PROTON EXTRACTION AND TRANSPORT FOR PBAR PRODUCTION IN TEVATRON I

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Summary

The design, fabrication, and commissioning of the extraction and beam transport systems required for pbar production for the FNAL Antiproton Source will be described. The extraction system utilizes a fast kicker and Lambertson septum magnets to extract in a single turn one booster batch of 120 GeV protons from the FNAL Main Ring. The extracted beam is transported a distance of 174 m by a beam transport system consisting of 12 dipoles and 14 quadrupoles. The last 8 quadrupoles are configured as 4 pairs which focus the beam to a small round spot (radius 0.4 mm) on a pbar production target. The extraction channel is also designed to inject 8 GeV cooled pbars from the Accumulator Ring into the Main Ring, or extract 8 GeV protons from the Main Ring for diagnostic and tune-up work in the Antiproton Source beam lines and rings.

Introduction

For $\bar{p}$ production in Tevatron I[1], once every 2 seconds, a single booster batch of 2×10^{12} protons must be extracted at 120 GeV from the Main Ring at the F17 medium straight section, transported to the Antiproton Source target station, and focussed to a small spot (σ= 0.4 mm) on the target. Because of the requirement of bunch narrowing, the momentum spread of this beam will be ± 0.2%; this sets the momentum bandwidth of the extraction channel and beam transport line. The transverse emittance of the 120 GeV proton beam is expected to be 0.2 π mm-mrad at full intensity. Additionally, most of the same system will be required to transport and reverse inject an 8 GeV $\bar{p}$ beam, of transverse emittance 2 π mm-mrad and momentum spread ±0.09%, into the Main Ring. This last mode of operation can be tested without $\bar{p}$'s, by extracting an 8 GeV proton beam from the Main Ring and transporting it to the target station: the beam dynamics and orbits will be the same for both cases. This mode of operation is also required to provide 8 GeV protons for commissioning of the other beam lines and rings of the Antiproton Source.

The extraction system at F17 (see Fig. 1) was installed and commissioned during January of this year. The beam transport line to the target station was installed during December and January, and commissioned (both for 120 and 8 GeV operation) during February and March. The following report will discuss the system design and present some of the commissioning results.

F17 Proton Extraction

The dynamics of the process of proton extraction for pbar production is straightforward. The extraction of one booster batch is carried out during a single turn, using a fast kicker at E17. Prior to extraction, the closed orbit between E12 and E14 is modified by energizing small dipoles at these locations. The resulting orbit bumps are roughly out of phase with the kicker coherent oscillation, and serve to minimize excursions from the nominal Main Ring center until F17. To effect extraction, the E17 kicker is energized to produce coherent betatron oscillations, which result in a beam displacement of roughly -42 mm at F17. Fig. 2 shows the last turn before extraction in the Main Ring.

The extraction channel is formed by two 162" Lambertsons, followed by two 118.4" C-magnets. The extraction magnets kick the beam vertically up sufficiently far that the extracted beam line passes above the next Main Ring dipole. The total vertical distance above Main Ring center at the end of the extraction channel is 9.7". To make room for the system, the Main Ring B2's at slots F17-4 and F17-5 have been replaced with a modified B2, which has twice the number of turns, and which is run in series with the rest of the Main Ring. The layout of the extraction channel is shown in Fig. 3. The extraction orbit shown in Fig. 2 has a residual angle of about 1 mrad at F17. This angle is cancelled by rotating the first Lambertson by 6.4°.

Extraction system components

The E17 kicker is a standard lumped inductance system (similar to that described in ref. 2) which is driven to 5 kA by the discharge of a capacitor bank through a thyratron switch. The current waveform is a half-sine wave of duration 35 μsec, appropriate for the single turn extraction of a single booster batch (of duration 1.6 μsec). The voltage required for this kicker is quite modest (5 kV).

The correction elements in the Main Ring at E12 and F14 are 20" long, 200 turn dipoles ramped to 50 A over a period of 1 sec. The extraction channel Lambertsons and C-magnets are similar in design and fabrication to existing components[3] in the Main Ring and Tevatron. However, to minimize their power consumption and to eliminate perturbations of the 8 GeV circulating beam due to stray fields in the "field-free" regions, they are pulsed to 2800 A at extraction time. The current waveform is a full sine wave of duration 70 msec, produced by discharging a large (13 mf) capacitor bank through a set of SCR switches. For targeting stability, the pulser is required to have very good pulse-to-pulse regulation; this is achieved by a digital control system described in ref. 4.

