BEAM DIAGNOSTICS FOR TEVATRON ELECTRON LENS

X.Zhang, J.Fitzgerald, G.Kuznetsov ,M.Olson, V.Shiltsev, N.Solyak, FNAL, Batavia, IL 60510
A.Sleptsov, BINP, Protvino, 142284, Russia

Abstract

In the frame of the beam-beam compensation project at Fermilab, the first Tevatron Electron Lens (TEL) has been built, commissioned and installed in the Tevatron. Successful operation of the TEL has been recently demonstrated [1]. This paper presents overview of the electron and proton (antiproton) beam diagnostics, which allow us to measure beams intensity, waveform, losses, position, timing and beam profiles. Shortly described other proton (antiproton) diagnostics, available from the Tevatron control system, which are used for tuning beam parameters in TEL (tune-shift, orbit, emittances, lifetime measurements, etc). We present the results of calibration and measurements of the beam parameters.

1 BEAM POSITION MONITORING

We have installed two pairs of pickup electrodes in our TEL system near both ends of the main solenoid, that enables us to measure horizontal and vertical positions of electron, proton and antiproton beams entering and exiting the TEL. Each pick-up electrode pair is made of a SS cylinder with a diameter of 70mm and cut diagonally in half. We have two sets of the BPM electronics for electron and for proton/antiproton beams.

1.1 (Anti)proton BPM system

The proton BPM system[2] is composed of a LabVIEW application program operating on a Macintosh computer utilizing a Tektronix TDS520 digital oscilloscope for data acquisition as in Fig 1.

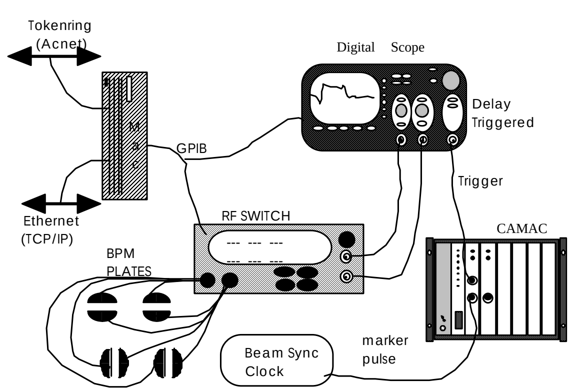

Fig.1: Proton BPM configuration.

The four position detectors are sequentially connected to the oscilloscope's inputs through the Keithley RF Multiplexer. The computer communicates with the oscilloscope and the multiplexer through a GPIB interface and links with ARCnet through Ethernet. A Beam Synchronous pulse generated by a Camac 279 module triggers the scope's main sweep. The oscilloscope must be operated in the delay trigger mode to obtain the finer timing resolution required to capture the 20 ns bunch signal. The delay must be adjusted properly for each position detector to compensate for differences in cable lengths and beam flight times. The default delays for the oscilloscope trigger is automatically set from a look-up table depending upon selected bunch and BPM detector, which have been empirically determined to trigger the oscilloscope about 10 ns before the bunch arrives.

When the beam traverses the detector, it generates a doublet current signal as the one illustrated in Fig.2 on each plate of the same detector. Then both signals are digitized to 500 points by the oscilloscope and transferred to computer through the GPIB interface. The vertical scale of the oscilloscope can also be changed to improve the performance according to the bunch intensity.

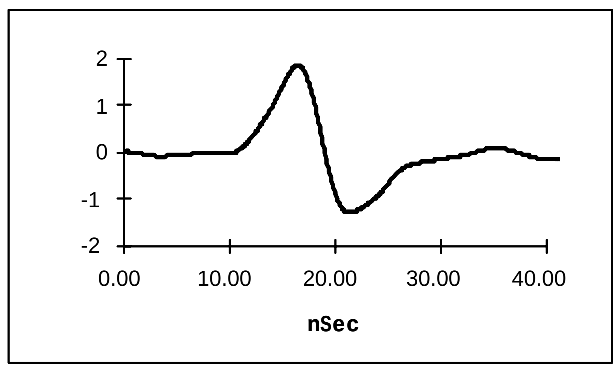

Fig.2: Typical BPM doublet signal

To calculate the beam position, first the digitized signal is passed through a software 5-90 MHz Band Pass Filter to optimize the signal to noise ratio. Then the most positive and most negative points of the trace are found and the points between them are fit to a cubic polynomial. The zero crossing of the polynomial is found and the signal is rectified by multiplying all points after the zero crossing with -1. The advantage of above procedure over a simple addition is that the offset, noise, ringing, or satellite bunch signals outside the central bunch greatly minimized. The signal strength of the two plates is then determined by digitally integrating the rectified signals respectively. Finally, a difference over sum calculation is performed to obtain a position reading. The above process repeats until all four proton and all four antiproton beam positions have been obtained.

This BPM is not only capable for proton and antiproton beams, but also works for electron beams. Practically, we calibrate the BPM readings by moving the electron beam transversely by changing steering coil currents. Fig.3 shows the measurement of the linearity of one pair of

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electrodes made with the electron beam. One can see that the BPM system is extremely linear in the range of ±6 mm around centerline (the beam pipe diamter is 70 mm). By this way, we can also get the calibrated geometry factor of the BPM system.

