Status of the Tevatron Low Beta and Separator Projects

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Abstract

Two low beta insertions and a set of electrostatic separators have been installed in the Tevatron. This gives the Tevatron two independently adjustable low beta insertions and the ability to separate the colliding beams everywhere except at the low beta collision points. The status of the installation will be summarized and the initial operating experience with the equipment will be reported.

1. INTRODUCTION

Two new low beta insertions [1] and 22 electrostatic separators [2] have been installed in the Tevatron. The old low beta insertion at the B0 interaction region of the Tevatron has been replaced and a second and essentially identical low beta insertion has been installed at D0. The D0 low beta insertion will serve the D0 detector which will come on line during the 1992 collider run scheduled after the new systems have been commissioned.

In the past, the Tevatron Collider has operated with a single low beta insertion [3] located at B0, the location of the Collider Detector Facility (CDF). This insertion functioned reliably but was not matched to the rest of the lattice. This mismatch introduced beta function and dispersion distortions to the rest of the Tevatron lattice that made it difficult to add additional low beta insertions to the Tevatron or to obtain uniform proton- antiproton beam separation with electrostatic separators.

The beta functions and dispersion of the new low beta insertions are completely matched to the lattice. This allows two or more insertions to operate simultaneously, coupled only through the tunes. Each low beta insertion adds approximately a half unit to the tunes of the lattice. The dispersion at the interaction point of the old low beta insertion was approximately 0.2 m. The dispersions at the interaction points of the new low beta insertions are approximately zero.

The low beta insertions increase the luminosity of the interaction regions. The luminosity of a proton-antiproton interaction point is given by the expression,

$$L = \frac{3\gamma f B N_p N_{\bar p}}{\beta^* (\varepsilon_p + \varepsilon_{\bar p})} F \qquad (1)$$

where γ is the relativistic factor of the protons and antiprotons , f is their revolution frequency , B is the number of proton (or antiproton) bunches, N_p and $N_{\bar p}$ are the number of protons and antiprotons per bunch respectively, F is a form factor that compensates for the longitudinal bunch length, ε_p and $\varepsilon_{\bar p}$ are the 95% normalized transverse emittances of the beams, and β^* is the value of the beta functions, assumed equal, at the interaction point. The low beta insertions increase the luminosity by lowering β^* from the nominal 70 m of a standard straight section down to .25 m.

The electrostatic separators separate the proton-antiproton closed orbits everywhere except at the B0 and D0 interaction points. This reduces the beam-beam tune shift experienced by the protons and antiprotons to a minimum by eliminating the unwanted beam crossings in the Tevatron. The antiproton beam-beam tune shift per beam crossing is given by the relation,

$$\Delta\nu = .00733\, N_p/\varepsilon_p \qquad (2)$$

where N_p is in units of 10^{10} and ε_p is in units of π mm-mr. Without separators, the total antiproton beam-beam tune shift [4] in the Tevatron for 12 crossings (6 proton bunches on 6 antiproton bunches) has reached a value of .025. This equals the available working space in the tune diagram bounded by resonances of 10th order or less. The separators will permit an increase in the luminosity of the two Tevatron interaction regions by permitting an increase in the proton phase space density (N_p/ε_p) and an increase in the number of beam bunches.

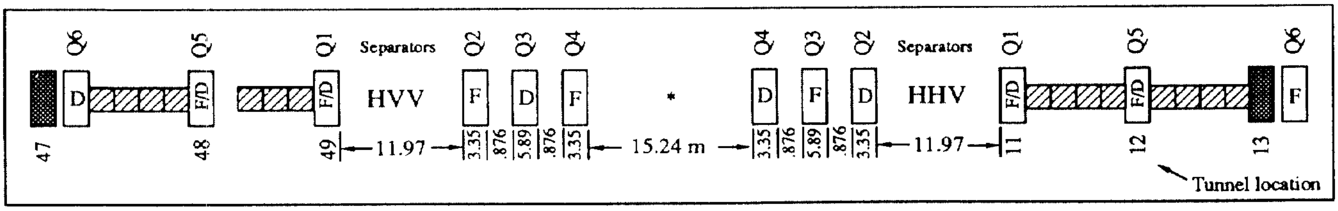

Figure 1. Central part of a low beta insertion. The magnetic lengths of the low beta quadrupoles and their relative placements are shown in meters. The filled elements are the remaining standard lattice dipoles and quadrupoles.

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2. LOW BETA INSERTIONS

Each of the new low beta insertions consists of 18 quadrupoles designed and fabricated specifically for this application. The quadrupole parameters are given in Table 1. Two types of quadrupoles were utilized; a high gradient, high current 2-shell design for strong focusing at the center of the insertion, and a standard gradient, low current 1-shell design mounted at the start and end of the insertion for matching to the rest of the lattice. The low operating current of the 1-shell quadrupole is achieved by winding with 5-in-1 cable. Each cable contains 5 individually wrapped, oversized strands connected in series for an effective maximum current of 5 kA.

