UPGRADES OF THE TEVATRON ELECTRON LENS

X.Zhang, J.Crisp, J.Fitzgerald, G.Kuznetsov, M.Olson, H.Pfeffer, G.Saewert, A.Semenov, V.Shiltsev, N.Solyak, D.Wildman, FNAL, Batavia, IL 60510, USA
K.Bishofberger, UCLA, Los Angeles, CA 90095-1547
E.Kashtanov, S.Kozub, L.Tkachenko, V.Sytnik, IHEP, Protovino, Russia
M.Tiunov, BINP, Novosibirsk, Russia

Abstract

This paper will describe the main upgrades of the Tevatron Electron Lens (TEL) during the year 2003. The bending angle of the electron beam entrance and exit to the main solenoid will be decreased from 90 degrees to 53 degrees and three more solenoids will be added to each of the two bends, which will allow us to control the electron beam size more freely. A new gun will also be installed which will give us a Gaussian transverse beam distribution in addition to the flat beam with much smoother edge to minimize the nonlinear effect of the beam-beam force. In addition, a new BPM system will be installed to let us have more precise beam position measurements for proton, antiproton and electron beams. A knife-edge beam profile measurement system will replace the space-consuming scanning wires. We expect that these upgrages will improve the ability to increase the lifetime of the (anti)proton beam during beam-beam compensation operation.[1]

ELECTRON GUN UPGRADE

The structure of the old electron gun is shown below. It has a cathode, an anode, and an additional control electrode to change the transverse electron beam

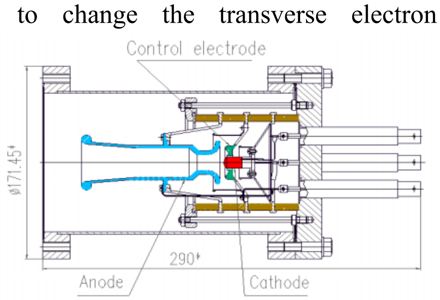

Figure 1: Electron gun structure

distribution. It was designed to provide several amps of beam current with a rectangularly uniform distribution of

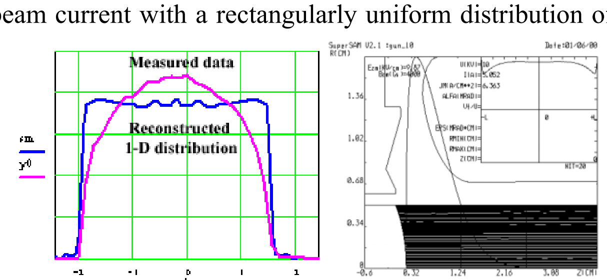

Figure 2: The measured electron distribution (left) and the designing of (right) for the old gun

electron beam and a measured perveance of about 5.8 μP. The measured value is 6.0. The perveance of an electron gun relates the beam current to the applied anode voltage, and is defined as the following:

$$I(A) = PV^{\frac{3}{2}}$$

Where the I is the electron beam current and the V is the voltage between the anode and the cathode of the electron gun. The P is the perveance, typically in units of micro-perveance (μP).

Figure 2 shows the wire scan of the beam transverse distribution, which is the magenta curve. The blue curve is the reconstructed beam transverse profile. Inaccuracies in the measurements are the likely cause of the three central bumps. Since this gun has a sharp edge, which produces a large nonlinear force, the beam acts as a soft collimator and causes the high loss and shorter lifetime for the proton beam. It provided a smaller tune region that obtained good proton beam lifetime. The maximum lifetime achieved was only 70hrs. [2]

To resolve this problem, a new gun was built and

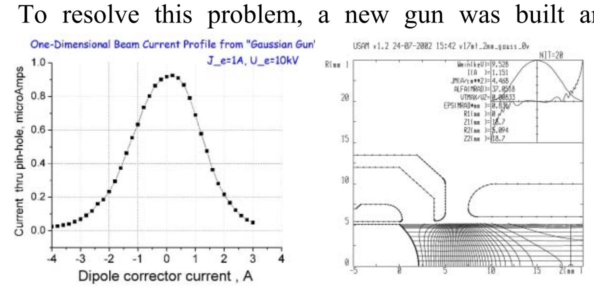

Figure 3: The measurement (left) and the designing of the new Gaussian gun

installed. The distribution-control electrode was changed as in Figure 3. The electron beam profile can be changed from Gaussian to uniform by adjusting the voltage on this electrode. For typical use as a Gaussian beam, the perveance was designed to be 1.2 μP. The reason for the lower perveance is due to the fact that the distribution-control electrode effectively suppresses current from the beam edge. The measured perveance was 1.8 μP in pulsed mode and 1.3 μP in DC mode. The reason for this difference is currently being explored.

