A Dynamic Lattice Insertion for Main Injector Extraction

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Prior to the workshop a solution for the Main Injector to Tevatron transfer line had not been found. The difficulty was in matching the vertical dispersion. Although both rings are planar and therefore have no vertical dispersion, the beam line itself requires vertical dipoles, and it is the dispersion from these dipoles that needs to be supressed at the end of the line. In order to better understand the need to match, a criterion was developed indicating how much mismatch is allowable. [1] Then a design was found which uses different quadrupole settings in the Main Injector itself to change the lattice functions at the beginning of the line and therefore make the beamline design less demanding.

It should be noted that all of the beamline design effort at Breckenridge was concentrated on beamline solutions for MI_11, the lattice of choice prior to the workshop. During the course of the workshop a new lattice was designed [2] which allows for longer beamlines, and therefore less demanding constraints on the beamline design. After the workshop this new lattice was chosen as the preferred lattice, and other beamline solutions were adopted. However, the technique explained here is presented as a solution to a beamline design problem.

The Main Injector is required to do a number of tasks. Among them are the acceleration of protons and antiprotons destined for collision in the Tevatron. It also must transfer protons into the Tevatron for the high energy fixed target program. However, the Main Injector will have its own fixed target program, and therefore must be capable of slow extraction. Because of the siting of the Main Injector a single straight section has been assigned the following tasks:

- Extraction of 150 GeV protons to the Tevatron
- Extraction of 120 GeV protons to the antiproton target
- Extraction of slow spilled 120 GeV protons to the Switchyard
- Injection of 8 GeV antiprotons from the antiproton source

[1] R. Gerig, "A Dispersion Mismatch Criterion for the Main Injector to Tevatron Transfer Line", These Proceedings

[2] R. Gerig, "A New Lattice for the Main Injector", These Proceedings

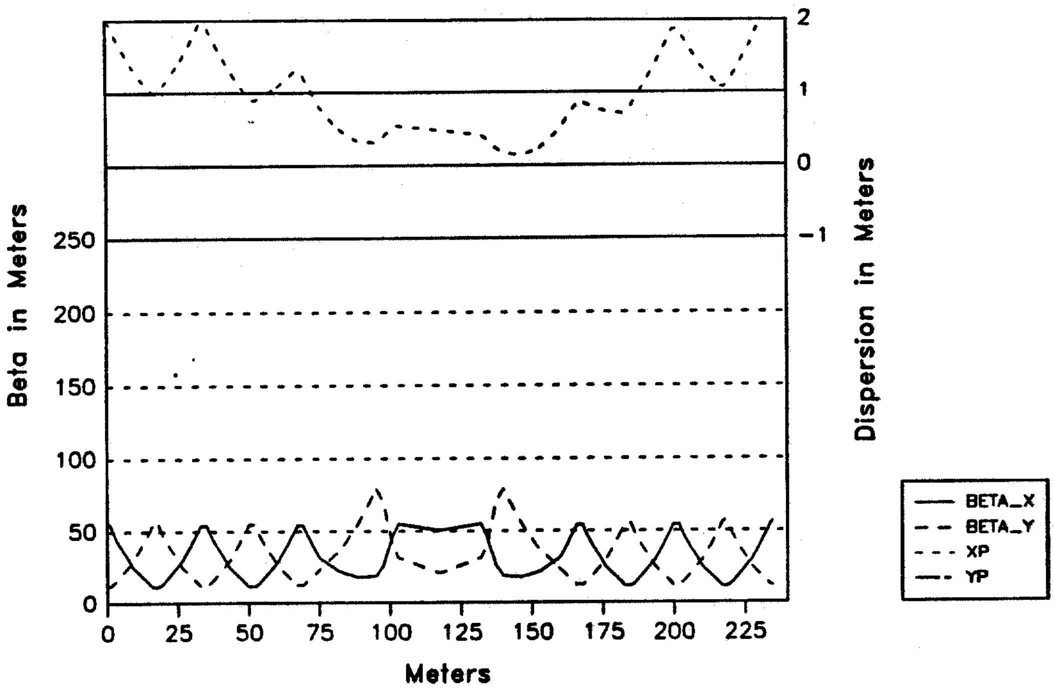

Figure 1: Lattice functions in normal straight section

Each of these functions imposes certain constraints on the design of the beamline. Slow extraction requirements determine that the extraction channel magnets bend the beam vertically. The injection of 8 GeV antiprotons in these devices leads to the determination of the aperture size; and the need for transportation of 150 GeV beam determines ultimate field strength and therefore bend angles. Furthermore, the beamline between the Main Injector and the Tevatron is the shortest of these beamlines.

