Summary of TeVatron Spool Data.
Beams-doc-1160-v1

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Introduction

John Tomkins has recently completed a useful compilation of the measurement data on the Tevatron correctors. This note attempts to summarize the data from his compilation in a slightly different way, namely the averages and standard deviations are calculated for each spool type separately.

The data on the harmonic composition of the magnetic field of the spools was obtained from measurements made at room temperature using at 11Hz. Similar measurements were made on the Tevatron dipoles so that the data could be used to reshim the magnets to minimize the b_1 and a_1 moments. Therefore this note includes a comparison of the room temperature measurements of the dipoles with the cold measurements.

Comparison of the Room Temperature Measurements of the Tevatron Dipoles with the Cold measurements.

The measurements of the multipoles of the existing spools in the Tevatron lattice were done at room temperature (RT) at 11Hz. Room temperature measurements are less familiar to us in the Accelerator Division than the measurements made on magnets when they are cold.[1] As part of the fabrication of the Tevatron dipoles, the magnets were measured at RT. The measured RT values of b_1 and a_1 were used to determine the initial values

[1] Both the RT and cold measurements discussed here are to be found in the RIM database of magnet data. These data are being moved to a Sybase database.

of the shims used to eliminate these multipole moments before the magnets were installed in the tunnel.

There are several comparisons we can make between the RT measurements and the cold measurements:[2]

- If the RT measurements of the b_1 and the a_1 were correct, and if the algorithm used to calculate the values of the shims was correct, then we would expect, for the cold measurements, that the average values of b_1 and a_1 would be 0 with a small spread;
- We can compare the average and RMS spreads of the values of b_3, b_4, a_3, and a_4.

Table I shows the comparison of the measured values of the b_1-b_4 and a_1-a_4 high order multipoles. They are also plotted in Figure 1.

Table I
Averages of the b_1-b_4 and a_1-a_4 High Order Multipoles
Measured at RT and Cold.

Moment	Number	RT Average	RT σ	Number	MTF Average	MTF σ
b_1	890	0.584	2.592	774	0.083	0.488
b_2	888	-0.998	4.104	774	0.826	3.022
b_3	890	0.357	1.843	774	-0.236	0.742
b_4	889	0.513	2.308	774	-0.584	1.303
a_1	888	-0.105	3.660	774	0.171	0.534
a_2	885	0.937	3.263	774	0.116	1.152
a_3	887	-1.175	2.016	774	-0.094	1.443
a_4	884	-1.520	4.797	774	-0.104	0.438

The cold (MTF) measurements of b_1 and a_1 are indeed small, and with a small spread. Hopefully this would indicate that the shimming done on the basis of the RT measurements was accurate. We know however that the shims except for the fact that the final shim values were determined from cold measurements of the moments.[3] Thus there is no useful comparison that can be made between the RT and cold measurements of the b_1 and a_1.

[2]The MTF data used are those obtained at 4000A. The change in the b_3, b_4, a_3 and a_4 moments with current is small.

[3]Ray Hanft, private communication.