Proton Transport to the Target

Fig. 4 is a layout of the AP-1 beam line[5], which transports the 120 GeV beam from the Main Ring to the $\bar{p}$ production target, located in the Antiproton source target station[6]. The beam line consists of 10 dipoles and 14 quadrupoles, augmented by 5 trim magnets.

There are beam position monitors (electrostatic pickups) located after each quadrupole, and 6 secondary emission monitors (for beam profile

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measurements) located as shown in fig. 4. Additionally, there are 25 beam loss monitors distributed roughly equidistantly along the line. The first 5 secondary emission monitors have a resolution of 3 mm; the last one, located very close to the final focus at the target, has a resolution of 0.25 mm.

The beam line may be viewed as a transport section and a focussing section. The last 8 quadrupoles (configured as 4 pairs) are the focussing section. They focus the beam to a small dispersionless spot on the target. The first part of the line transports the beam from the Main Ring at F17 to the beginning of the focussing section. The focussing section has the ability to vary the beta functions at the target over a range from β=5 m to β=25 m. For an emittance of 0.2 π mm-mrad, this corresponds to a full width (95% of the beam) of 2 mm to 4.5 mm. The lattice functions for AP-1 are illustrated in ref. 5. Fig. 5 illustrates the measured beam spot on the target. The beam emittance for this measurement was ϵ_x=.1π mm-mrad, ϵ_y=.18π mm-mrad. The extraction and transport efficiency has been established by a comparison of beam current measurements in the Main Ring with the current measured at the end of AP-1. The best estimate for this efficiency (limited by calibration uncertainities of the current monitors) is >95%.

8 GeV pbar injection/proton extraction and transport

The 8 GeV cooled pbar beam will be extracted from the Accumulator and transported along a 341 m beam line (AP-3)[7], to the matching point with AP-1 shown in fig. 4. It is then transported along AP-1 to F17 and injected into the Main Ring. The beam is kicked onto a closed orbit in the Main Ring by a kicker at E48. Orbit modifications (for horizontal and vertical position and angle control at F17, and for kicker-cancelling orbit distortion between F17 and E48) are carried out using the 8 GeV dipole correction elements in the Main Ring.

For commissioning, before pbars are available, the system has been operated for 8 GeV proton extraction. Protons from the booster are injected into the Main Ring as usual, and circulate for about 0.5 sec. Appropriate Main Ring correction dipoles are ramped from their injection values to new values to create conditions suitable for extraction, and the E48 kicker is fired to extract the beam at F17. The last turn before extraction is shown in fig. 6.

The E48 kicker is a lumped inductance system, driven to 500 A by the discharge through SCR switches of a capacitor bank charged to 500 v. The current waveform is a half-sine wave of duration 35 μsec. For 8 GeV operation, the extraction channel magnets are not pulsed, but simply powered by a separate low-current DC supply. There are also separate power supplies for all the dipoles and quads in AP-1 for 8 GeV operation.

The 8 GeV extracted beam has been transported along AP-1 to the target, with reasonable agreement between expected and measured beam profiles. Because the 8 GeV operation uses the same magnets as the 120 GeV operation, but running at lower currents, remnant field effects in the AP-1 magnets have caused some problems during the commissioning: these effects are currently under investigation.

In addition to serving to commission the 8 GeV pbar transport and injection system, the 8 GeV proton extraction mode of operation has also been utilized extensively to provide 8 GeV beam for commissioning of the other beam lines and rings of the Antiproton Source.

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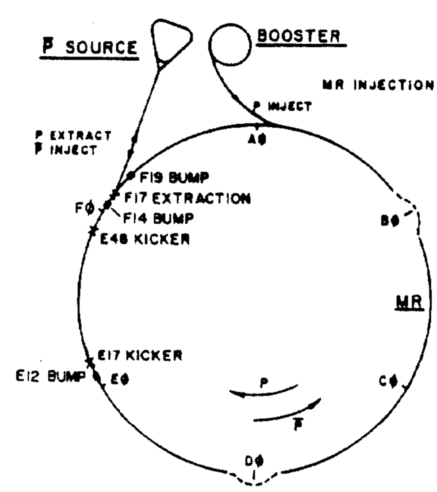

Fig. 1. Layout of the F17 extraction/injection system.