The initial source of the vertical dispersion is the extraction lambertson. In the site configuration associated with MI_11 the Main Injector is physically 22.5 inches (.5715 meters) lower than the Tevatron. Thus the most straightforward scheme is to come out of the Main Injector vertically up and level off at the Tevatron elevation. A minimim extraction angle is needed to clear the first quadrupole downstream of the straight section and this angle is sufficient to get the beamline to the Tevatron elevation in 44 meters. At this point a dipole can be inserted which levels the beam off. However, since these dipoles bend in opposite directions they need to be a multiple of 360 degrees apart in order for the induced dispersion to cancel. To get 360 degrees of phase advance in 44 meters requires an average β of 7 meters. This is not achievable. An alternative is to make the phase advance between the bend centers as small as possible. For instance, a phase advance of 20 degrees is generated by an average β of 125 meters.

To keep the beam size small at 8 GeV the lattice of the Main Injector was designed as a very strong focusing machine. As a result the lattice functions at the long straight section are also small as can be seen in Figure 1. The vertical β is around 30 meters at the beginning of the straight section and is focussed to 20 meters at the center of the straight section. This

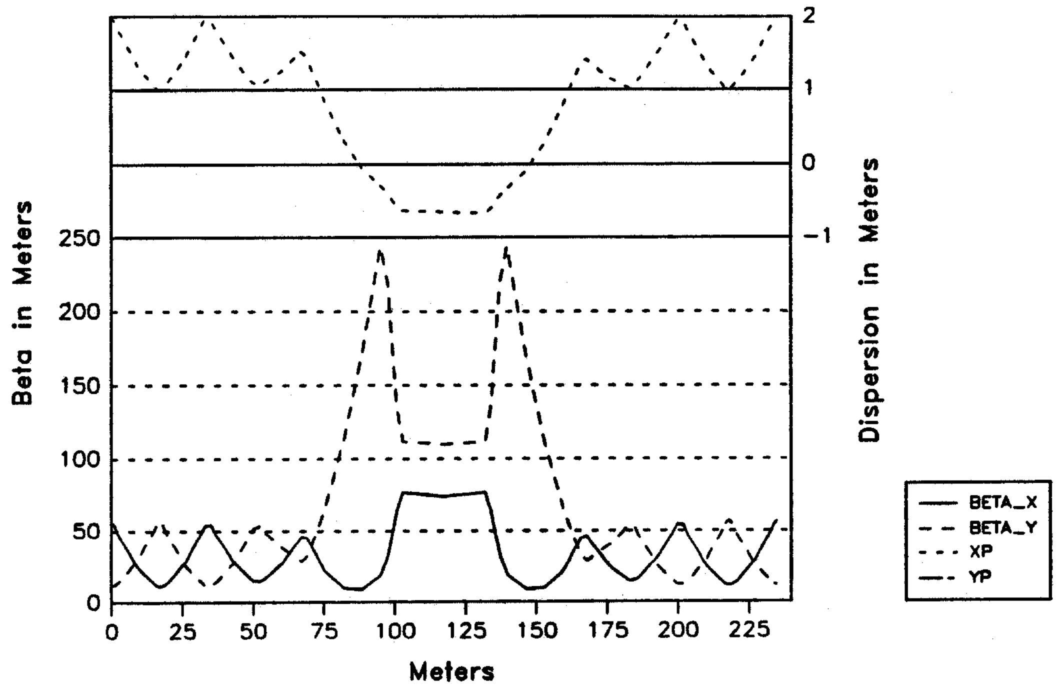

Figure 2: Lattice functions in high β straight section

small initial β led to the problem in reducing the final dispersion in the beamline. The design presented here uses trim supplies on the quadrupoles around the straight section to increase the vertical β in the straight section. Figure 2 shows these lattice functions.

These circuits would only be powered at 150 GeV during transfer to the Tevatron. The beam size at 8 GeV resulting from the peak β of 220 meters is too large, prohibiting use of this design at all energies. The straight section insertion in the Main Injector is symmetrical. In order to introduce this matched high β insertion, six quadrupoles on either side of the straight section are individually powered. Three of these quadrupoles are the special quadrupoles used for matching in the normal lattice, and three are standard cell quadrupoles. Table 1 list the currents in these quadrupoles as a ratio from the current in the normal lattice. It is included to show that the needed changes from the normal lattice current are not large. The outer matching quadrupole, (defocusing) is the only one substantially different. It is a very short quadrupole and therefore requires large gradient changes to effect the lattice. If this design were to be pursued, we are confident that an easier solution from an engineering standpoint could be found to accomplish the lattice changes.