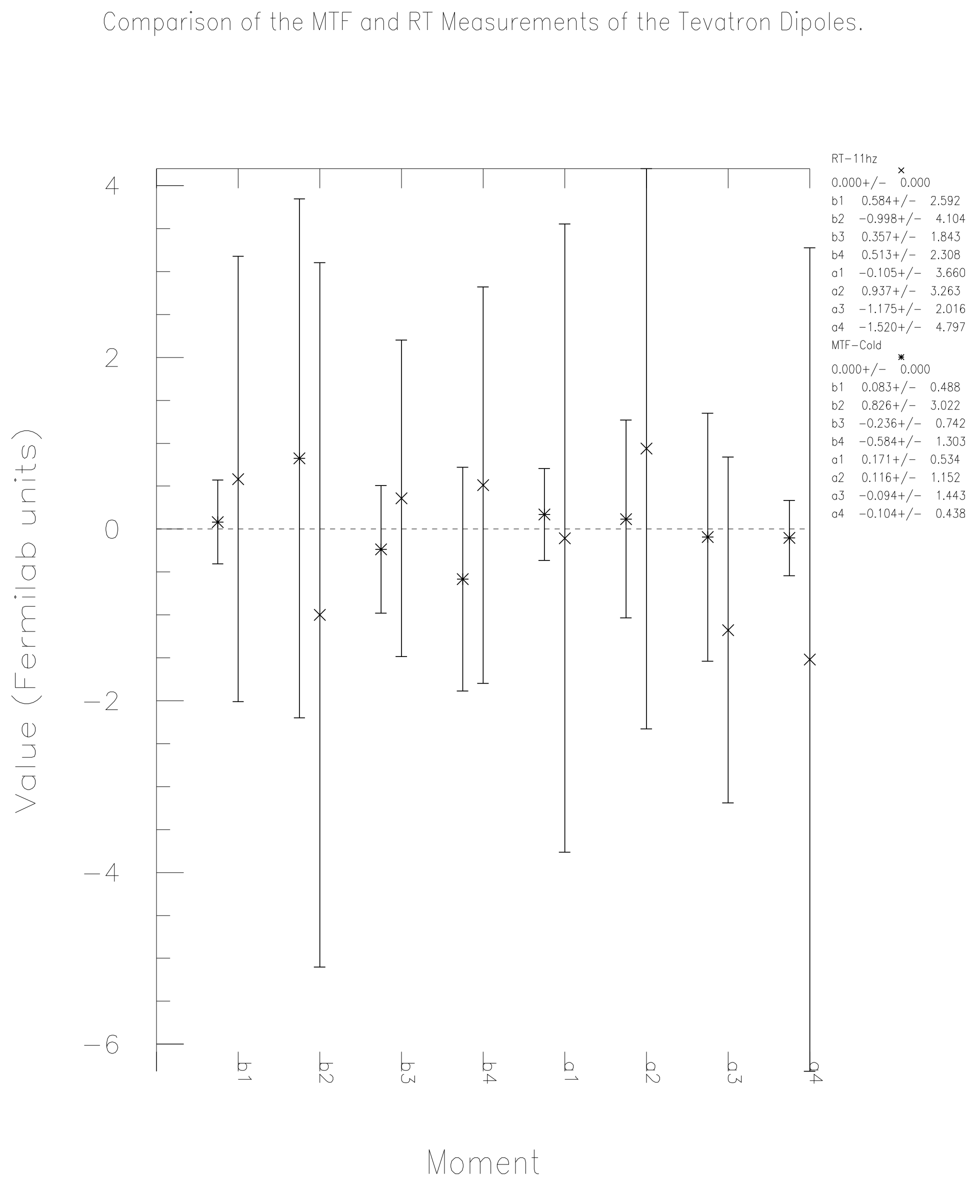

Figure 1: Comparison for Tevatron Dipoles of the RT Measurements with the Cold Measurements at MTF

The b_2 values cannot be compared due to the large hysterisis in b_2 and the drift in this moment.

The b_3 and b_4 moments agree in magnitude but have the opposite sign. Whether the difference is real or due to a different definition in the two measurements I cannot at this time say.

The a_3 and a_4 moments are both zero, within the rather large spread associated with each measurement, for both the RT and cold measurements.

In general the spread in the RT measurements is at least twice that of the cold measurements.

In conclusion I would say that the RT measurements on the arc dipoles gave values for the multipoles that are at best indicative of the values measured cold.

Dipole Correctors

The normal (horizontal) dipole correctors are in the first package of the **A, C, E,** and **G** type spools.[4] Figure 2 gives the values of the transfer constants (in kG$\cdot in$).[5]

The average strength, at 50A, of the **A,C** and **E** coils is $152 \pm 6kG \cdot in$.[6]

The nominal strength of these correctors, at a current of 50A, is 170 $kG \cdot in$, or 181 $kG \cdot in$ depending on the source of the information. The warm measurements at 11Hz of the dipole strength are only about 90% of their design strength. It is important to recall the observed strength depends on the frequency (11Hz vs. DC measurement) and the temperature at which the measurements were made. From cold measurements made on two spools the average integrated strength was $\approx 174kG \cdot in$.[7] This is close to the nominal value.

Based on these facts caution must be exercised before one can be confident that the measured values of the transfer constants in the spools can be used to predict the performance of the spools in the TeVatron. The nominal

[4] The **H** spools have both a normal and skew dipole coil. There are no data distributed on the normal dipole for the **H** spools.

[5] There are unfortunately inconsistencies in the data. TSD303 is listed as a normal (horizontally bending dipole) while the TSD have skew (vertical) dipole coils. This, and other problems in the data, should, at least in princple, be resolved.

[6] The data for the **G** type coils includes suspect values which led me to not include them in the average. TSG309 is anonymously weak with a transfer constant of $109kG \cdot in$ while TSG372 has a listed strength of $484kG \cdot in$.

[7] Ray Hanft, private communication.

