Beams-doc-491

Strong Systematic Steering Correction in Regions of the Tevatron*

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Several Regions of the Tevatron are seen to have vertical dipole correction magnets which are running systematically strong. The average vertical corrector strength for the ring is about 16 μrad. (The average of the horizontal correctors, for comparison, is 0.7 μrad.) In some cases, several cells worth of vertical correctors are running with average strengths of 70 μrad or so, as in E-sector. In B sector, 7 cells (7 consecutive vertical correctors, over a distance of about 0.4 km) are all running at about 80-90 μrad. A logical explanation for this effect is that the dipole magnets in these regions have become systematically rolled, tilting toward the inside of the ring. Several small sets of roll measurements were performed in 2002. During the January 2003 shutdown over 95% of the dipole magnets in the tunnel had their roll measured. Below we compute the roll angles required to explain the systematic dipole corrector settings and compare with the recent magnet roll measurements performed in the Tevatron tunnel.

Consider a proton circulating clockwise in the Tevatron and suppose the magnets in a particular region are systematically rolled by an angle ϕ. A positive value of ϕ tilts the magnets toward the inside of the ring. The ideal dipole field is up, and therefore the rolled dipoles within a half-cell will generate a horizontal field component to steer the beam vertically by an amount $\theta = -\phi\theta_0$, where θ_0 is the total bend angle of the half-cell. During orbit smoothing, the correctors are adjusted to steer the beam through the middle of the quadrupoles (and BPM's) in the otherwise ideal accelerator. We will, for now, ignore the coupling introduced by the rolled quadrupoles in the calculation.

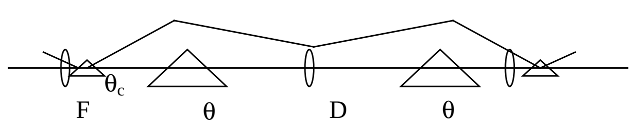

Figure 1: Correction of rolled dipole magnets in a FODO cell.

For a periodic cell within this region, the scheme is diagramed in Figure 1. Here, θ_c is the corrector strength, y_0' is the initial beam angle just after the corrector, L is the half-cell length, and F is the focal length (absolute value) of the thin lens quadrupole magnets. Since the beam is

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centered in the BPM's, the equation for the periodic trajectory through the system is given by

$$M_q M_L M_{-q} M_L \begin{pmatrix} 0 \\ y_0' \end{pmatrix} + M_q M_L M_{-q} M_{L/2} \begin{pmatrix} 0 \\ \theta \end{pmatrix} +$$
$$M_q M_{L/2} \begin{pmatrix} 0 \\ \theta \end{pmatrix} + \begin{pmatrix} 0 \\ \theta_c \end{pmatrix} = \begin{pmatrix} 0 \\ y_0' \end{pmatrix}$$

where $M_{\pm q}$ are the 2×2 matrices for focusing and defocusing (in vertical plane) quadrupoles, M_L, $M_{L/2}$ are the matrices for drifts of lengths L and $L/2$. Solving for the slope y_0' in terms of θ,

$$y_0' = -\theta \;\frac{1 + \frac{1}{2}\sin\mu/2}{1 + \sin\mu/2}$$

and solving for the corrector strength,

$$\theta_c = -\theta \;\frac{2 + \sin\mu/2}{1 + \sin\mu/2} \;=\; 2y_0' \,.$$

Likewise, solving for the roll angle,

$$\phi = \frac{\theta_c}{\theta_0}\;\frac{1 + \sin\mu/2}{2 + \sin\mu/2} \,.$$

As a numerical example, take $\mu = 70^\circ$ and $\theta = 4(2\pi)/774 = 32$ mrad. If $\theta_c = 70$ μrad, then the average roll angle of the magnets in the tunnel would be 1.3 mrad. On October 22, 2002, roll measurements were performed on 56 magnets from E27-1 to E42-1 in the Tevatron tunnel. The average measured roll angles of the 44 dipole magnets through this region was 1.34 mrad.

For the case of a systematic correction of 70 μrad, the BPM's in the region will read zero, but the maximum vertical displacement in the middle of the half-cell will actually be

$$\Delta\hat{y} = y_0'(L/2) = (\theta_c/2)(L/2) = (35\ \mu\text{rad})(15\text{m}) = 0.53\ \text{mm}.$$

In the regions where $\theta_c \approx 100$ μrad, the average roll angles must be around 2 mrad, and the vertical displacements within the half-cell regions may be about 0.75 mm.

