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THE BØ LOW-BETA INSERTION DESIGN FOR THE TEVATRON

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Abstract

The low design of the low-beta insertion installed at the BØ straight section of the Tevatron is presented. This design replaces two of the regular lattice quadrupoles with stronger, separately powered quadrupoles and adds an additional triplet in the free space on either side of the interaction point. By varying the four separate quadrupole circuits, and two trim quadrupole tuning circuits, it is possible to go smoothly from the normal, fixed-target configuration with $\beta^* = 75$ m in each plane to the colliding-beam mode of operation with $\beta^* = 1$ m in each plane, while maintaining a constant tune for the Tevatron.

A detailed study of the low beta insertion for the BØ experimental area has been carried out and is described below. The purpose of the study was to see if it is possible to turn on the insertion in a smooth and continuous manner and tune the insertion to a value of β^* of less than one meter while maintaining the overall tune of the Tevatron at a constant value. This was found to be possible. An examination of chromaticity corrections for the Tevatron with the low beta insertion on in various configuration was also undertaken.

A layout of the low beta insertion is shown in Fig. 1. It requires the replacement of the 32" quadrupoles at Tevatron magnet stations A48 and B12 with separately powered 66" quadrupoles and the addition of two 180" quadrupoles and six 144" quadrupoles within the long-straight section. These ten quadrupoles are powered anti-symmetrically on four separate circuits and must reach a maximum gradient of 25.5 KG/in at 1 TeV. In order to keep the maximum luminosity point close to the Tevatron BØ location, the quadrupoles at A48/B12 must be pushed as far upstream as possible. To do this, the normal dipole interace-to-quadrupole magnetic slot length has been reduced from 18.137" to 7.137" by changing the upstream bellows and moving the beam detector to the downstream end of the quadrupoles. This motions puts the maximum luminosity point 0.9 inches downstream of the Tevatron BØ for the final low beta of about one meter.

For normal fixed target operation, Q1 must run at approximately 10 KG/in and Q2, Q3, and Q4 must all be off. By contrast, at the "beginning of low beta", all of the quadrupoles must be on and running quite hard. The problem is to find a method of connecting these two solutions in a stepwise continuous manner while maintaining the overall tune of the Tevatron. This is by no means a simple straightforward process. The two solutions are in fact quite different and cannot be connected without disturbing the normal lattice functions outside the insertion region. A method has been found, however, which does not greatly disturb the rest of the machine. The required quadrupole gradients versus step number are listed in Table I and plotted in Fig. 2. On Figure 2, step number 0 corresponds to a retuned fixed target mode and step number 28 corresponds to a low beta of approximately one meter in each plane. The step size is rather arbitrary. This turn-on sequence was initially made of steps such that no gradient changed by more than 1.3 KG/in per step. A curve was then drawn through a plot of those points, larger step sizes were taken and connected by straight lines. These are the points shown. On the left side of Fig. 2 are listed β^* values for several steps. It should be noted that β^* does not decrease linearly with these steps. That is, if one looks at step 27, for example, one should not infer a value of $\beta^* = 1.5$. Gradients read off the graph for number 27 will indeed give a good low beta with β^* between one and two meters, but closer to two than one.

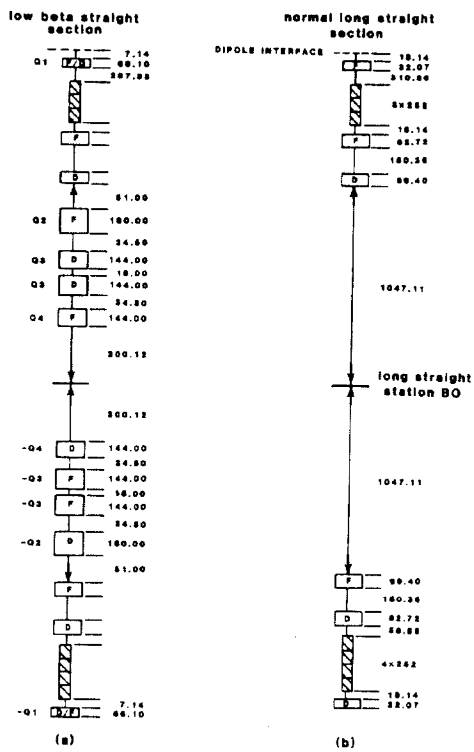

Fig. 1 Schematic layout of BØ straight section as initially configured with the low-beta magnets. Cross-hatched symbols are dipoles.