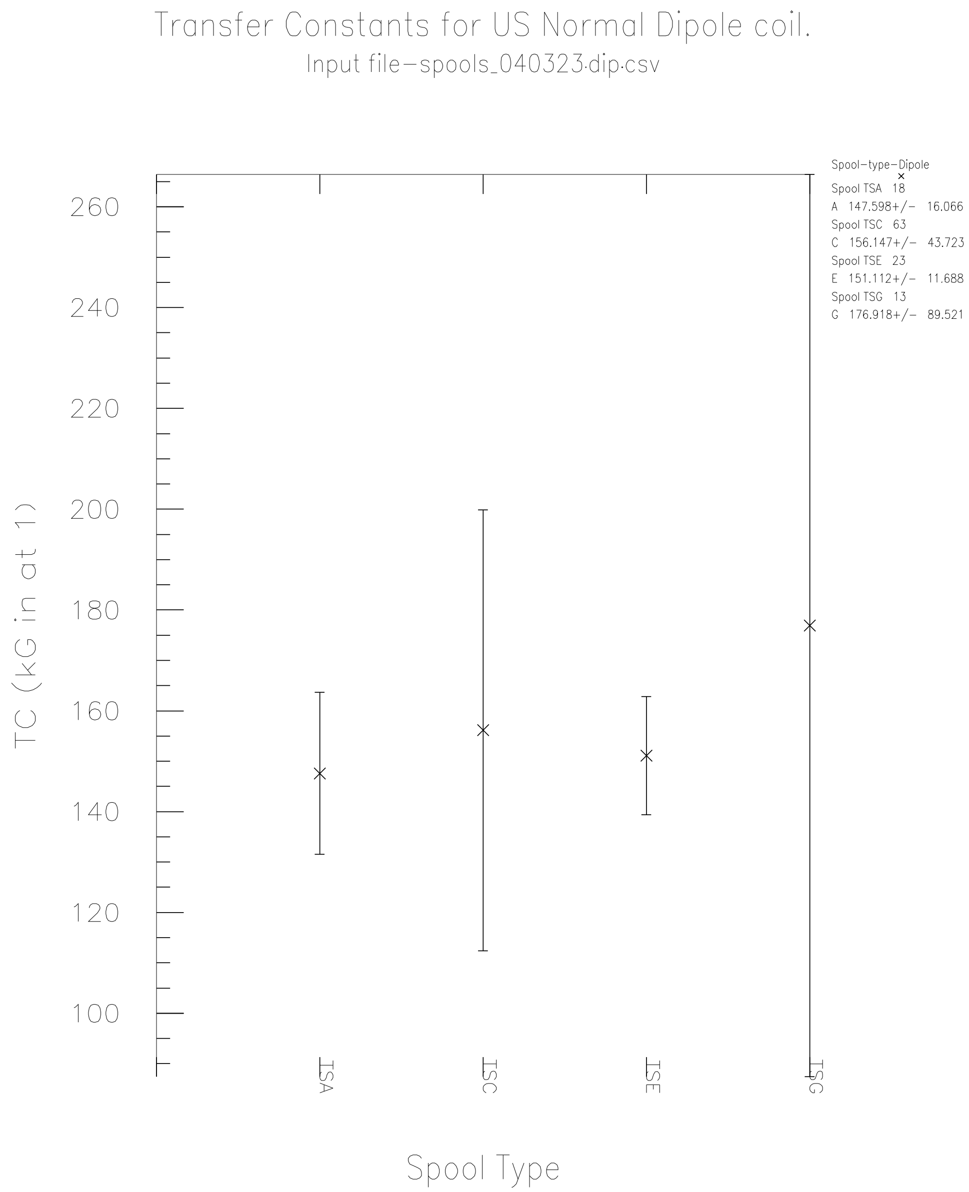

Figure 2: Measured Strength of the Horizontal Dipole Corrector Coils ($kG \cdot in$).

values of the transfer constants seem to be reasonable, based on the two spools with cold measurements, and are probably more accurately represent the performance of the spool coils in the tunnel than do the warm 11Hz measurements.

The skew (vertical) dipole correctors are in the first package of the **B, D, F,** and **H** type spools. Figure 3 gives the values of the transfer constants (in kG· in). The average strength, again at a current of 50A of the **B,D** and **F** coils is $151 \pm 6kG \cdot in$, the same as for the horizontal correctors.[8]

The measured high order multipoles (HOM)for the dipole coils are displayed in Table IIa and are plotted in Figure 4 for the different types of spools with normal dipoles. Table IIb contains the data for the skew dipoles which are plotted in Figure 5. The only statistically significant moments are the b_2 for the normal dipoles and the a_2 for the skew dipoles. All the other HOM are smaller than the variance on the multipole.

Table IIa
High Order Multipoles for the Normal Dipole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
A	US	Dipole	Normal	b0	18	-0.717	1.068
A	US	Dipole	Normal	b1	18	-3.978	41.765
A	US	Dipole	Normal	b2	18	-181.556	60.649
A	US	Dipole	Normal	b3	18	-3.233	18.315
A	US	Dipole	Normal	a0	18	-36.961	113.828
A	US	Dipole	Normal	a1	18	-10.344	37.425
A	US	Dipole	Normal	a2	18	-8.311	9.810
A	US	Dipole	Normal	a3	18	-3.294	16.273
A	US	Dipole	Normal	TC	18	147.598	16.066
C	US	Dipole	Normal	b0	63	-1.109	1.585
C	US	Dipole	Normal	b1	63	-3.863	29.953
C	US	Dipole	Normal	b2	63	-177.225	54.373
C	US	Dipole	Normal	b3	63	6.825	17.868
C	US	Dipole	Normal	a0	63	-12.724	148.803
C	US	Dipole	Normal	a1	63	0.854	33.427
C	US	Dipole	Normal	a2	63	-9.863	11.355
C	US	Dipole	Normal	a3	63	-4.486	19.219
C	US	Dipole	Normal	TC	63	156.147	43.723

[8]The data for the **H** type coils includes suspect values which led me to not include them in the average. TSH367, TSH368 and TSH373 have anomalously large values.

