Tevatron Antiproton Injection Kicker Waveform Analysis

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1. Introduction

This note describes the measurements of the waveform of the Tevatron antiproton injection kicker using the 150 GeV proton beam.

This new horizontal kicker was installed at D48 during the summer of 1995 shutdown. These measurements were taken in two sessions [1] starting on Oct 10 and Oct 18, 1995.

The measurements use the Tevatron BPM and flying wire systems.

This note is a companion to the Tevatron proton injection kicker note published recently [2].

The design specifications for the kicker are given in Dinkel et al., [3].

2.1 Overall Waveform

Figure 1 shows the overall waveform. Note that we follow the convention of EXP 191 in which it is stated: "Because the kicker is being delayed, and the beam is always arriving at the same time, the rising edge of the kicker is actually on the right side of the plot, and the end of the flattop is on the left."

For this measurement, the horizontal BPMs at D48 and D49 were used to record the net deflection of the beam at the injection lambertson at D49. The timing of the kicker was changed by using T:TD48KE and M:D48DLY.

The figure shows the overall characteristics of the waveform: rise time less than 375 nsec, flattop of greater than 1205 nsec, and fall time of about 1000 nsec. The observed size of the kick is 15.7

• D48-D49 Pos #1 (Measurement # 1)

× D48-D49 Pos #2 (Measurement # 2)

D48 Kicker Measurements

Figure 1: Overall D48 Kicker waveform. Arrows indicate location of beam bunches; the 4 on top are antiprotons and the two on the left are circulating protons. Two separate measurements were taken for each time. Note the -2.9 mm offset on the position is due to the closed orbit.

mm at 55 kV which corresponds to a field of 1.005 kGauss. The design field is 1.053 kGauss.(As an aside, the deflection at D49 is only 15.7 mm due to the small phase advance between D48 and D49 of 12.8 degrees; the corresponding deflection in the arcs at beta = 100 meters and 90 degrees of phase advance would be 68 mm.)

2.2 Rising Edge

Figure 2 shows the rising edge in more detail. As in Figure 1, the D48 and D49 BPMs are used to measure the deflection. Here it is shown that the deflection rises from zero to 15.7 mm in 360 nsec.

Figure 2: D48 kicker risetime. The arrows indicate the location of the bunches and the labels their relative timing. Note the -2.9 mm offset on the position is due to the closed orbit.

2.3 Flattop

Figure 3 shows the flattop with a duration of 1.37 microseconds. The least bit resolution of about 0.16 mm of the BPMs is apparent, but nevertheless, the overall flattop covers a range of 15.49 mm to 15.81 mm.

The four arrows indicate where one arrangement of the four antiprotons could be injected. Here, the first antiproton (on the right side of the plot) would be injected on the leading edge of the kicker. In this case the four antiprotons would receive kicks in the range

- D48-D49 Pos #1
- × D48-D49 Pos #2

Figure 3: D48 kicker flattop. Arrows indicate location of the antiproton bunches, and the labels their relative timing. Note the -2.9 mm offset on the position is due to the closed orbit.

15.49 to 15.81 mm. This represents a flatness of $\pm 0.4\%$. The specification is $\pm 0.5\%$.

Note that the first antiproton is injected near the leading edge of the waveform which is changing at about 0.9 mm per 18.83 nanoseconds. If the bunch was slightly displaced in time (while the field is still changing) the leading edge of a 18 nsec long bunch would receive slightly less kick than the rest of the bunch (less than 1 mm).

The slight slope on the flattop is due to dispersion in the PFL cables. The design report calculations indicate a voltage droop of 1.1%. From Figure 3 we measure that the field is changing by about 1.5% from beginning to end.

2.4 Trailing Edge

Figures 4a to 4c show the trailing edge. In each figure a baseline measurement is indicated at the far left of the plot which corresponds to no kick.

Figure 4a. RMS deflection due to falling edge. The arrows indicate the locations of two proton bunches.

Figure 4a shows the rms from the flash BPM data of the turn after an ideal kicker would have settled to zero. These data show the unwanted deflection of proton bunches from the real kicker. The location of the first two proton bunches in 36 bunch operation are

indicated by the arrows, and their rms deflections are 0.18 mm and 0.60 mm.

Figure 4b shows the emittance growth due to the trailing edge of the kicker. Here the emittance growth measured from the horizontal turn by turn (TBT) is compared to the emittance measured by the horizontal flying wires (FW). These data show that the growth is shared in a ratio of about 4 to 1 for the first circulating proton bunch (horizontal to vertical) and 1 to 1 for the second bunch. The authors note, but do not venture to explain, why the wires show a growth about a factor of two larger than the TBT analysis.

Figure 4b. Trailing Edge Data. Horizontal emittance growth measured by the TBT uses the left hand axis while the vertical emittance from the FW's uses the right hand axis. The vertical arrows indicate the positions of two of the circulating protons.

Figure 4c compares the horizontal and vertical flying wire emittance measurements.

• Vert FW After

× Hor FW After

D48 Trailing Edge Data

Figure 4c. Comparison of horizontal and vertical emittance growth. The arrows indicate the positions of the first and second proton bunches.

3. Conclusions

1. The kicker rise time is within design specifications. The specification is 376 microseconds and the measured value is 336 microseconds.
2. The kicker flattop is within design specifications. The kicker is flat to $\pm 2.9\%$ overall, which is not acceptable. However, if the first of the four antiprotons is timed to be injected at the top of the rising

edge of the kicker, the four antiprotons receive the same kick to $\pm 0.4\%$. The specification is $\pm 0.5\%$.

3. The kicker fall time is within design specifications. The two proton bunches which enter the kicker during its fall time will receive kicks of 0.79% and 0.28% of full field. The specification is $\pm 1\%$ of full field. The measured emittance growth for proton bunch 1 is 4 pi-mm mrad from the TBT and 10 to 13 pi-mm mrad from the horizontal flying wires; for proton bunch 2 the values are 0.8 pi-mm mrad from the TBT and 2 to 4 pi-mm mrad from the horizontal flying wires

4. Comments

The trailing edge of the kicker is within design specifications, but will disturb the circulating protons too much. There are three options being discussed to minimize this disturbance. The first is to get transverse dampers in the Tevatron to work and damp the oscillations due to the kicker. A second option takes advantage of the fact that only one of the two magnets are needed at E48 for the Main Injector. In this case, the second magnet can be installed and used as a bumper magnet, powered by a 4 bit high power DAC with a range of $\pm 2\%$ of full field. The third option is to inject only 3 antiproton bunches instead of 4. This allows us to cut a considerable amount of PFL cable which would reduce dispersion effects and move the trailing edge bump away from the protons.

5. References

- [1] ED Log 44, pages 17 to 26 and pages 109 to 114.
- [2] EXP191, G. Annala and B. Hanna, "Tevatron Proton Injection Kicker Waveform Analysis".
- [3] J. Dinkel et al., "D48 Design Review", EXP-197A.