The tune scans for the Gaussian gun showed that it provided a larger area with low proton losses. The maximum lifetime of the proton beam was 160hrs for same tuneshift as the flat-distribution gun, which is a significant improvement[2].

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ELECTRON BEAM BENDS

The bending angle of the electron beam is 90 degrees for the present layout of the TEL[1]. The electron beam path through the bends and the final beam size are both determined by the ratio between gun solenoid and the main solenoid; therefore, the field combinations of gun/collector solenoid and the main solenoid for electron beam to pass without scraping the walls are limited. Also, there is not much freedom to vary electron beam sizes to adapt to the larger-than-designed (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.

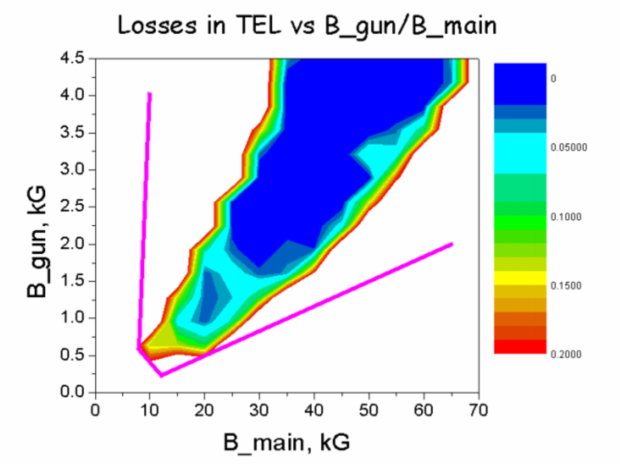

Figure 4: Electron losses in the path

Figure 4 shows the measured transmission rate for above configuration. In this measurement, the average electron beam current was 0.2mA. So the color code of 0.2 represents the electron beam was totally lost in the path.

Decreasing of the electron bending angle (see Figure 5) with additional solenoids in the bending path expect to at east double the transmission region of Figure 4 between the magenta lines. The magnetic field simulations show that this will allow 60% larger e-beam size variation than present system. Figure 5 shows the future layout of the TEL with 53 degrees of bending angle. The new support with additional solenoids in the bending section (three for gun side and three for collector side) is already built and tested. These solenoids will be used to strengthen the magnetic field in the bends to keep the electron size smaller and the beam path more controlled.

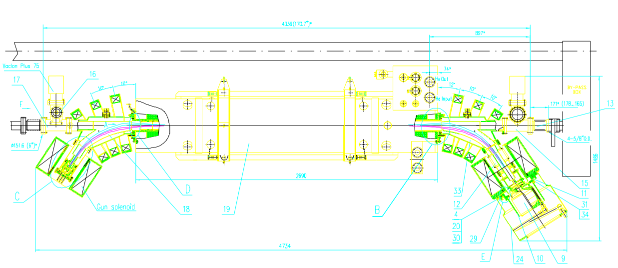

Figure 5: New layout of the TEL

The results of the magnetic measurements are shown in Figure 6. The three red rectangular represent the solenoids in the gun bend and the green box represents the aperture limit for the electron beam. The blue line is the designed trajectory and the magenta line shows the electron beam trajectory deduced from the magnetic field measurement. The maximum difference is about 1cm at the exit of the last solenoid, which can easily be compensated by adjustments in various solenoid currents and correctors.

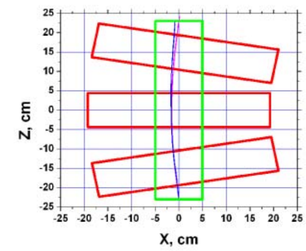

Figure 6: The path of the electron beam in the bends: designed (magenta) and measured (blue)

BPM UPGRADE

The BPM pickups installed in TEL are a diagonally cut cylinder type shown in Figure 7. This kind of BPM gives good linear measurements of positions. For TEL operation, we want to measure electron beam position relative to proton or pbar beam positions very precisely. However, offsets arise from the different BPM impedances for electron beam and proton beam signals, since for proton-like signal the main frequency component is about 53MHz while for electron beam the main frequency component is less than 2MHz. The cross-talking between different electrodes can also contribute to the offset.[3] The maximum measured offset with a fixed position wire for main signal frequency from 50MHz to 10MHz is over 1mm as shown in Figure 7.

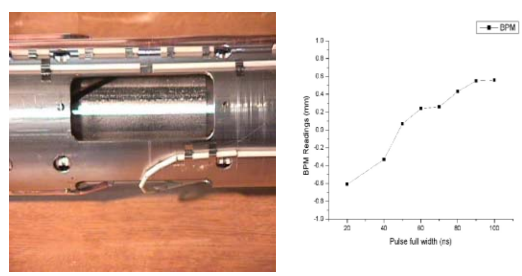

Figure 7: The diagonally cut TEL BPM system

A new BPM system with four plates has been designed and is under testing (see Figure 8 left). It's compact and has built-in electromagnetic shields between neighboring plates to minimize crosstalk. The measured response versus the signal frequency for this BPM is shown in Figure 8. This BPM has a maximum offset of only 0.065mm, compared to 1mm for the old BPM.