In all of this sequence, the Tevatron has been retuned to 19.585 in each plane. For particle-antiparticle collisions it is desirable to be above the half integer and the value of .585 centers of the tune in a region free of all resonances of order lower than 11th. The correction quadrupoles consist of two families, QFC and QDC, located next to the corresponding quadrupoles, QF or QD, at all stations 13 through 47. These corrections have a range of approximately ±2 KG/in at 50 amps. QFC has been plotted and ranges from +0.4 KG/in to -0.9 KG/in. QDC is given simply by

$$QDC = 0.0457 - QFC \text{ (KG/in)}$$

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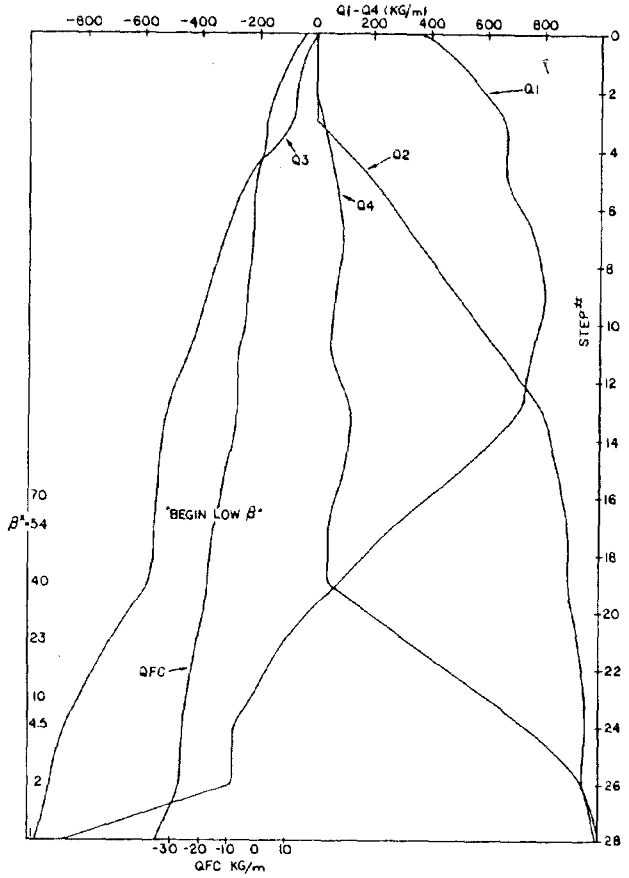

Fig. 2 Low-beta quadrupole gradient functions followed in turn-on sequence.

In this turn-on sequence, there is some disturbance to the lattice functions outside the insertion region. This is due to three distinct reasons.

1. The "off" solution and the "low beta" solution are, in fact, quite different. It is doubtful that they can be connected without allowing some mismatch.

2. The initial sequence, in steps of less than 1.3 KG/in, was not a very smooth curve. Some amount of mismatch was allowed in order to produce the curves plotted in Figure 2.

3. It was found that a higher luminosity can be achieved in the "1 meter low beta" by introducing some mismatch. This is because the long-straight sections are not exactly anti-symmetric, one side has more dipole edge focusing than the other, while the low beta quads of necessity are symmetric.

The amount of disturbance to the normal lattice functions, however, is quite small and insignificant as the low-beta squeeze will not be done until machine is at high energy where the beam is very small. The amount of disturbance can be easily calculated. If the mismatch at the end of the insertion is given by $\Delta\alpha$, $\Delta\beta$, where σ and β are the usual lattice parameters, then the amplitude of oscillation about the normal functions is given by

$$A = \frac{\beta_o}{2\sin 2\pi\nu}\left[\frac{a^2 + b^2}{1 + b}\right]^{1/2}$$

where ν is the tune, and a and b are give by

$$a = \Delta\alpha - \alpha_o \Delta\beta/\beta_o$$

$$b = \Delta\beta/\beta_o$$

with σ_o and β_o the matched lattice functions. In terms of A, the percent increase in the average lattice functions due to the mismatch is

$$\langle A\rangle = (\beta_o^2 + A^2)^{1/2}/\beta_o$$

For the sequence given, this quantity has a maximum of about 1.40 around step number 13. Table I lists various lattice functions versus step number for this tuning sequence. Figure 3 and 4 show plots of beta and dispersion functions across the BØ straight section for the fixed target mode of operation and for the 1-meter low-beta configuration.