The B0 and D0 low beta insertions utilize interchangeable quadrupoles that have identical relative quadrupole placements. However, their physical supports and separate ancillary cryostat units reflect physical differences in the two collision halls. The center portion of an insertion is shown in Figure 1. The quadrupole pairs Q1 through Q5 are placed symmetrically relative to the center of the straight section. They are powered as focusing, defocusing pairs with equal gradients, equal effective lengths, and opposite gradient polarities. The remaining quadrupoles are mounted within special correction coil cryostats (called low beta "spools"). These "spools" are located downstream and adjacent to the normal lattice quadrupoles at the 43, 44, 46, 47, 13, 14, 16, and 17 locations of the standard lattice. These quadrupoles also function as focusing, defocusing pairs. However, as their placement is not exactly symmetric relative to the center of the insertion, they require slightly different currents in the upstream and downstream quadrupoles. A 15.24 m central region, equal to the region of the older B0 low beta insertion, has been left for the interaction region detector.

The low beta quadrupoles are powered independently of the Tevatron bus. This allows β^* to be programmed over a 1.7 m through .25 m range. The beta functions are antisymmetric relative to the center of the low beta insertion. The dispersion function is nonzero except at the interaction point. The dispersion could not be made uniformly zero within the low beta insertion because the insertion contains lattice dipoles. The dipoles could not be removed because of tunnel constraints.

The Tevatron alternates between periods of fixed target and collider operation. During fixed target operation, the D0 straight section contains the Tevatron's extraction septa. Therefore, the inner low beta components of the D0 low beta insertion are designed to be easily removable.

The low beta insertions are unpowered during fixed target operation as they add considerably to the heat load that the refrigerators have to remove. For example, each insertion adds 36 helium cooled power leads to the refrigeration system plus the cyclic heat load generated within the quadrupole coils. During collider operation, the cyclic heat load of the lattice magnets and low beta magnets is absent and the additional heat load of the low beta insertion is tolerable. During fixed target operation with powered low beta components, the refrigerator satellites adjacent to the low beta insertions would have required added capacity. The exception to the not-powered rule are the Q2, Q3, and Q5 quadrupoles at B0, and the Q5 quadrupoles at D0. Their currents during fixed target operation are readjusted to mimic the function of the standard lattice quadrupoles that were removed to make place for the low beta insertion.

Table 1: Quadrupole parameters

	2-shell	1-shell
Number of quads per insertion	12	6
Peak gradient (T/cm)	1.4	0.58
Peak current (kA)	4.8	1.0
Q1 (T7) magnetic length (m)	1.4	.762
Q2 (T8)	3.35	.762
Q3 (T9)	5.59	.762
Q4	3.35	
Q5	1.4	
Coil inner diameter (cm)	7.5	7.5
Number of turns/pole inner	19	13
Number of turns/pole outer	28	
Strand diameter (size)(mm)	.528	1.09x1.76
Number of strands/cable	36	5*
Cable dim. w/o insulation(mm)	.897x9.78	1.09x8.8
Copper/superconductor ratio	1.5	1.5
NbTi short sample 5T,4.2K (A/mm^2)	3000	3000
* Each strand is insulated		

During collider operation, beam is injected into the Tevatron and accelerated to peak energy with β^* equal to 1.7 m. This lowers β_{max} on either side of the insertion to approximately 250 m, and reduces the probability of beam loss near the interaction region detectors during the time of the acceleration cycle when the beam is at its largest. The newly installed vertex detector at B0 is particularly sensitive to radiation damage. After the peak energy has been reached, β^* is reduced to increase the luminosity.

3. ELECTROSTATIC SEPARATORS

A 9 m long clear space has been left on both sides of the low beta insertion for electrostatic separators. The distribution of all the electrostatic separators within the Tevatron is shown in Figure 2. The horizontal and vertical separators are physically identical, differing only in their 90 degree relative orientation when installed. Each separator has a 3 m slot length, an electrode separation of 5 cm, and a nominal maximum operating field of 50 kV/cm. The electrode pairs are connected to separate power supply pairs that have opposite voltage polarities relative to a common ground. Up to four separators have been connected to a common power supply pair to obtain the required kick angle.

The separators have been made as strong as possible and are placed symmetrically and as close as possible to the interaction point. This separates the colliding proton-antiproton bunches before they reach the next beam crossing points on both sides of the interaction region. Beam crossings at small bunch separation are believed to be more harmful to the beam than head on crossings and may ultimately limit the maximum number of bunches that are injected into the Tevatron.