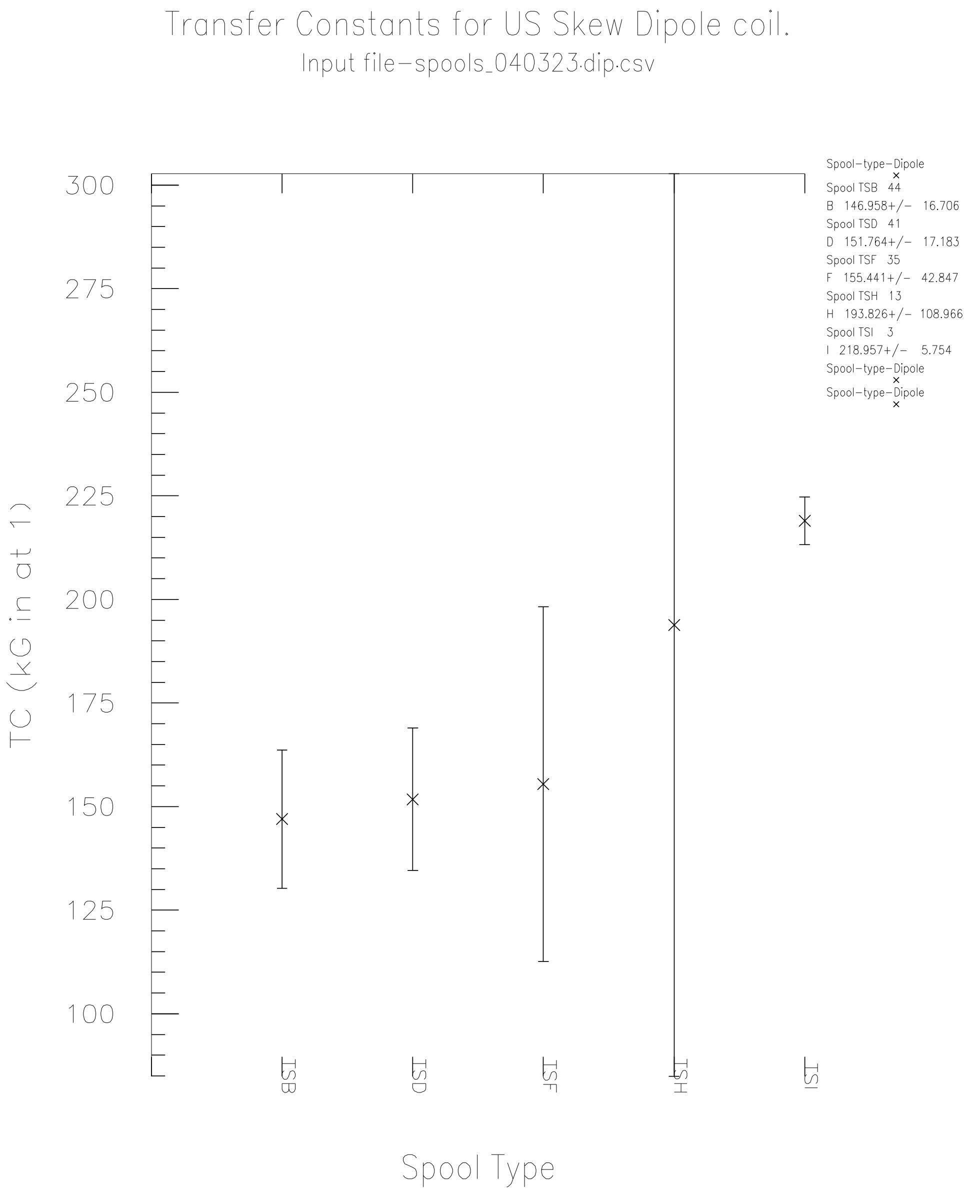

Figure 3: Measured Strength of the Vertical Dipole Corrector Coils ($kG \cdot in$).

Table IIa

High Order Multipoles for the Normal Dipole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
E	US	Dipole	Normal	a0	23	-32.309	139.455
E	US	Dipole	Normal	a1	23	2.196	31.017
E	US	Dipole	Normal	a2	23	-5.900	10.154
E	US	Dipole	Normal	a3	23	-6.100	13.344
E	US	Dipole	Normal	TC	23	151.112	11.688
E	US	Dipole	Normal	b0	23	-1.017	1.305
E	US	Dipole	Normal	b1	23	3.391	47.779
E	US	Dipole	Normal	b2	23	-160.557	50.561
E	US	Dipole	Normal	b3	23	9.470	16.343
G	US	Dipole	Normal	b0	13	-1.985	1.360
G	US	Dipole	Normal	b1	13	-11.692	42.675
G	US	Dipole	Normal	b2	13	-154.362	44.658
G	US	Dipole	Normal	b3	13	1.238	16.313
G	US	Dipole	Normal	a0	13	-105.792	168.473
G	US	Dipole	Normal	a1	13	-13.223	33.752
G	US	Dipole	Normal	a2	13	-3.500	5.684
G	US	Dipole	Normal	a3	13	1.769	16.144
G	US	Dipole	Normal	TC	13	176.918	89.521

