COMMISSIONING OF THE SECOND TEVATRON ELECTRON LENS AND BEAM STUDY RESULTS*

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Abstract

In the framework of Fermilab's Beam-Beam Compensation (BBC) project, the 2nd Tevatron Electron Lens (TEL2) was installed in the Tevatron during Spring 2006 shutdown. It was successfully commissioned and a series of beam studies has been carried out in single bunch and all-bunch modes. The paper describes TEL2 commissioning and beam studies results.

INTRODUCTION

The BBC system at Fermilab is designed to mitigate head-on and long range beam-beam effects of Tevatron proton antiproton collider [1]. The first Tevatron Electron Lens (TEL1) was commissioned in 2001. In the TEL an electron beam with energy up to 10 keV is guided onto either proton or antiproton orbit in the Tevatron by solenoidal magnetic field. After interacting with high energy protons or antiprotons electrons are extracted to the collector. The TEL can generate dc or pulsed electron beam. The latter allows BBC on a bunch-by-bunch basis. TEL1 is installed at F48, where horizontal β-function is about three times the vertical one. It primarily generates horizontal tune shift. The tune shifts as well as antiproton emittance growth suppression have been demonstrated [2]. It was also used to remove unwanted particles from the beam abort gaps for reducing the risk of quenching the Tevatron and damaging the detectors in case of beam abort. Currently TEL1 is still required to be operated in abort gap cleaning mode during every HEP store.

It has been shown that two TELs are needed in order to be able to effectively compensate beam-beam effects in the Tevatron [3]. The second Tevatron Electron Lens was installed at A11 (see Fig.1) in order to generate vertical tune shifts.

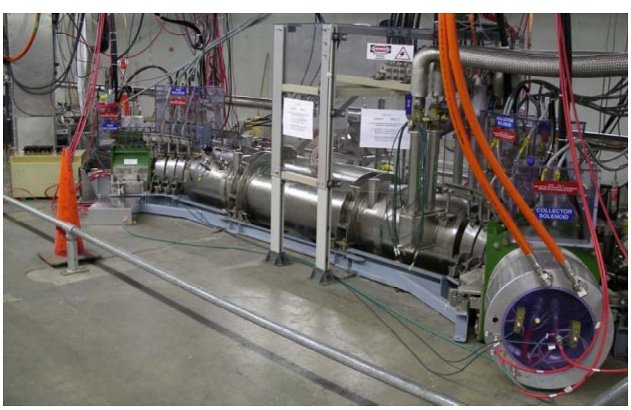

Figure 1: TEL2 installed in the Tevatron.

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TEL2 DESIGN

Magnetic System

The TEL2 magnetic system consists of eight conventional solenoids and a cryostat that houses the 65 kG superconducting (SC) main solenoid, four short 8 kG and two long 2 kG SC dipole correctors (see Fig.2). The cryostat is a part of the Tevatron magnet string cryogenic system. The warm magnets are the gun and collector solenoids and six additional short solenoids located in the 57°. As compared to TEL1, TEL2 magnetic system has been improved to provide a strong magnetic field in the transition region between the gun/collector solenoid and the main solenoid. By doing so, the electron drift is minimized, the magnetic field lines at both ends of the main solenoid are smoothed, and the electron beam size in the bending region is reduced. Therefore, the ratio of the gun solenoid field to the main solenoid field can be varied in a wider range leading to a greater adjustment flexibility of the electron beam size in the interaction region. The electrons generated by the electron gun pass through the interaction region where they share the trajectory with high energy (anti)protons, and are then extracted to a water cooled collector. The four short SC dipole correctors at both ends of the main solenoid and two long SC correctors in the middle allow precise steering in position and angle of the electron beam onto the beam circulating in the Tevatron.

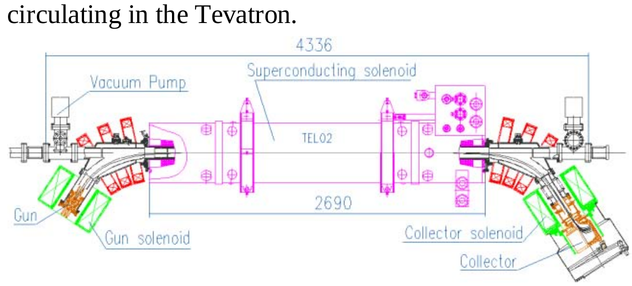

Figure 2: TEL2 layout.

Decreasing the electron bending angle in combination with additional solenoids greatly improved the electron beam transmission in the bends. Another improvement of the magnet design is the center tap in the superconducting coils. These center taps help to improve the precision and stability of the quench protection system and detect quenches faster.