The separators function as "3-bumps" in the vertical and horizontal planes to form separated orbits. The proton-antiproton bunches are on the unseparated closed orbit as they collide at B0 and D0. When the bunches exit the interaction region, the separators kick them off-axis vertically and horizontally. The bunches now oscillate around the unseparated orbit and the approximately 90 degree phase difference between the vertical and horizontal oscillations prevents any head-on crossings . The proton-antiproton displacements relative to the unseparated closed orbit are always equal but of opposite sign. Vertical and horizontal separators located between B0 and D0 are adjusted to bring the bunches back on the unseparated orbit as they cross the third set of vertical and horizontal separators before entering B0 and D0. The third set of separators is adjusted to cancel the orbit slopes present as the bunches enter the separators. This maintains the bunches on the unseparated orbit as they again cross B0 and D0 for another collision.

The acceleration sequence of the Tevatron collider is as follows: The proton bunches are first injected onto the unseparated Tevatron closed orbit. Then the horizontal separators at B11 and B17, and the vertical separators at C17 are turned on. These separators result in totally separated orbits for the protons and antiprotons with the proper orbit displacements at the antiproton injection septum magnet after the antiprotons are injected. The counter-rotating bunches are accelerated on these orbits and remain on them until the low beta insertions are adjusted to a lower β^*. Finally, the remaining separators are rapidly turned on to bring the protons and antiprotons into collision at the B0 and D0 interaction regions.

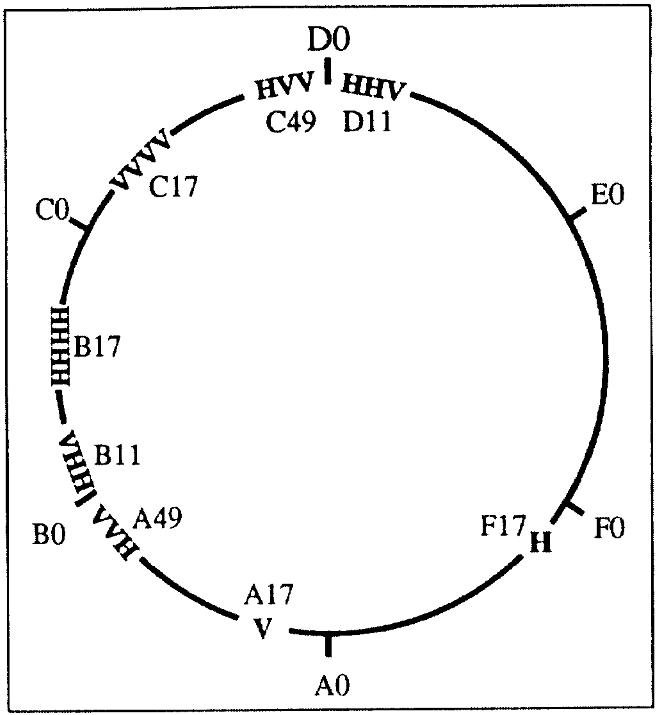

Figure 2. Tunnel placement of the electrostatic separators.

4. STATUS

All of the B0 low beta insertion, and all of the D0 low beta insertion except Q1 through Q4, were installed and commissioned prior to the 1991 fixed target run. The remaining D0 insertion quadrupoles were installed during the February 1992 shutdown after the completion of the fixed target run. The successful completion of the fixed target run indicates that the low beta insertions installed at B0 and D0 have not degraded the Tevatron's fixed target capability.

Approximately half of the electrostatic separators had been installed and commissioned prior to the February 1992 shutdown. The rest were installed during the shutdown. Six of the separators were powered during the fixed target run to measure their tunnel sparking rate in the presence of beam. The separators were tested "parasitically" by forming local orbit bumps with the separators and adjacent lattice correction dipoles. At 50 kV/cm, a single spark occurred during a full week of operation.

The performance of the B0 low beta insertion in collider mode was tested with protons immediately after its installation down to a β^* of .5 m. Prior to the February 1992 shutdown, it was further tested with protons, antiprotons, and separators as follows: Protons and antiprotons were injected into the Tevatron and accelerated to full energy on separate closed orbits; the B0 low beta insertion was adjusted to a β^* of .5 m; and the separators were reprogrammed to bring the beams into collision at B0.

The first test of the whole system will be the collider run scheduled for this year. At this time, the D0 low beta insertion and the remaining electrostatic separators are still undergoing electrical tests without beam. The next phase of commissioning will include a short period of beam studies and tuning, followed by the first collider run with separated orbits and two low beta insertions in the Tevatron.

5. REFERENCES

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