In addition to this betatron mismatch, there is an unavoidable change in the dispersion function around the machine as this low beta is turned on. This is reflected in the change of maximum dispersion listed in Table I. Again, this should cause no problem due to increased beam size as the momentum spread at 1 TeV is much smaller than at injection. This could lead to a problem with chromaticity corrections, but it has been found that it does not. The correction sextupoles are also in two families and located at the same places as the correction quadrupoles. They have an integrated field of

$$B''\ell = \pm 100 \text{ KG/in at } 50 \text{ A}$$

During the low beta turn-on sequence, the natural, uncorrected chromaticity ranges from -21 to -30. For colliding beam mode, the chromaticity should be made slightly positive in order to avoid longitudinal head-tail instabilities. This has been accomplished for both the "off" solution and the one meter low beta solution as well as for the intermediate steps. The needed sextupole ranges from 11.4, -19.1 KG/in to 14.6, -23.5 KG/in for the two families.

A solution for the actual running of the BØ low beta has been presented. Beam can be injected into the normal Tevatron lattice and the low beta can be slowly and smoothly turned on after acceleration to 1 TeV. There is an increase in the beta and dispersions functins during the turn on which does not present a beam size problem due to the small emittance and momentum spread at 1 TeV. Both the overall tunes and chromaticities can be held constant with the standard correction elements as this tuning sequence is followed. The major objection to this sequence is the large number of steps to be programmed into the various power supplies. While this is not a serious problem, it would be nice to have many fewer steps. Recent reports from other colliding beam machines, CERN-SPS, PETRA, indicate that they have been found to be able to turn on a low beta region in a few steps typically 3 to 5. The final operation of the Tevatron low-beta system will be adjusted for a minimal number of tune steps.