Vacuum system

The TEL2 vacuum components were certified according to standard Tevatron vacuum requirements including cleaning and vacuum baking. An in-vacuum heater has been installed to achieve the necessary in-situ

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baking temperature after the assembly and installation. Three 75 l/s ion pumps and a TSP are installed to maintain the ultra high vacuum in the system. The pressure is in the range of $8{\cdot}10^{-10}$ – $3{\cdot}10^{-9}$ Torr during normal operation. The vacuum valves at both ends ensure that the system can be separated from the Tevatron vacuum to perform maintenance if needed.

Electron Gun

TEL2 is equipped with a newly designed electron gun (see Fig.3) with a smooth-edge-flat-top (SEFT) transverse current density distribution [4].

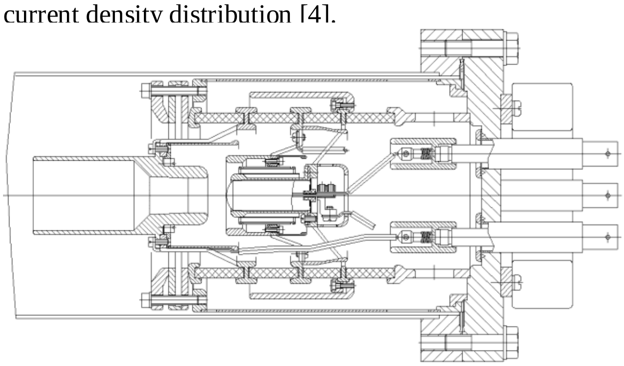

Figure 3: SEFT electron gun.

The electron gun utilizes a dispenser cathode with convex spherical radius. The gun is assembled on a 6 ¾ CF flange and is designed to generate up to 4 A of electron current at cathode voltage of up to 10kV. A dispenser cathode can be reactivated after it has been exposed to air. This allows for extensive testing of electron guns on a test bench and subsequent installation into the TEL. The nominal operating temperature of the cathode is about 1000°C.

Instrumentation

Electron beam needs to be precisely aligned to proton or antiproton beams. Two beam position monitors (BPMs) and a short L-shaped pickup electrode are installed in TEL2. In addition several isolated tube-shaped electrodes are available in the bending sections. They can be used to diagnose electron beam losses or for trapping ions or electrons if connected to a source of dc voltage. The BPMs are capable of delivering position and angle information for all three particle species [5]. The BPM signals are acquired by means of a digital scope which is read out by a LabView program running on a PC. The program performs Gaussian and spline fits to the data in time domain to reduce signal noise.

COMMISSIONING

All the components of the magnetic system had been assembled first at E4R test facility. The cool down of the main solenoid to 4.5K took about 16 hrs. It had been run up to 6.5 Tesla design value without quench and special training. Various types of magnetic field measurements have been performed. All the magnets passed the tests.

After the magnetic field measurements were completed we proceeded with the assembly of vacuum components. The TEL2 vacuum system has been vacuum baked by means of external and in-vacuum heaters in order to achieve design vacuum parameters. Once vacuum performance has been demonstrated the electron gun was installed into TEL2 under nitrogen purge without further baking. First electron current in TEL2 was demonstrated on December 19, 2005 at the E4R test facility. Several hours of collector conditioning were required to get back to nominal vacuum with electron beam on. The conditioning was performed by slowly increasing the average electron current, which caused outgasing on the collector surface being hit by electrons, while keeping the pressure in the vacuum chamber lower than $5{\cdot}10^{-7}$ Torr..

During the Spring 2006 shutdown TEL2 was installed in the Tevatron at A11. After the installation we vacuum baked the whole system again and spent several hours conditioning the collector. The electron gun underwent conditioning as well. The conditioning of the gun was performed with additional resistors put in series with HV power supplies to limit discharge currents. First discharges have been observed at 7kV. However after two hours of conditioning we were able to increase the voltage to 13kV and keep it without sparking for 1.5 hrs with cold cathode and the gun solenoid field of 3.8 kG.

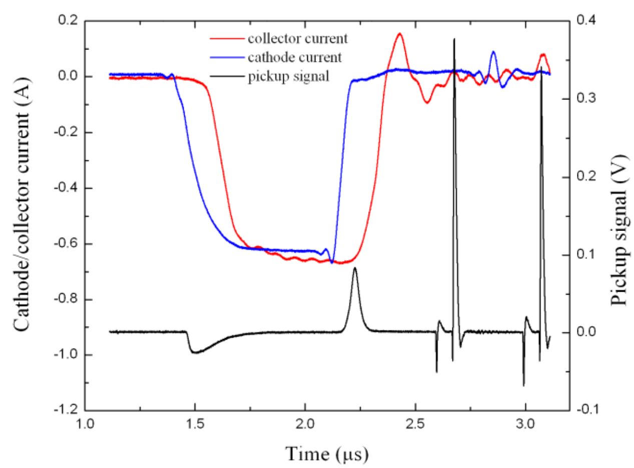

Figure 4: Cathode (blue) and collector (red) currents measured by current transformers. The artifacts on the right hand side are caused by the instrumentation. Pickup signal (black) featuring the electron pulse, two proton and two antiproton bunches. For clarity the electron pulse is shown timed to the abort gap where no bunches are present. The scope bandwidth was intentionally set to 20MHz to reject high frequency noise and limit bunch signal amplitude.