Table IIb

High Order Multipoles for the Skew Dipole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
B	US	Dipole	Skew	b0	44	-27.677	124.654
B	US	Dipole	Skew	b1	44	-10.270	36.112
B	US	Dipole	Skew	b2	44	7.607	8.174
B	US	Dipole	Skew	b3	44	1.907	19.821
B	US	Dipole	Skew	a0	44	0.566	1.310
B	US	Dipole	Skew	a1	44	-2.977	33.286
B	US	Dipole	Skew	a2	44	-186.461	96.131
B	US	Dipole	Skew	a3	44	-2.320	21.189
B	US	Dipole	Skew	TC	44	146.958	16.706
D	US	Dipole	Skew	b0	41	-22.244	149.030
D	US	Dipole	Skew	b1	41	-1.620	40.828
D	US	Dipole	Skew	b2	41	5.312	12.322
D	US	Dipole	Skew	b3	41	-3.593	22.407

Table IIb
High Order Multipoles for the Skew Dipole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
D	US	Dipole	Skew	a0	41	1.117	1.765
D	US	Dipole	Skew	a1	41	7.273	40.537
D	US	Dipole	Skew	a2	41	-171.280	77.659
D	US	Dipole	Skew	a3	41	-4.990	18.008
D	US	Dipole	Skew	TC	41	151.764	17.183
F	US	Dipole	Skew	b0	35	-16.223	133.343
F	US	Dipole	Skew	b1	35	-7.191	36.158
F	US	Dipole	Skew	b2	35	5.880	9.078
F	US	Dipole	Skew	b3	35	-5.097	16.556
F	US	Dipole	Skew	a0	35	0.897	1.748
F	US	Dipole	Skew	a1	35	8.391	35.664
F	US	Dipole	Skew	a2	35	-178.200	54.646
F	US	Dipole	Skew	a3	35	-9.357	16.283
F	US	Dipole	Skew	TC	35	155.441	42.847
H	US	Dipole	Skew	b0	13	-111.508	284.199
H	US	Dipole	Skew	b1	13	2.085	23.514
H	US	Dipole	Skew	b2	13	2.915	13.004
H	US	Dipole	Skew	b3	13	0.731	9.413
H	US	Dipole	Skew	a0	13	4.677	12.415
H	US	Dipole	Skew	a1	13	6.954	17.096
H	US	Dipole	Skew	a2	13	-168.654	58.501
H	US	Dipole	Skew	a3	13	-0.546	6.724
H	US	Dipole	Skew	TC	13	193.826	108.966
I	US	Dipole	Skew	b0	3	-246.367	30.208
I	US	Dipole	Skew	b1	3	27.633	54.274
I	US	Dipole	Skew	b2	3	0.533	7.962
I	US	Dipole	Skew	b3	3	-1.400	14.176
I	US	Dipole	Skew	a0	3	-3.067	0.741
I	US	Dipole	Skew	a1	3	-4.600	13.903
I	US	Dipole	Skew	a2	3	82.900	39.872
I	US	Dipole	Skew	a3	3	-0.033	6.323
I	US	Dipole	Skew	TC	3	218.957	5.754