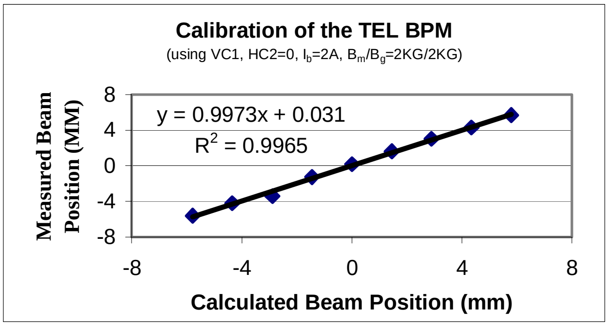

Fig.3: The linearity measurement of the BPM.

A beam resolution of about 30 µm was achieved at Single Sweep Averaging mode with 16 averages, 2 A peak current of 800 ns electron pulse, delayed trigger mode with full scope band width. But for a single proton bunch with the intensity of 9.4×10^{10}, the measured resolution is about 0.1 mm. The ringing that caused by the imperfectly matched connections is mainly responsible for this. Recent improvement of the vacuum connector led to substantial reduction of the ringing. We expect to get a much better resolution of the (anti)proton bunch position.

1.2 Electron BPM system

The TEL BPM system uses common pickups for the electron, proton and anti-proton beams. A RF switch is used to switch the signals between two electronic systems, one for the electron beam BPM and one for proton and anti-proton beam BPM which is described in above section.

There are four sets of identical electronics for electron beam BPM system. Each is for one of the four pairs of BPM detectors. Fig. 4 shows the schematic drawing of one set of electronics.

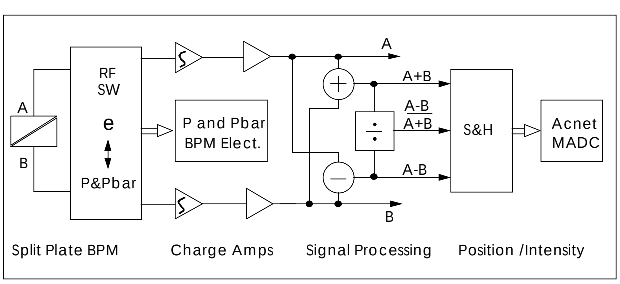

Fig.4: Diagram of electron BPM

The pulsed electron beam produces a bipolar current charge output. When the RF switch is set to electron beam BPM, this current signal is converted to a voltage output at the charge amps. Then the voltage signals are further processed to give Difference, Sum and Difference over Sum for indicating position and intensity. The BPM and electronics has a gain of approximately 0.2 dB/mm, and resolution to 0.05 mm. Fig. 5 is the typical electron beam signal from the upper stream horizontal BPM.

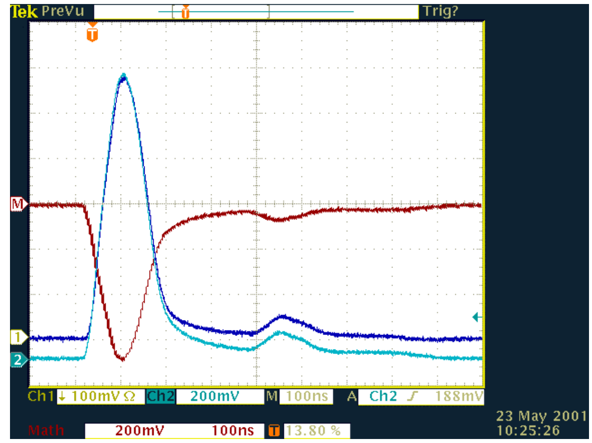

Fig.5: The signal from electron beam BPM system *(The two blue traces are the signals from different plate of the same pair of pickup electrodes; the red trace is the difference signal of them.)*

The further commissioning and upgrade is underway for the electron beam BPM systems. One improvement under research is try to increase the system bandwidth to allow it to be able to measure the proton beam positions.

2 ELECTRON BEAM PROFILE

Beam profile is important characteristic of the electron lens. For linear beam-beam compensation the electron beam should have profile with the uniform charge distribution. Non-linear beam-beam compensation (possible further development of this project) will require electron beam with other charge distribution closer to the Gaussian distribution.

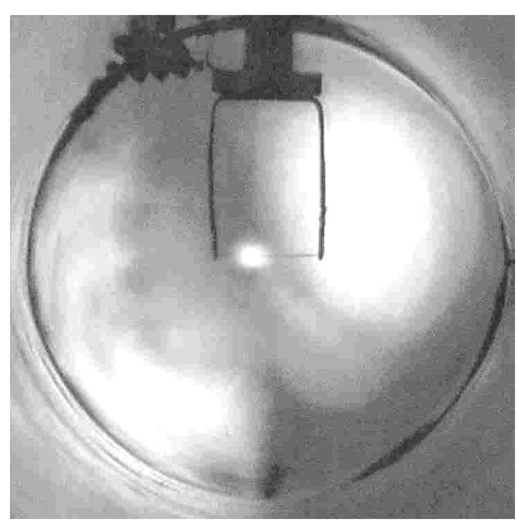

Fig.6: Shining electron beam on the scanning wire.