To generate high voltage pulses needed to drive the anode of the electron gun (see Fig. 3,4) a solid state Marx generator built by Stangenes Industries Inc. is used [6]. The generator failed twice due to exposure to radiation in the Tevatron tunnel which led to activation of internal components. After a few days of cool off period the residual radioactivity dropped to background level and the device became operational again. In order to prevent such failures radiation shielding made of steel was installed in the tunnel to protect the generator mainly from high energy neutrons coming from the beam dump. In addition, hardware modifications have been made which allow the accelerator control system to remove input voltage and shut down the generator prior to the beam abort (termination of the HEP store). No failures occurred for the last 6 months of operation.

During our first beam studies with TEL2 in pulsed mode we observed a significant lifetime degradation of the proton bunch that was interacting with the electron pulse. It was found to be caused by a significant timing jitter (>10 ns) of the electron pulse which translates into electron current variation if the electron pulse does not have a perfect flat top. By replacing a function generator and a delay card we managed to reduce the jitter to less than 1ns and resolve the proton lifetime issue.

BEAM STUDY RESULTS

The absolute majority of the beam studies were carried out in “parasitic” mode meaning that both experiments continued to take data. However there were a few dedicated studies.

An interesting observation was made when the Marx generator was malfunctioning. It actually allowed us to study the effect of variation of peak electron current on the proton emittance growth rate (see Fig. 5). Due to irradiation of solid state switches (before the shielding was installed) the Marx generator output was very noisy. It is reasonable to assume that the electron current variation was close to white noise.

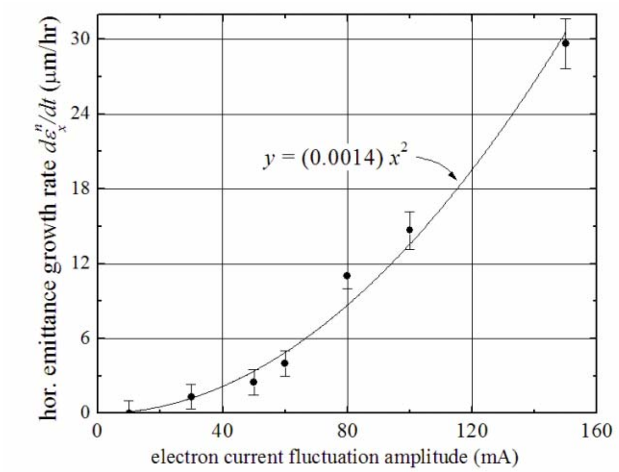

Figure 5: Proton emittance growth rate versus electron current fluctuation amplitude.

To experimentally confirm the expected tune shifts the 1.7GHz Schottky pickup was used. The measurement was performed in single bunch mode, so TEL2 was set to shift the tune of a single proton bunch and the Schottky detector was gated to the same bunch (see Fig. 6). The measurement agrees with theoretical prediction very well.

More experimental results, including demonstration of proton lifetime improvement of 100% in the beginning of an HEP store are presented in [4,8].

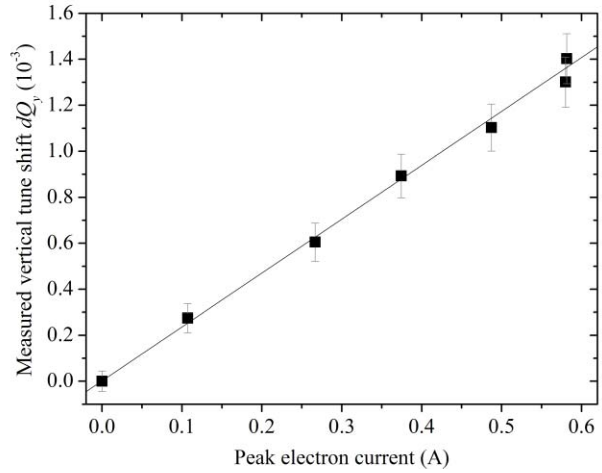

Figure 6: Dependence of proton vertical tune shift, measured with 1.7GHz Schottky detector, on TEL2 peak electron current.

SUMMARY

The second Tevatron Electon Lens has been successfully commissioned and is being used for single bunch and all bunch (dc electron current) beam-beam compensation studies. Equipped with the solid state Marx generator TEL2 is capable of introducing tune shifts of up to 0.002 to any single bunch in the Tevatron. TEL2 operating at 0.3-0.6A of peak electron current has been shown to significantly improve lifetime of a proton bunch it was acting on. Two alternative HV pulse generators are being built and are expected to be available for installation during the summer/fall 2007 shutdown. They will add multi-bunch compensation capability to the TELs.

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