DESIGN OF THE MAIN INJECTOR EXTRACTION BEAMLINES*

D. E. Johnson†
Fermi National Accelerator Laboratory P.O. Box 500, Batavia, IL 60510

Abstract

The Main Injector (MI) supports the Tevatron Fixed Target and Proton-Antiproton Collider modes of operation as well as providing 120 GeV/c resonantly extracted beam for the Main Injector Fixed Target Program. A set of beam transport lines, called A1 and P1, from the Main Injector converge on the injection point of the Tevatron, with the A1 being used to transport 150 GeV/c antiprotons (pbars) to the Tevatron. P1 is used to transport 150 GeV/c protons to the Tevatron, 120 GeV/c protons to the pbar target, and eventually 120 GeV/c resonantly extracted protons to the existing Fixed Target areas. In addition, the P1 line will be used to transport 8.9 GeV/c pbars from the Source back to the MI and recycled 150 GeV/c pbars at the end of Collider stores. In order to accomplish the second and third function, the P1 beamline is continued beyond the Tevatron injection point in a section of the decommissioned Main Ring, called the P2 beamline. This transports the protons to a magnetic switch used to select either the modified transport line, used for targeting protons for pbar production, or the transport line which connects to the existing Fixed Target beamlines. The design of these beamlines will be discussed.

1 BEAMLINE LAYOUT

The MI is 2-fold symmetric about the center point (Q605) of the long straight section which contains the RF and instrumentation. This straight is parallel to and offset from the Tevatron injection straight section by 11.31 meters. The MI is 2.133 meters below the Tevatron and the P2 line (which is comprised of a remnant section of the decommissioned Main Ring) is 0.646 m above the Tevatron. Figure 1 shows a cartoon of the plan and elevation of the P1 and A1 beamline layout wrt the MI, Tevatron, and the P2 beamline. The MI extraction straight sections for protons and pbars are located symmetrically about Q605 in the MI and the injection point (TEV60) in the Tevatron injection straight section. The horizontal angle between the MI extraction and Tevatron injection straight sections is 305.8 mr. The total length of each beamline is 260 m.

Each line includes three 2.8 m vertical bending Lambertsons and a 3.3 m vertical c-magnet for extraction; fifteen 6 m dipoles (recycled from the decommissioned Main Ring, MR); four vertical bending c-magnets, and four vertically bending Lambertsons used for injection. The focussing is provided by: sixteen quadrupoles where seven are 2.1 m recycled quads from MR (Q3-Q9), seven new 3 m quads (Q1, Q2, Q10-Q14) and two new 1.5 m quads (Q12B and Q13B). Both the A1 and P1 dipoles and quads are powered by the same set of power supplies and are alternately energized through a load transfer switch. Eight horizontal and seven vertical BPM's along with six multiwire profile monitors are used to monitor the orbit and optical properties of the beam. Ion chamber loss monitors are located on Lambertsons, c-magnets and each quadrupole. Horizontal (vertical) trim dipoles are located at each focussing (de-focussing) quadrupole for orbit correction and control.

2 OPTICAL DESIGN

a. Extraction lattice

Each extraction straight is a dispersion free FODO lattice made up of three MI half cells, with a half-cell length of 17.288 m and a β_{max} of 60 m. Figure 2 shows the elements and lattice functions of the P1 extraction straight section starting at the beginning of the two cell dispersion suppressor. Extraction of protons and pbars is initiated by a pair of horizontal extraction kickers (s= 55 m) located at the proton (or pbar) upstream end of the straight 90 ^{o} in phase of a set of three vertically bending Lambertsons (s=85 m) and a c-magnet (s=98 m). The P1 extraction kicker is designed for multiple energies and pulse lengths to accommodate the various functions of the P1 beamline while the A1 extraction kicker is a single energy /pulse length kicker. A pair of electrostatic septa (s=63 m) used for resonant extraction is located just downstream of the P1 kickers, filling the straight. The beam enters the first quad (s=100 m) of the transport line at an elevation of 218 mm above the MI centerline at an upward angle of 28.5 mr.

b. Tevatron Injection

Half of the 52 m Tevatron F0 straight section, bounded by a doublet, is used for injection with the remaining half used for RF cavities. The lattice functions of the Tevatron injection straight section are anti-symmetric with non-zero horizontal

