COMMISSIONING OF THE B0 LOW BETA INSERTION

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Introduction

One of the first steps towards using the Tevatron in its new role as a collider has been taken in the testing of the new low beta insertion at B0. Although it may be several months before proton-antiproton collisions take place in the B0 collision hall, the new magnets and associated devices have been tested and are ready to play their part. Just as additional lenses can be used to improve the sensitivity of a microscope, the new magnetic lenses which make up the low beta insertion are expected to improve the power of the Tevatron as a collider by almost a factor of a hundred.

The arrangement of magnetic elements in the Tevatron, its **lattice**, was originally designed for slow resonant extraction. In order to fully exploit the machine as a proton-antiproton collider, the lattice must be modified by inserting a new subset of magnetic elements near the experimental collision area. An **insertion** of quadrupoles in this region can be used to change the size of the beam, proportional to the square root of the **beta function.** In the case of the CDF experiment at B0 the quadrupoles must focus the beam tightly at the very center of the interaction region. The small beam size, or **low beta** function, increases the density of the particle beams and consequently the interaction rates.

The interaction rate R is the product of the machine luminosity L, and the interaction probability or cross section σ. The luminosity is a property of the machine, depending on the beam sizes and intensities, I_1 and I_2. The measurement of the cross section is usually the goal of the experiment.

$$R = L\,\sigma\ (s^{-1}),\ \text{where the luminosity}$$

$$L = \frac{k\ I_1 I_2}{\varepsilon\ \beta}\ (cm^{-2}s^{-1});$$

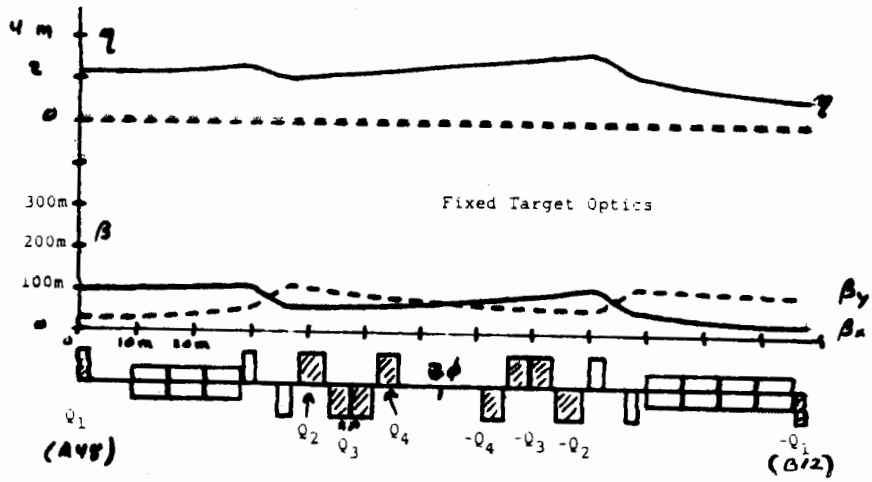
k includes the longitudinal distribution of the beam or bunching factor, ε is the emittance, β is the beta function, and $\varepsilon\beta$ is the square of the beam size. Here ε and β are taken to be the rms averages of the horizontal and vertical values.[1] The highest possible luminosity is needed to see rare processes.

Details

The original studies of low beta insertions in the Tevatron were made by Tom Collins and Dave Johnson.[2,3] Higher-current versions of the Tevatron quadrupoles, developed by Gene Fisk,

determined the particular insertion which was installed this spring under the direction of Karl Koepke. This effort involved the collaboration of over 200 people from all parts of the Laboratory and a budget of about 8 million dollars. Besides 10 new superconducting quadrupoles and their associated power supplies, refrigeration, quench protection, and control circuitry, many other devices were needed. New beam position monitors, steering dipoles, a laser alignment system, and 6 flying wire scanner systems were also part of the effort.

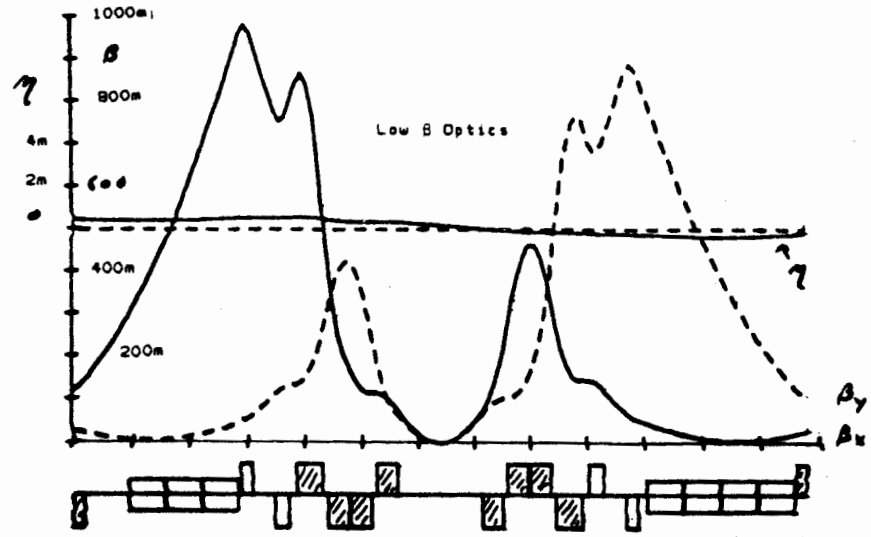
The figure below shows the lattice of the Tevatron at B0 with the new quadrupoles indicated. Also shown are the horizontal and vertical beta functions and the momentum dispersion function. In the low beta configuration there are 4 new electrical circuits. All use quadrupoles which are similar to those of the Tevatron but with a superconducting cable capable of higher maximum currents (6 kA vs. 4.5 kA) and fields. The cable has 20 micron diameter NbTi filaments (compared to 8 microns) and Cu/NbTi of 1.3 (vs. 1.8) by volume.