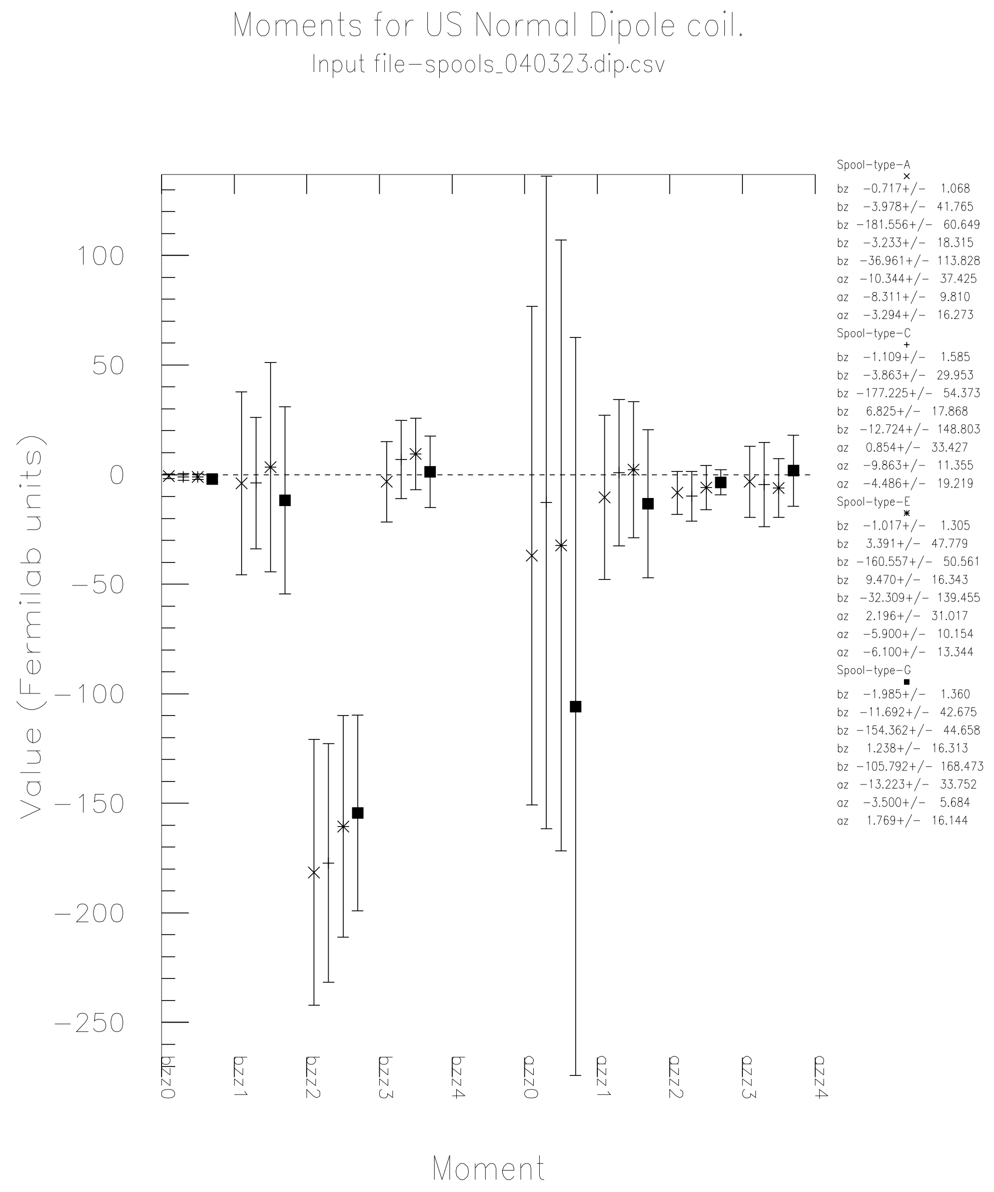

Figure 4: Measured Strength of the Multipoles for the Normal Dipole Corrector Coil (Fermilab units.)