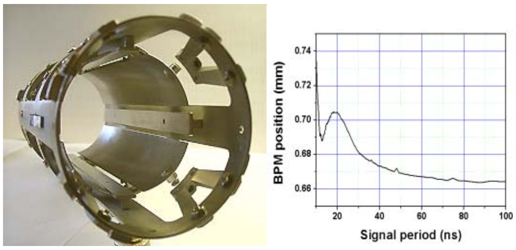

Figure 8: The prototype of new TEL BPM

MODULATOR UPGRADE

A pulse modulator is used to apply the short high-voltage pulse to the anode in order to produce the necessary pulsed current for beam-beam compensation. To obtain a tune shift of 0.01, we need a peak current of 2A from the uniform-profile electron gun[1]. The traces in Figure 9 show the electron pulse shape seen at the cathode, collector, and a BPM plate. On the left graph, the blue trace is the cathode current, cyan trace is the collector current, and the magenta is the BPM signal. The BPM signal shows the spikes of proton bunch signals and an additional 30MHz ripples caused by the circuit resonance of the modulator.

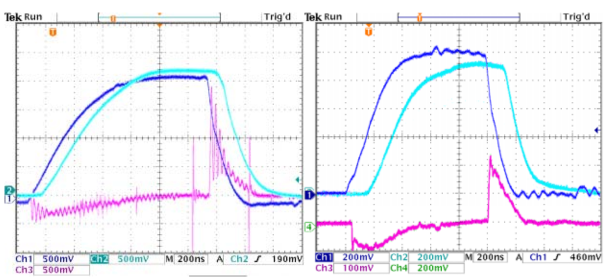

Figure 9: Electron beam pulse shape

The 30MHz problem was solved by changing the inductor and resistor in the modulator circuit. In addition, we also improved the pulse rise time by the adjusting the modulator circuits. The graph on the right shows the traces after this upgrade: the blue and magenta were the cathode and collector current signals; the cyan and green were BPM intensity and position signals respectively. We can see that the rise time is shorter and the 30MHz ripple is gone.

Another problem was the pulse-to-pulse current fluctuations at 15Hz, 60Hz and 120Hz, which were caused by the ripple from the power line feeding into the RF tube in the modulator. Changing the modulator's filament power supply to DC and adding 60Hz and 120Hz RF compensation to the screen and grid power supplies greatly minimized the ripple. Figure 10 shows the 120Hz ripple before and after compensation. With all these efforts, the electron beam pulse-to-pulse stability now is better than 0.1%. We also decreased the timing jitter for electron pulse to less than 1ns.

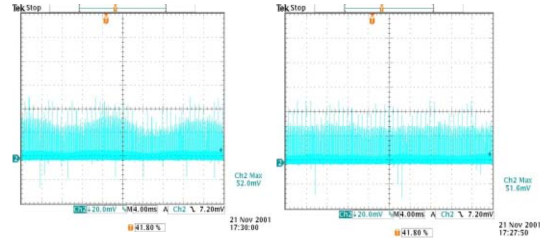

Figure 10: The 120Hz ripple before (left) and after adding the compensation (right)

The present modulator can only output about 7kV pulse, which can only produce 600mA peak electron current from the new Gaussian gun. This current is not enough for beam-beam compensation. In addition, the modulator produces an undesired trailing pulse, shown as in Figure 11, which excites proton bunches during Tevatron abort gap cleaning operation[4]. Therefore, we have to set offset voltage of about -500V in order to eliminate this trailing pulse, which further decreases the available voltage to produce electron current. A new modulator is needed to provide 14kV pulses and not have any trailing pulses.

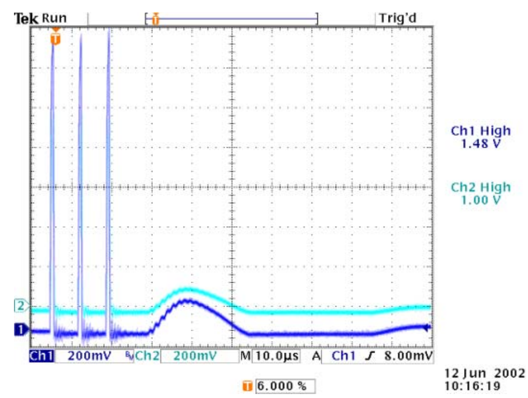

Figure 11: The trailing pulse in 3-pulse of every 7 beam revolution for Tevatron DC beam cleaning operation.

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