Schematic of the low beta insertion at B0. The boxes above (below) the line represent horizontally focusing (defocusing) quads; the boxes which cross the centerline are normal Tevatron dipoles. The magnets which were added for the low beta insertion are shown shaded. Also shown are the lattice functions for the case of the fixed target configuration. The new quads at A48 and B12 replace the shorter quads of the normal Tevatron lattice. The new quads reduce the magnet-free region from 50 to 15 m.

The Q1 circuit has two 66 in. long quads which replace two of the 32 in. long quads in the regular Tevatron lattice. The Q1 circuit is the only one of the four which must be programmed

during the operation of the Tevatron in the fixed-target mode. It is also unusual in that its polarity changes at one point in the transition to the low beta configuration.



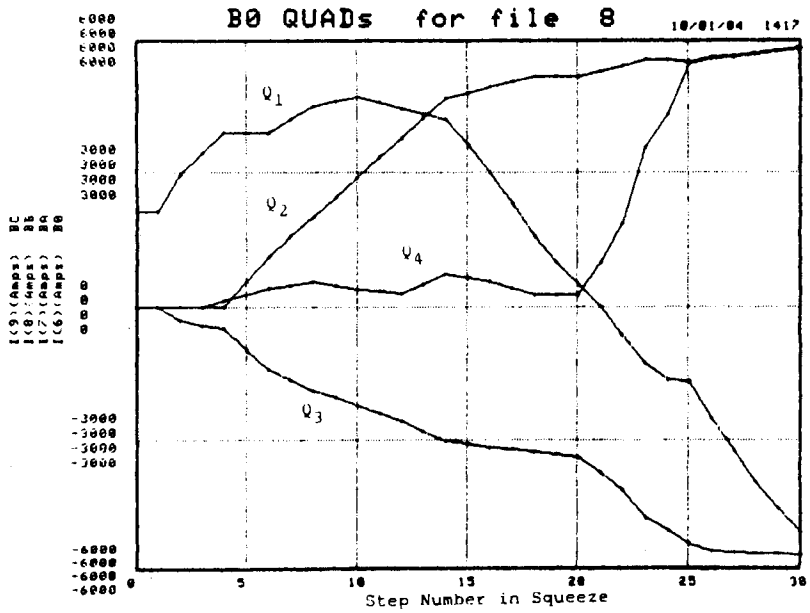
Schematic of the low beta insertion showing the lattice functions with all magnets energized. The beta values at the interaction point are approximately 0.85 m in each plane. The large beta values near the (unshaded) Collins' quads prohibit injection with the insertion energized; an adiabatic change from the fixed target or injection lattice to the low beta configuration while the beam is stored at high energy is necessary.

The Q2 circuit has two 180 in. quads, the Q3 circuit has four 144 in. quads, and the Q4 circuit uses two 144 in. quads. The number of circuits is of particular importance for a superconducting low beta insertion because each transition from the normal conductor to the cold region is an additional load on the refrigeration system. At the CERN SPS where this is not an additional constraint, a similar low beta insertion requires 15 independently controlled supplies.[4]

Refrigeration for the new magnets is provided by the satellite refrigerators at A4 and B1 which have each been upgraded to provide an additional 100 Watts of cooling at 4.2°K.

The installation of the superconducting quadrupoles and the additional beam position monitors and correction dipoles took place during the three week shutdown in February. Most of the commissioning studies took place during April and May.

A design criterion for the insertion was to be able to start with stored beam at high energy (where the beam is smaller than at injection energy) with the Tevatron in its fixed-target lattice configuration and to continuously vary the lattice until the low beta is reached. This requirement manifests itself in 28 separate configurations or steps, each a lattice solution. Each step needs values for the new quad currents and the correction elements which are affected by the changes in the insertion. The figure below shows how the currents in the four new circuits change for these steps.