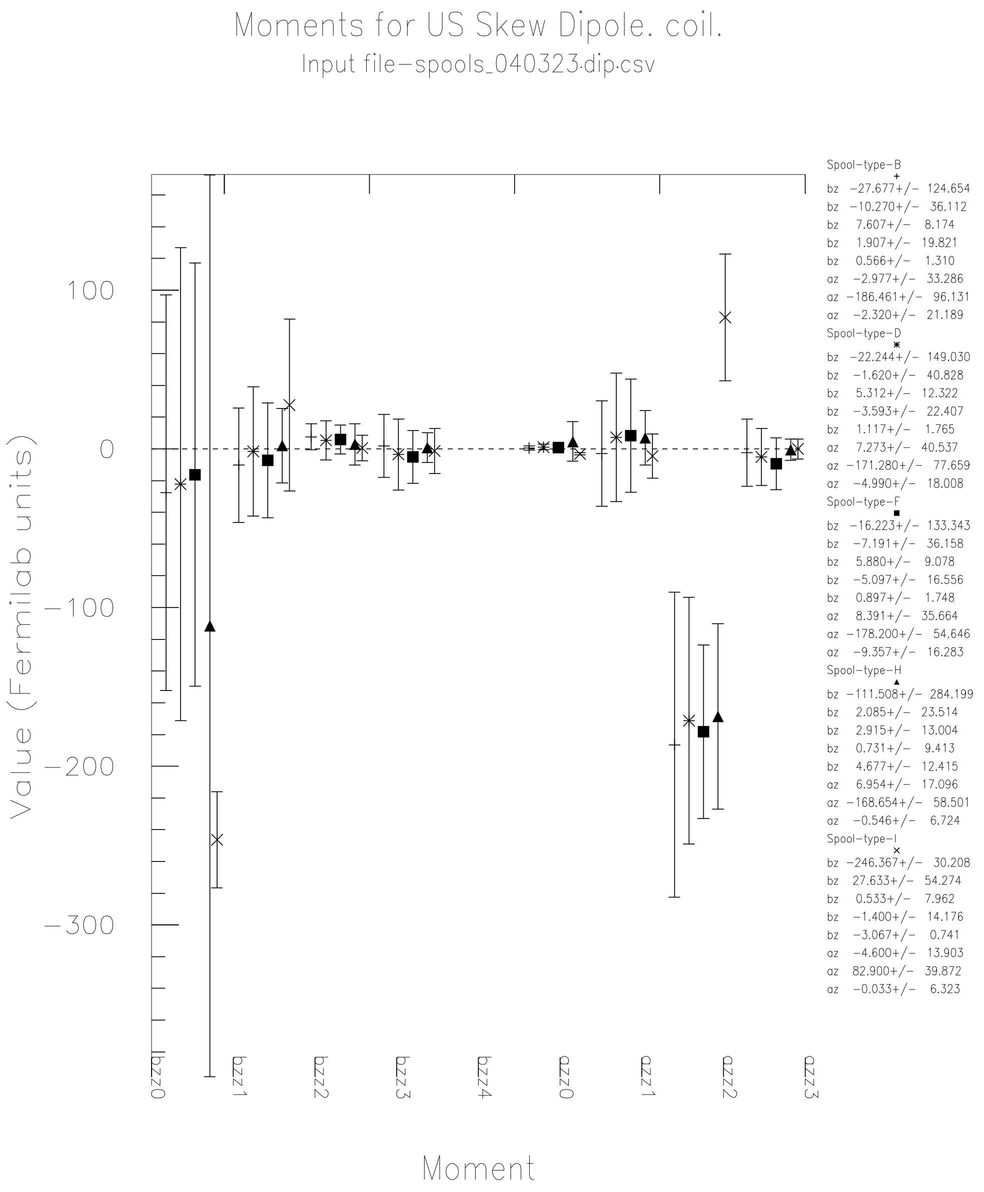

Figure 5: Measured Strength of the Multipoles for the Skew Dipole Corrector Coil (Fermilab units.)

Effect of the Dipole Correctors on the Tevatron Tunes

The quadrupole, the sextupole with a helical orbit, components of the dipole corrector fields will cause a tune shift. Since the tune shift is expected to be small it will be estimated with the perturbation result:

$$\delta\nu_{x,y} = (1/4\pi) \cdot \Sigma\beta_{x,y} \cdot \delta k$$

where δk is the deviation from the expected strength of the quadrupole and is equal to $\delta k = \delta B^{'} l/[B\rho]$.

In the case of the dipole correctors $\delta B'$ is just the strength of the quadrupole component of the dipole correctors. Using Fermilab representation $B^{'} = b_0 \cdot l \cdot b_1$ giving $\delta k = b_0 \cdot l \cdot b_1/[B\rho]$.

To simplify the calculation the summation will be performed assuming that the value of b_1 is constant. Summing the value of $\beta_{x,y}$ at the locations of the dipole correctors (approximately 100 of each H and V correctors) we find that:

$$\delta\nu_x \approx (1/[B\rho]) \cdot (862 \cdot < b_1 >_h + 333 \cdot < b_1 >_v)$$

and

$$\delta\nu_x \approx (1/[B\rho]) \cdot (374 \cdot < b_1 >_h + 826 \cdot < b_1 >_v)$$

Using a weighted average over the different kinds of spools the computed values are: $< b_1 >_h = -3.7 \cdot 10^{-4}/in$ and $< b_1 >_v = -9.9 \cdot 10^{-4}/in$. At 1TeV the resulting tune shifts are:

$$\delta\nu_x = -2.2 \cdot 10^{-3}$$

$$\delta\nu_y = -2.5 \cdot 10^{-3}$$

Over the full range of the currents in all the dipoles (-50A to +50A) we could see a variation in tune of perhaps $\delta\nu = 5 \cdot 10^{-3}$. At 150GeV the range would be expected to be similar.[9]

On the helix the sextupole component of the field in the dipole correctors could also shift the tune. In this case $\delta k = b_0 \cdot l \cdot 2 \cdot x \cdot b_2/[B\rho]$. If we sum over the ring, and assume that there is no correlation between the value of b_2 and x, then $\Sigma b_2 \cdot x = \Sigma b_2 \cdot \Sigma x$. On the helix $\Sigma x \approx 0.0$ so that we expect that the sextupole in the dipole should make, at worst, a negligible tune shift.[10]

[9] It is true that that the strength of the quadrupole component would be larger at 150GeV by the ratio of 1000/150 it is also true that the maximum current in the corrector would be lower by the same ratio since we would want to ramp the corrector to 1TeV. The factors cancel giving the same range for the tune shift.

[10] The tune shift could be significant if $< b_2 \cdot x >$ is not 0.0. If we set $< b_2 \cdot x >=<$

Quadrupole Correctors

Normal quadrupole correctors are found in the upstream coil packages in all the spool types, viz, the **A, B, C, D, E, F, G** and **H** spools. There are also quadrupole coils in the downstream package of the **E** and **F** correctors.

Skew quadrupole correctors are in the upstream package of the type **H** correctors and the downstream package of the **C, D,** and **G** type correctors.

Figure 6 gives the values of the transfer constants (in kG· in/in) for normal quadrupole coils in the upsteam package, Figure 7 for the normal quadrupoles in the downstream package, and in Figure 8 is plotted the transfer constant for skew quadrupole coils.