For the electron beam profile measurement, two wire scanner are installed in the TEL close to the middle plane of the main solenoid. One is for horizontal plane and the other is for vertical plane. Wires can be moved in or out of the beam pipe by remotely controlled step motor. In normal operation with the proton beam they are moved completely out of the beam orbit in order not to disturb the proton beam or/and not to burn out the wire. The geometry of the wire is shaped like a "fork". The distance between the fork claws is 15mm, from the wire to top edge 22mm, wire diameter 100μm, the tube diameter 70mm. Fig.6 shows that the vertical wire is on and ready for measure the electron beam profile. By the way, the dimensions give us a good scale for calibration of steering strength of correctors for the electron beam and in turn, to calibrate the pick-up BPM systems.

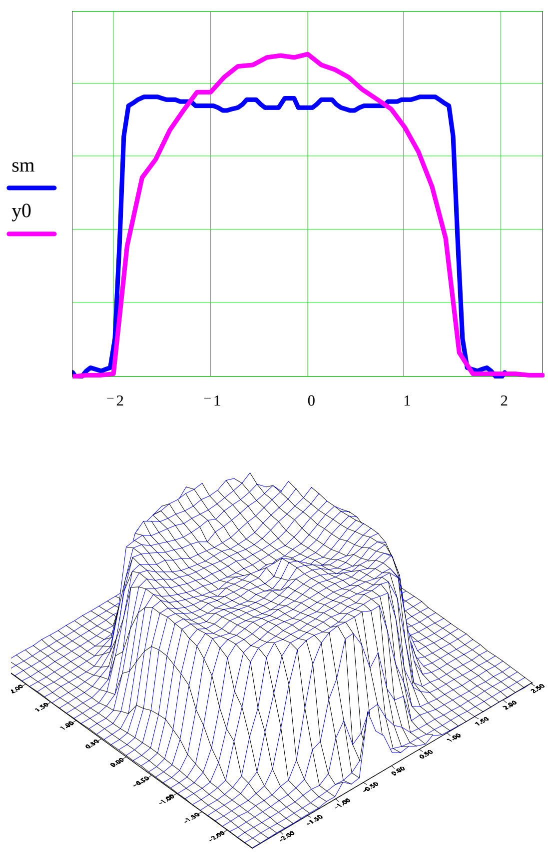

Fig.7: 1-D and 2-D beam profiles (magenta-signal from the wire, blue-restored beam profile). I_{peak}=2A.

Changing the electron beam position by upstream vertical or horizontal SC dipole correctors one can scan the beam on the wire. Signal from wire gives sliced X (or Y) beam profile (pink curve of Fig. 7), and then the radial beam profile can be restored. This restored beam profile has small hogging in center, but taking into account about 6% difference in velocities between beam center and edge due to electron space charge, the charge density profile, which affects to tune shift, is more flat.

Measured (X-slices) and restored beam profiles are shown on Fig. 7 (top). The beam diameter is about 3.5 mm. Restored profile is in a good agreement with the two dimension electron current profile (bottom), previously measured by special beam profile-meter on the TEL prototype. That profile-meter measured a small portion of the beam current, that goes through tiny hole in electron collector [3]. By scanning the electron beam in XY plane we can measure the 2-D electron current profile.

3 (ANTI)PROTON DIAGNOSTICS

Besides the BPM system of the TEL, we also use the beam diagnostics of the Tevatron to monitor proton and antiproton parameter, which include intensity, emittance, orbit, lifetime and tune[4]. The Tevatron orbit measurement system has a resolution of 150 micrometer. The tunes are measured by the Shottky spectra analyser. A new bunch-by-bunch tune meter[5] is under commissioning. Its resolution needs to be improved to be better than 0.001. The beam emittances are measured by the flying wire systems[6]. We found that the flying wire system gives large errors, e.g., about 14% in horizontal proton emittance. We expect that recently installed synchrotron light monitor will perform better and will allow us to monitor the proton or antiproton emittance variations during the beam-beam compensation studies[7]. The beam lifetime is monitored by the Fast Beam Integrator (FBI), which relies on the wall current monitor[4]. We will also be able to monitor the luminosity and the proton losses bunch-by-bunch, which is supplied by the D0 and CDF detector via ARCnet. And we also can 'tickle' the proton or antiproton beam orbit by modulating the electron beam current[1]. That method provides us the information for precise centering of the electron beam onto the proton (or antiproton) beam.

4 CONCLUSION

The beam diagnostic systems for the TEL electron lens played a crucial role in commissioning. We were able to measure the electron beam parameters and have successfully steered the electron beam to pass through the whole system with negligible loss. Unfortunately, the proton BPMs did not give us reliable information on the proton position, and we performed the electron beam steering on base of the proton beam tuneshift and tlifetime. We plan to put more efforts into further improvements on the beam diagnostics in order to secure the successful operation of the TEL in future.

5 REFERENCE

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