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Effects of $\int G d\ell$ Fluctuations

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By early July, 1982 it was apparent that the normal (66.1") Tevatron quadrupoles were showing small but significant systematic variations in $\int G d\ell$. To appraise the potential effects of these variations we undertook to calculate the $\Delta\beta/\beta$ caused by them. This note summarizes the results of these calculations. The effects found are of the expected magnitude and do not suggest any serious problems.

Quadrupole Data

Ohnuma[1)] summarized the quadrupole data that were available and suggested that the available magnets can be partitioned into four classes (see Table 1). (All magnetic field parameters are measured at 1000 A, corresponding to 225.8 GeV/c beam momentum.)

At the time these calculations were made, the 60 normal quadrupoles required had been assigned to E and F sectors and their parameters were used. In the other four sectors, magnets were distributed from the four classes as follows[1)]: (i) class H at B24, 25, 34, 35 and C24, 25, 34 and 35, (ii) mixture, 28 L's and 20 R's for D sector and B22 through B47, excluding B24, 25, 34 and 35, and (iii) mixture, 41 R's and 23 M's for A sector, B13 through B21, and C sector, excluding C24, 25, 34 and 35.

Values of $\int G d\ell$ were selected at random for quadrupoles in each class from flat distributions of width $\pm 2\sigma$ defined by the means and sigmas given in Table I.

At the time this work was done, data were not yet available for the special quadrupoles required at locations 11, 12, 48 and 49 in all sectors.

To provide a simple estimate of potential problems, computer runs were made assuming uniform shifts of 0.4% in each of the special quads.

Results

For each set of quadrupole error terms generated as described, program TEVLAT was used to calculate a table of β-function around the ring. The figure of merit used is $\Delta\beta/\beta$, computed with respect to the ideal lattice. The values of $|\Delta\beta/\beta|_{max}$ and the rms average of $\Delta\beta/\beta$ around the ring are taken to summarize the results.

The fluctuations in $\int G d\ell$ result in small tune shifts, typically less than .01. Comparing results for several cases with and without using the trim quads to reset the tune to their unperturbed values showed no significant effect; all results reported here omit tune correction.

1. Normal (66.1") quadrupoles

Ten sets of quadrupole error terms were generated and, with all other lattice elements ideal, evaluated as described. The results are summarized in Table 2.

2. Special quadrupoles

Each special quadrupole was assumed to be in error by 0.4%. Results were obtained for each length special quad separately, all quads of that length being shifted. The results are summarized in Table 3.

3. Comparison with dipole b_1 term

Another contribution to variations in $\int G d\ell$ around the ring arises from the b_1 component in the main dipoles. To compare the effects from the two sources, five sets of harmonics were generated, including b_1 terms in the dipoles and $\int G d\ell$ fluctuation in the quadrupoles. The values of b_1 were selected from flat distribution of width $\pm 2\sigma$ using $\langle b_1 \rangle = 0.11\text{x}10^{-4}$ and $\sigma = 0.67\text{x}10^{-4}$ from MTF measurements on 490 dipoles. The sets were used to compute $\Delta\beta/\beta$ both using and excluding the dipole b_1 terms. The results,

Table 4, show that inclusion of b_1 terms in the dipole field does not significantly affect the $\Delta\beta/\beta$ distributions.

Reference

1. S. Ohnuma, Memos, July 2,1982; July 6, 1982

class	$\int G d\ell$	σ	number
R (regular)	287.9 kG	.34 kG	113
H (high)	288.6	.48	16
L (low)	287.0	.35	32
M (medium)	287.5	.35	19

Table 1. Means and sigmas of $\int G d\ell$ for the 4 classes of normal quadrupoles. The number shown is the expected mix in the final 180 magnet sample.

	$\lvert\Delta\beta/\beta\rvert_{x,max}$	$rms(\Delta\beta/\beta\lvert_x)$	$\lvert\Delta\beta/\beta\rvert_{y,max}$	$rms(\Delta\beta/\beta\lvert_y)$
	0.064	0.027	0.076	0.029
	0.059	0.025	0.078	0.039
	0.097	0.046	0.161	0.081
	0.104	0.055	0.090	0.037
	0.063	0.026	0.096	0.051
	0.069	0.028	0.055	0.026
	0.062	0.032	0.068	0.033
	0.084	0.044	0.069	0.037
	0.080	0.037	0.053	0.024
	0.104	0.040	0.036	0.013
avg:	0.078±0.018	0.036	0.078±0.034	0.037

Table 2. Maximum and rms average $\Delta\beta/\beta$ for ten sample distributions of $\int G d\ell$ values.

Length	$\|\Delta\beta\ \beta\|_{x,\ max}$	$rms(\Delta\beta/\beta)_x$	$\|\Delta\beta/\beta\|_{y,max}$	$rms(\Delta\beta/\beta)_y$
99"	.053	.027	.053	.027
90"	.017	.012	.017	.012
82"	.027	.011	.027	.011
32"	.009	.004	.009	.004
25"	.004	.003	.004	.003
(1)	.013	.007	.013	.007

Table 3. Maximum and rms $\Delta\beta/\beta$ resulting from systematic shifts 0.4% in $\int G d\ell$ for special quads. The line designated (1) results from combined errors of 0.25% in the 99" and 90" quads and of 0.15% in the 82" quads.

Horizontal:

	$b_1 \neq 0$		$b_1 \equiv 0$	
	$\lvert\Delta\beta/\beta\rvert_{max}$	$rms(\Delta\beta/\beta)$	$\lvert\Delta\beta/\beta\rvert_{max}$	$rms(\Delta\beta/\beta)$
	.059	.023	.088	.042
	.091	.045	.046	.018
	.061	.024	.052	.023
	.095	.044	.073	.034
	.088	.042	.086	.041
	.079 ± .017	.036 ± .011	.069 ± .019	.032 ± .011
Vertical:				
	.063	.029	.096	.054
	.098	.054	.061	.025
	.072	.030	.053	.018
	.075	.038	.059	.031
	.092	.036	.063	.032
	.080 ± .015	.037 ± .010	.066 ± .017	.032 ± .014

Table 4. Maxima and rms averages of $\Delta\beta/\beta$ for five cases showing the effect of including dipole b_1 components and quadrupole $\int G d\ell$ fluctuations.