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† Email: dej@fnal.gov

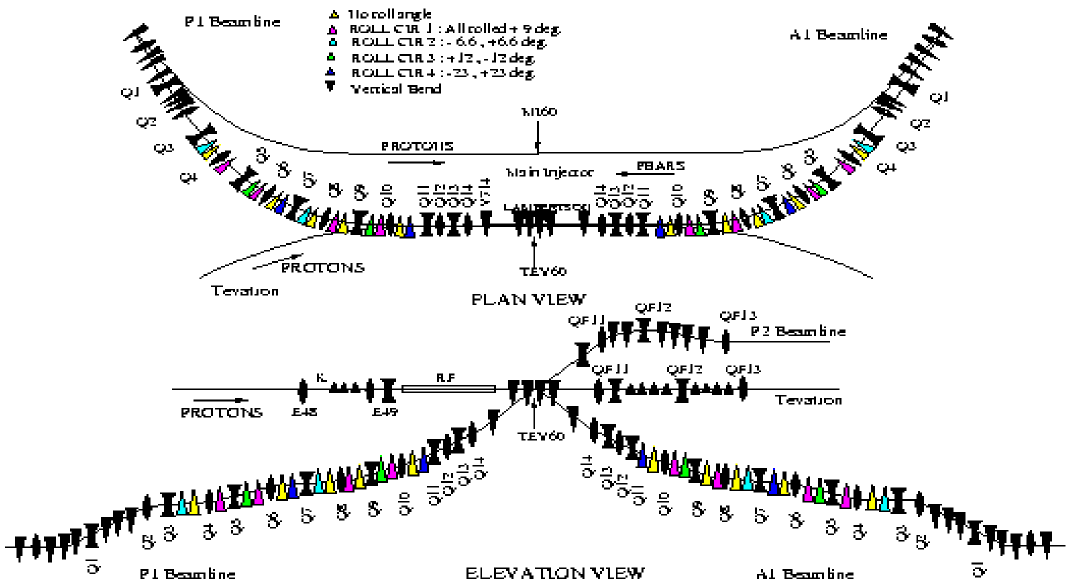

Figure 1. Plan and elevation of the P1, A1, and P2 beamlines in relation to the Main Injector and the Tevatron. The drawing is not to scale. The Main Injector and Tevatron magnets are not shown on the plan view for clarity.

dispersion, as shown in Fig. 3. Here the proton direction is from left to right. This requires two different optical

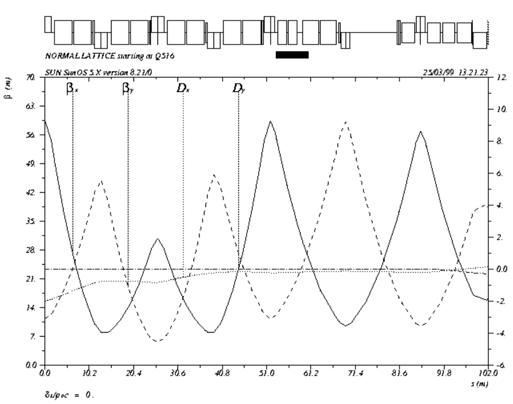

Figure 2. Main Injector Extraction straight section . The extraction kickers underlined in center of plot. The first quad in the beamline, Q1, is at s= 100 m.

solutions for the proton (via P1) and pbar (via A1) injection. Both protons and pbars approach the Tevatron from below. The 4 injection Lambertsons (s = 1058 m) remove the 24 mr vertical injection angle. The horizontal position and angle of the injected beam at the Lambertsons are removed by proton kicker, at F17, (s=1258 m) and pbar kicker, at E48, (s=988 m).

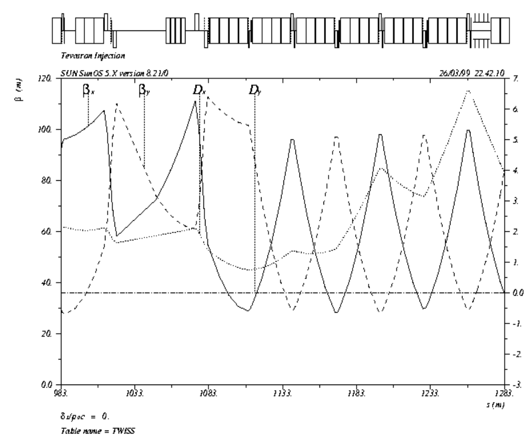

Figure 3. Tevatron injection lattice.

c. *Transport Lines*

The program TRANSPORT [1] was used to layout the central trajectory of the beamline. All of the di poles are powered by two horizontal and two vertical supplies. Fifteen of the horizontal dipoles are arranged on a single circuit. The second dipole after Q3 (fig. 1) is powered independently, and has a reversed polarity. The two vertical supplies control the vertical c-magnets at the beginning and end of the line. The fifteen dipoles are additionally arranged in four families of rolled dipoles to provide vertical trajectory and dispersion control.