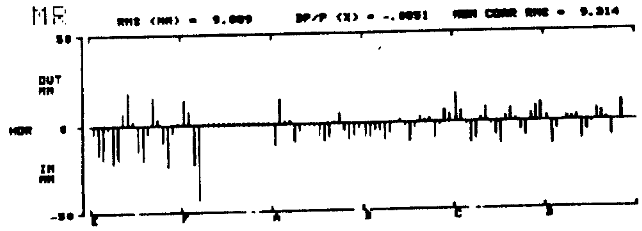

Fig. 2. 120 GeV Main Ring horizontal BPM measurement of the last turn before extraction at F17. The kickers is at E17; an orbit distortion between E12 and F14 limits excursions in this area.

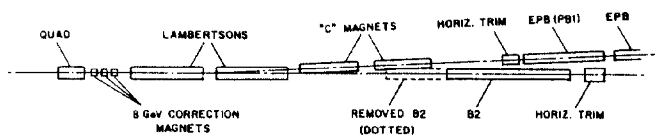

Fig. 3. Layout of the F17 extraction/injection channel.

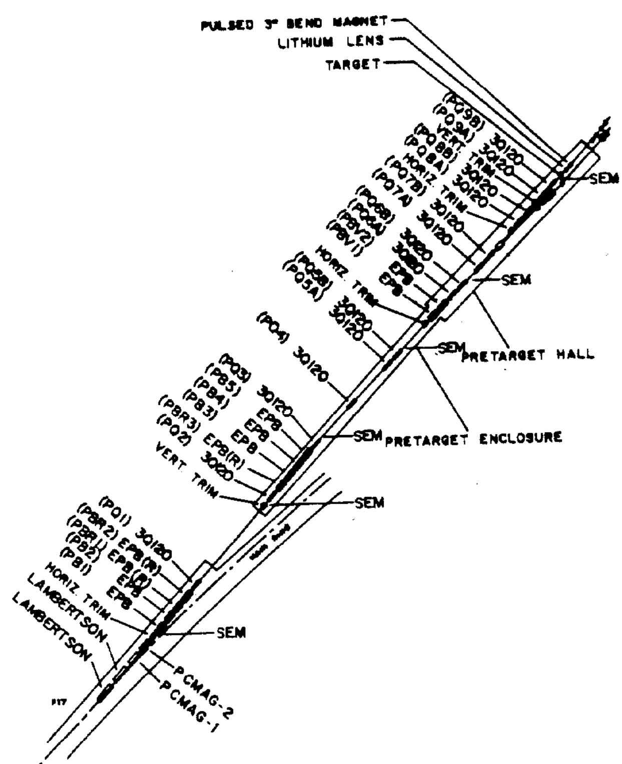

Fig. 4. Layout of the 120 GeV proton/8 GeV antiproton transport line (AP-1).

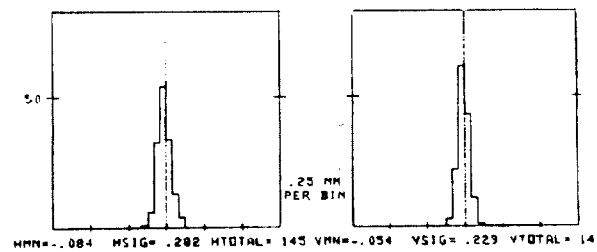

Fig. 5. Beam profile of 120 GeV beam at the $\bar{p}$ production target. Resolution of the secondary emission monitor is 0.25 mm; beam intensity was 10^{11}/pulse.

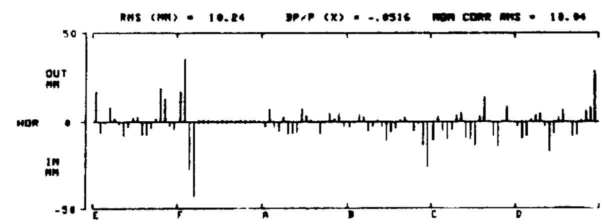

Fig. 6. 8 GeV Main Ring horizontal BPM measurement of the last turn before extraction at F17. The kicker is at E48; an orbit distortion between E49 and F14 limits excursions in this area.