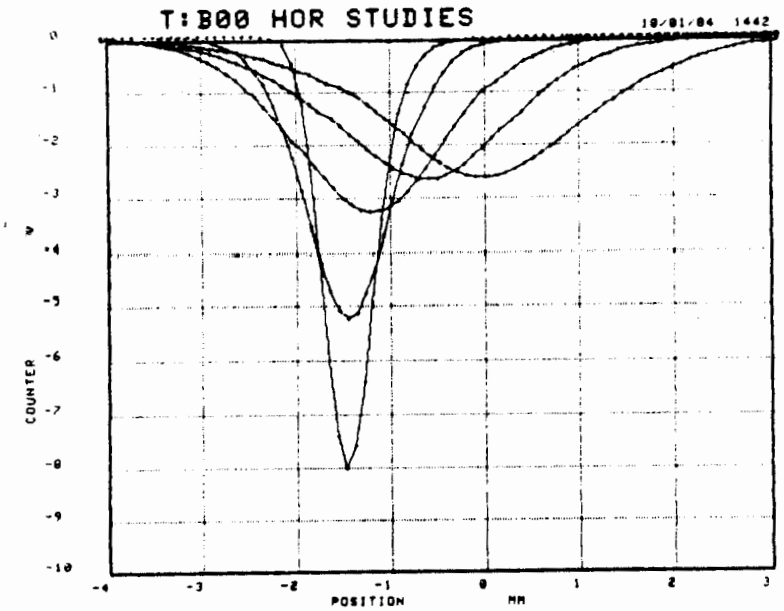


Current programs for the 4 new quad circuits in the adiabatic change from the fixed-target lattice to the low beta configuration at 1 TeV. There are approximately 30 steps in the process. Each step takes about 2 seconds and includes the simultaneous change of correction element power supplies which control the tunes, chromaticities, skew quad setting, and 20 dipole steering magnets. The total time for the "squeeze" is less than 2 minutes.

Dipole steering corrections are needed because the strong quadrupoles of the insertion magnify errors in the closed orbit. The extra focusing of the quads also causes changes in the betatron tunes which are compensated using the regular Tevatron correction quads. Including the skew quad and chromaticity-correcting sextupole circuits, some 29 function generators need

to be changed together for each of the 28 steps between the initial and final configurations.

To test that the machine behaved as predicted a flying wire scanner was used to measure the evolution of the beam size at each step in the squeeze. The flying wire scanner is a thin (0.002 in.) beryllium wire which is moved quickly through the beam (5m/s) while a downstream scintillation counter records some of the particles scattered out of the beam. The figure below shows the horizontal profile of the beam measured this way at the very center of the B0 interaction region at successive steps in the squeeze. When amplifier resolution corrections are applied, the predicted and actual beam profiles agree quite well.



Flying wire scanner measurements of the horizontal beam profile at steps 16, 18, 20, 22, and 24 in the squeeze. As the power supplies go through the steps in the squeeze and the lattice is modified, the predicted beam size can be compared with the measured values. Because of a problem with amplifier saturation the detailed comparisons at the smallest beam sizes were made directly from oscilloscope traces. The shifts of the profile centers are due to the changes in the closed orbit caused by the steering of the new quads. The first 20 steps are used to effectively turn off the Q1 circuit so that its polarity can be reversed.

Preliminary Conclusions and Future Activities

Final conclusions on the success of the low beta insertion will have to wait until proton-antiproton collisions are producing new physics results at B0. So far, however, things look very promising. The hardware and software for the low beta insertion all seems to work as predicted. Some questions about the alignment accuracy and physical stability of the magnet supports have preliminary answers. Judging by the original closed orbit distortions and subsequent variations in the closed orbit during the two months of commissioning, the quads were all placed to better than 0.007 in. and have moved less than 0.002 in. This is particularly impressive considering how the magnets have to be supported over the B0 detector pit.

The next beam studies, besides verifying that all systems work well at the highest possible energy, will be devoted to studying coasting beam while the low beta is working. Computer studies imply that there should be no degradation of the beam lifetime, although there may be unknown effects which were not in the simulations and can only be seen using the Tevatron itself.

References

[1] See the March 1984 **Fermilab Report** article by C. Ankenbrandt for a more comprehensive review of these relations. Basically, lowering the beta value at the interaction region is the most effective way to increase the luminosity. This is true up to the point where the beta value is smaller than the longitudinal beam dimension or the large beam at a corresponding high beta region encounters regions of poorer field quality leading to a diminished beam lifetime.

[2] D. E. Johnson, "A Low-β Insertion Design for 1981," TM-1035, March, 1981.

[3] D. E. Johnson, "Tevatron B0 Low Beta Tuning Report," TM-1106, May 1982.

[4] P. E. Faugeras, A. Faugier, A. Hilaire and A. Warman, Proc. of XII Int. Conf. on High Energy Accelerators, Fermilab, 1983.

The TeV I project. Beyond the ring service buildings is the Target Station Service Building.

(Photograph by Fermilab Photo Unit)