The correction of central trajectory errors due to quadrupole alignment errors, dipole roll errors, and dipole field errors was simulated with random misalignments (θ_x= θ_y = 0.25 mm and θ_{roll} = 0.5 mr) and field errors of $\Delta B/B$ = 0.25%. The installed corrector strengths of 0.72 kG-m and 0.52 kG-m are 20% stronger than required for correction .

The transport section both the P1 and A1 beamlines consist of 10 quads which make up four 90 ^{o} FODO cells in each plane. The half-cell length and quad focal length was chosen to replicate the amplitude functions in the MI. The first two quads in the transport line are on independent power supplies to aid in matching from the MI into the FODO lattice. Quads 3 through 9 are all powered on a single quad bus (QCELL). Additionally, the last quad, Q10, in the FODO lattice is individually powered to aid in matching. Figures 4 and 5 show the lattice functions for the P1 and A1 beamlines starting at Q1 and matching into the Tevatron in the proton and pbar directions, respectively.

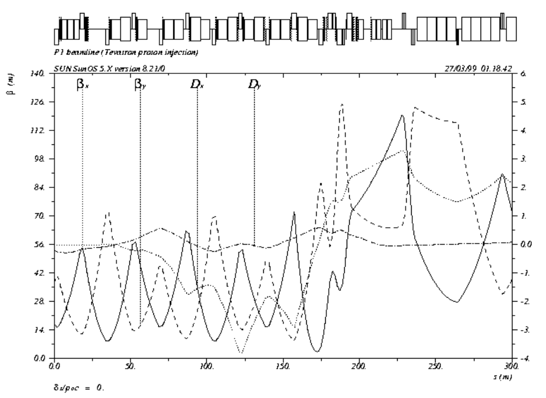

Figure 4. Lattice functions for the P1 beamline match into the Tevatron.

The matching section at the Tevatron end of the beamline contains four quads. These, along with QCELL, are used to match β_x, β_y, α_x, and α_y into either the Tevatron or P2 beamline, each with a different optical solution. For matching into P2, used at both 8.9 GeV and 120 GeV/c, the lattice functions in both x and y are set to a waist. Both TRANSPORT and MAD [2] were used for matching .

The vertical dispersion generated by the extraction Lambertsons is almost canceled by the injection Lambertsons. To complete the cancellation and aid in meeting the tight geometrical tolerances, four families of rolled dipoles are used. The first family, R1, consists of two pairs of dipoles separated by 180 ^{o}

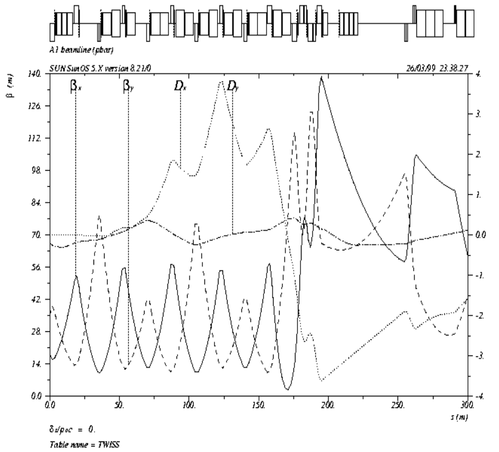

Figure 5. Lattice functions for the A1 beamline matched into the Tevatron.

and each pair separated by 90 ^{o}. All four dipoles are rolled 157 mr counter clockwise to produce the majority of the vertical elevation needed at the injection Lambertsons (1.5 m), with negligible effect on the vertical dispersion. The other three families, R1 (116 mr), R2 (210 mr), and R3 (410 mr) are used in pairs with opposite rolls for controlling η_y and η_y'. The residual coupling generated by these rolls is small, it can be removed by rolling the last four quads in the FODO lattice.

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3 REFERENCES

[1] K. L. Brown et al., “TRANSPORT, A Computer Program for Designing Charged Particle Beam Transport Systems”, SLAC-91, Rev. 2, SLAC, 1977.

[2] H Grote, F.C. Iselin, “The MAD Program”, CERN/SL/90-13 (AP).