Naturally, the actual corrector settings found in the Tevatron depend upon the transverse alignment of the quadrupoles and other error sources. Thus, random fluctuations about the mean settings are expected and observed. The correlation between the roll measurements of January 2003 and the vertical dipole corrector settings can be easily seen in Figure 2.

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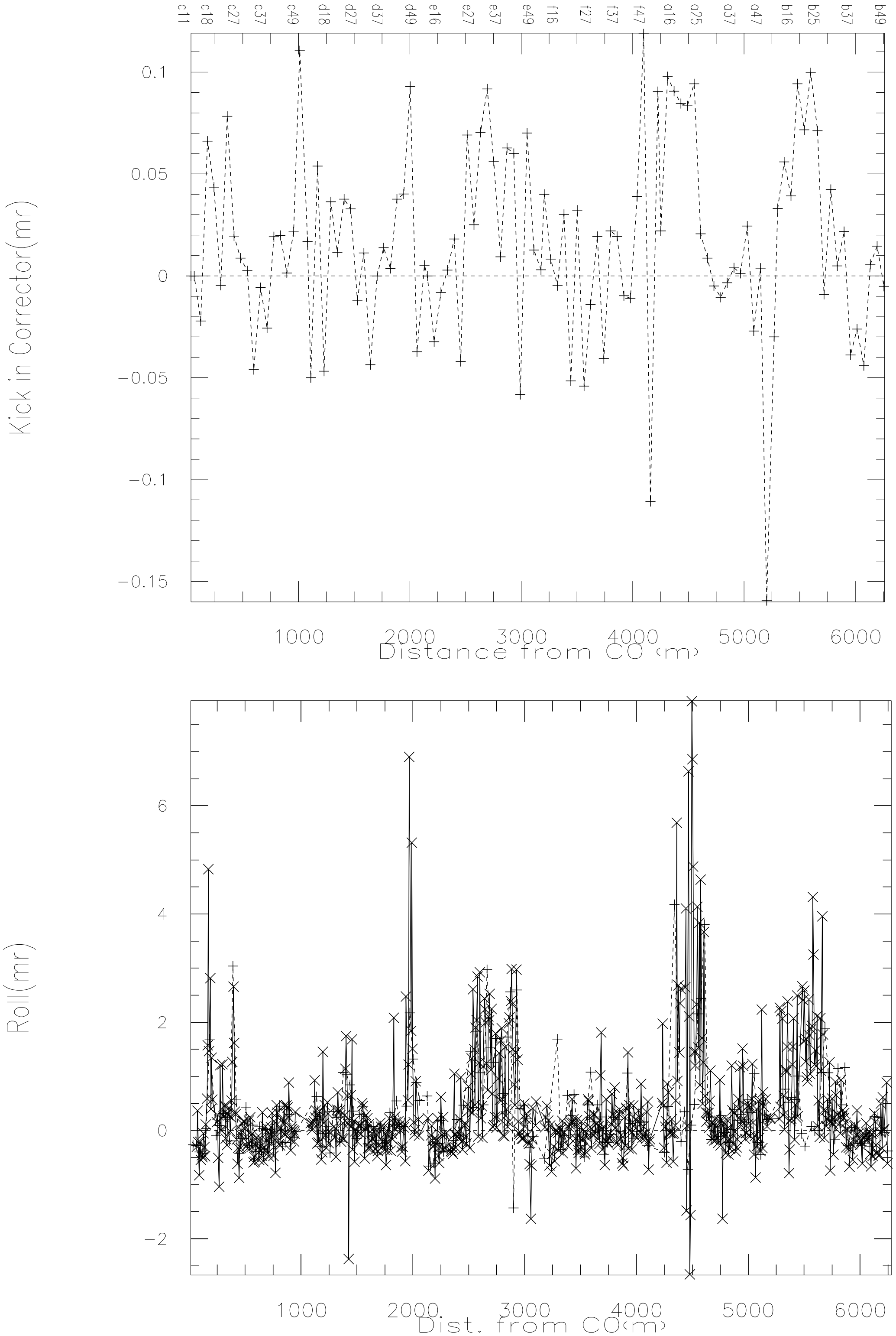

Figure 2: (a) Vertical dipole corrector strengths, and (b) measured magnet roll angles vs. distance from C0 (m). All angles are in mrad.