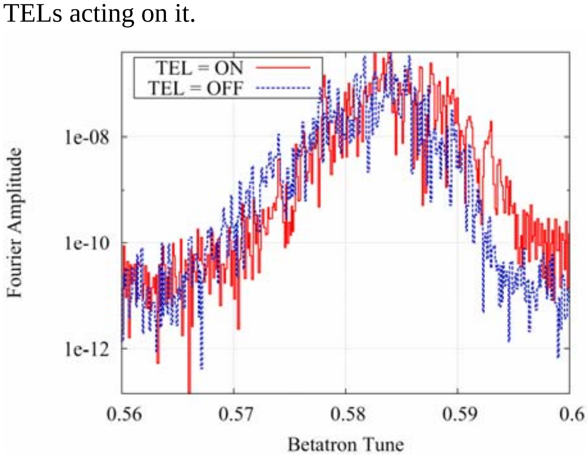

Figure 8: Proton horizontal Schottky spectrum computed with LIFETRAC code.

In Figures 8 and 9 the corresponding Shottky spectra are plotted. The TELs push the betatron tunes away from the 7th order resonance thus improving the beam lifetime.

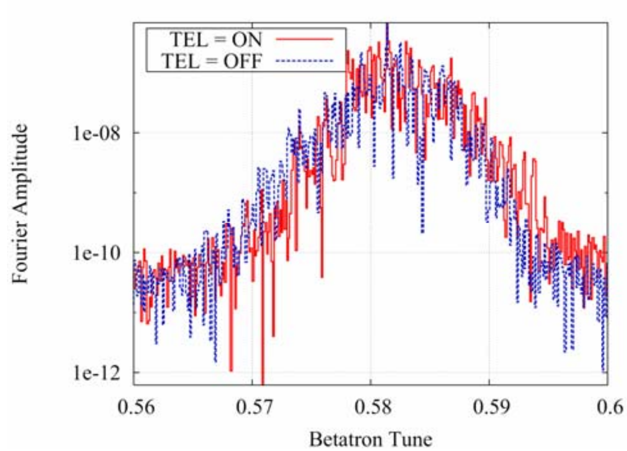

Figure 9: Proton vertical Schottky spectrum, computed with LIFETRAC code.

SUMMARY

The Tevatron Electron Lenses equipped with SEFT electron guns were operated in pulsed mode to perform single bunch beam-beam compensation. Significant lifetime improvement achieved in numerous beam studies is consistent with computer simulations carried out using weak-strong code Lifetrac. However a single result indicating that TEL2 made the lifetime of a bunch it was acting on better than the lifetime of any other proton bunch is not fully understood yet. BBC with dc electron beam using TEL2 has been performed as well. However it was not treated in this paper.

ACKNOWLEDGEMENTS

The authors would like to thank Brian Fellenz, Robert Hively, Gennady Kuznetsov, Marvin Olson, Howie Pfeffer, Greg Saewert, Vic Scarpine and Dan Wolff for their support.

REFERENCES

[1] V. Shiltsev et al, PRST-AB, 2, 071001 (1999).
[2] V. Shiltsev et al, Experimental Demonstration of Beam-Beam Compensation by Tevatron Electron Lenses and prospects for the LHC, these proceedings.
[3] V. Kamerdzhiev et al, Commissioning of the second Tevatron Electron Lens and beam study results, these proceedings.
[4] Run II Handbook.
[5] D. Shatilov et al, ``LIFETRAC Code for the Weak-Strong Simulation of the Beam-Beam Effect in the Tevatron'', PAC2005, Knoxville, Tennessee, 2005.
[6] A. Valishev et al, ``Computational Study of the Beam-Beam Effect in Tevatron using the LIFETRAC Code'', PAC2005, Knoxville, Tennessee, 2005.