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Table I

STEP	ν_x	QFC(2) (KG/m)	Q1 (KG/m)	Q2 (KG/m)	Q3 (KG/m)	Q4 (KG/m)	$\hat{\beta}_x$ (m)	$\hat{\beta}_y$ (m)	$\check{\beta}_x$ (m)	$\check{\beta}_y$ (m)	$\hat{\eta}$ (m)	$\check{\eta}$ (m)	β^*_x (m)	η^* (m)
0	19.585	16.80	369.6186	0.0000	0.0000	0.0000	249	248	28.0	28.0	5.7	1.2	72.8	2.72
1	19.581	9.69	510.0000	0.0000	- 50.0000	0.0000	289	274	19.0	20.0	6.7	0.6		
2	19.589	5.94	590.0000	0.0000	- 70.0000	0.0000	288	299	17.0	17.0	7.0	0.3		
3	19.585	2.95	670.0000	0.0000	- 78.0000	26.0000	270	273	15.0	15.0	7.1	0.4	51.1	1.75
4	19.585	2.10	670.0000	100.0000	-160.0000	50.0000	266	274	13.0	13.0	7.2	0.3		
5	19.582	- 0.52	670.0000	200.0000	-240.0000	75.0000	327	348	11.0	11.0	7.4	0.1		
6	19.586	- 1.08	720.0000	275.0000	-280.0000	85.0000	263	270	10.0	10.0	7.5	0.1		
7	19.585	- 1.45	770.0000	350.0000	-320.0000	100.0000	291	287	10.0	10.0	7.6	0.1	107.0	1.42
8	19.585	- 1.85	790.0000	425.0000	-350.0000	85.0000	345	339	8.0	8.0	7.7	-0.1		
9	19.582	- 3.88	805.0000	500.0000	-380.0000	70.0000	348	342	8.0	8.0	7.8	-0.1		
10	19.586	- 3.91	785.0000	575.0000	-410.0000	65.0000	367	361	7.0	7.0	7.9	-0.3		
11	19.583	- 6.44	760.0000	650.0000	-440.0000	55.0000	325	327	6.0	6.0	8.0	-0.3		
12	19.582	- 6.44	740.0000	725.0000	-480.0000	90.0000	364	360	5.0	5.0	8.1	-0.4		
13	19.588	- 7.00	720.0000	800.0000	-520.0000	130.0000	402	397	5.0	5.0	8.1	-0.5		
14	19.585	- 8.22	620.0000	825.0000	-530.0000	115.0000	378	376	3.0	3.0	8.2	-0.5	111.4	1.04
15	19.583	-11.77	520.0000	850.0000	-545.0000	100.0000	286	322	4.0	4.0	8.3	-0.4		
16	19.586	-12.43	400.0000	870.0000	-550.0000	75.0000	283	284	3.0	3.0	8.3	-0.5		
17	19.584	-15.61	275.0000	890.0000	-560.0000	50.0000	266	255	3.0	3.0	8.3	-0.5	54.0	
18	19.585	-16.53	180.0000	890.0000	-570.0000	50.0000	248	240	3.0	3.0	8.4	-0.6	47.2	0.76
19	19.585	-17.11	90.0000	890.0000	-580.0000	50.0000	246	250	3.0	3.0	8.5	-0.7	41.0	
20														
21	19.584	-20.57	-105.0000	930.0000	-710.0000	325.0000	313	307	3.0	3.0	8.7	-0.8	23.0	0.53
22														
23	19.585	-24.50	-215.0000	955.0000	-820.0000	610.0000	345	336	6.0	6.0	8.8	-1.0	10.0	
24	19.585	-25.62	-280.0000	956.0000	-870.0000	740.0000	430	413	4.0	3.0	8.9	-1.1	4.5	
25														
26	19.585	-25.99	-285.0000	945.0000	-925.0000	940.0000	436	419	2.0	2.0	9.0	-1.1	2.0	
27														
28	19.586	-35.00	-878.9719	1005.5897	-971.0883	999.1776	958	866	0.8	0.9	9.4	-1.3	0.81	0.18

(1) ν_y is very close to ν_y

(2) QDC = 1.80 - QFC (KG/m)

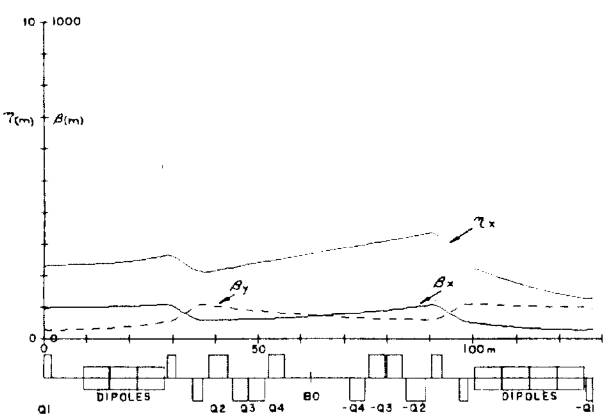

Fig. 3 BØ straight-section lattice functions in fixed-target mode of operation.

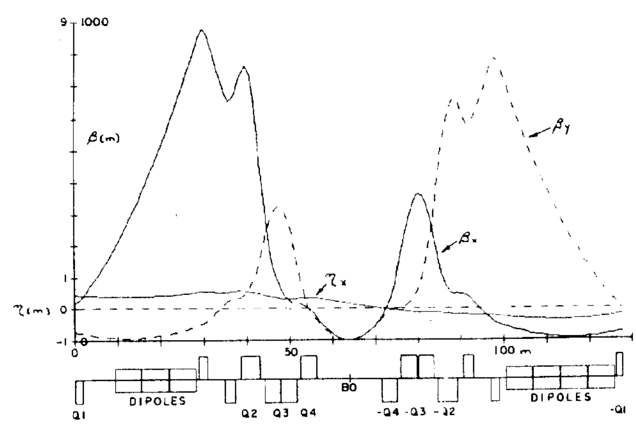

Fig. 4 Lattice functions for 1 meter low beta configuration.