At the location of the first vertical bend, the vertical beta is 110 meters. The lattice functions for this line are shown in Figure 3. For this design the vertical dispersion is sufficiently matched. The quantity $\frac{\Delta D_{eq}^2}{\beta}$ is .0027, and well within the established criterion. The vertical dispersion match is illustrated in Figure 4. This figure employs a Floquet transformation to plot the propagation of the vertical dispersion vector down the beamline. In this plot a dipole makes a horizontal step in the propagation of the vector. Through any other element the vector simply rotates. The length of this vector is the square root of the

Inner matching quadrupole, focusing	1.078
Inner matching quadrupole, defocusing	.901
Outer matching quadrupole, defocusing	.2
Cell quadrupole, focusing	.963
Cell quadrupole, defocusing	1.037
Cell quadrupole, focusing	.766

Table 1: Required changes to Main Injector Quadrupoles Expressed as Ratios of Normal Current

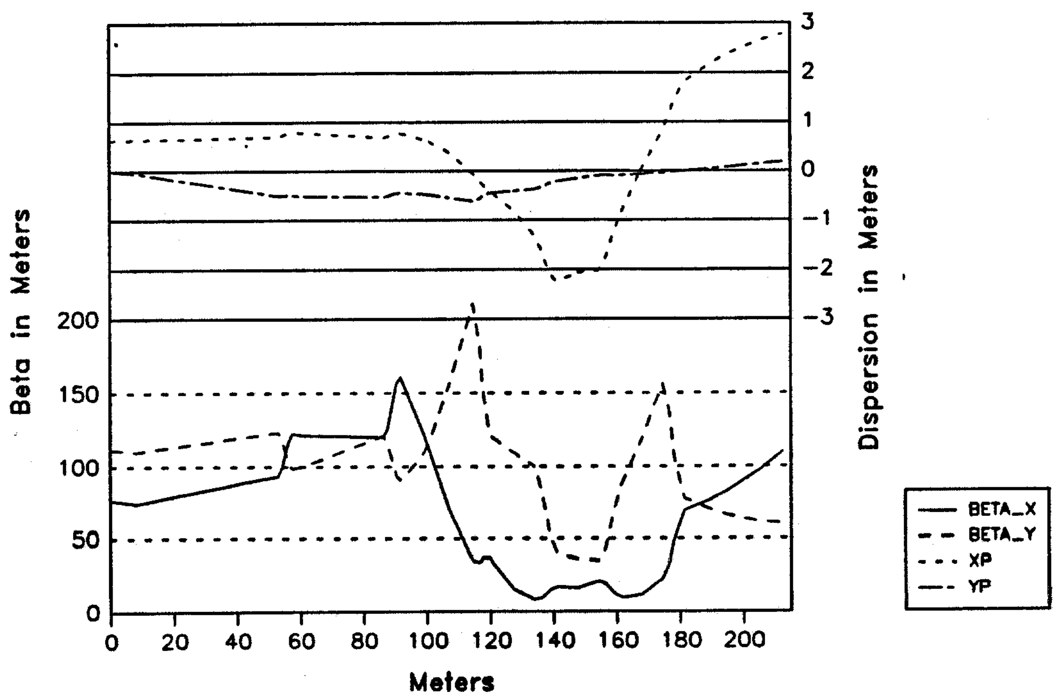

Figure 3: Lattice functions in the beamline

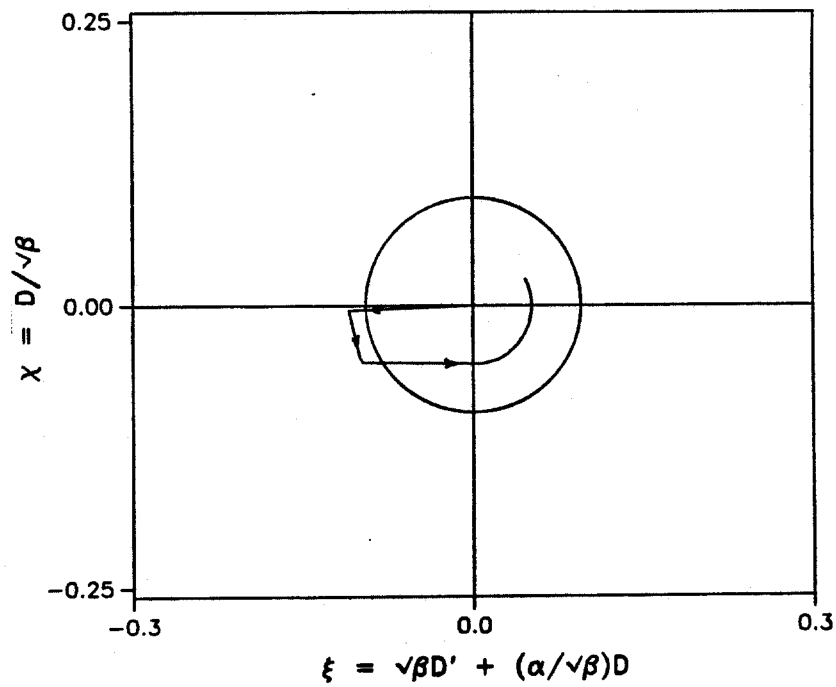

Figure 4: Propagation of vertical dispersion vector in beamline

dispersion invarient described in the reference. In Figure 4 the criterion is shown as a circle.