The average strength of the quadrupole coil in the **A, B, D,** and **F** spools is $68.7 \pm 0.4 kG \cdot in/in$. For the skew quadrupole coils in the **C** and **D** pools is $68.6 \pm 2.2 kG \cdot in$. The skew quadrupoles have the same average strength as the normal quads but with a greater measured spread. the nominal values for the transfer constants are $75.2 kG$. The measured values are again only about 90% of the nominal values. I am unaware of any cold measurements made on the strengths of the quadrupole, or higher, moments coils in the spools. Any attempt to draw a conclusion from the apparent agreement must be treated with some caution.

The measured high order multipoles (HOM)for the quadrupole coils are displayed in Table IIIa and are plotted in Figure 9 (upstream package) and Figure 10 (downstream package) for the spool types with normal quadrupole coils. The multipoles for the skew quadrupoles are presented in Table IIIb and plotted in Figure 11. I do not see any statistically significant moments for either the normal or skew quadrupoles.

$b_2 > \cdot < x >$ then $\delta\nu_x = -5.2 < x >$ and $\delta\nu_y = -2.2 < x >$. Thus for $< x >= 0.1mm$, $\delta\nu_x = -5.2 \cdot 10^{-4}$ and $\nu_y = -2.2 \cdot 10^{-4}$ at 50A.

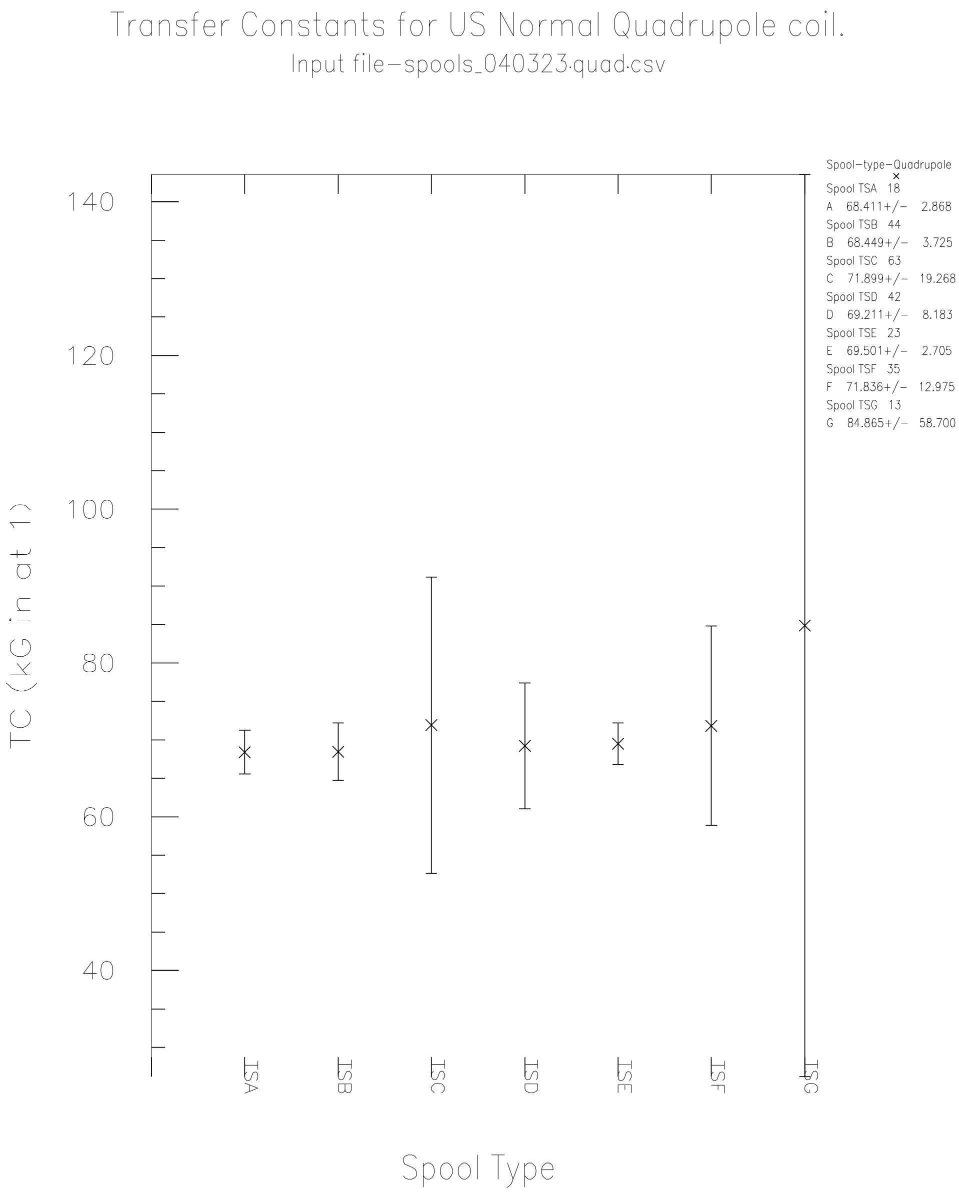

Figure 6: Measured Strength of the Upstream Normal Quadrupole Corrector Coils ($kG \cdot in/in$).

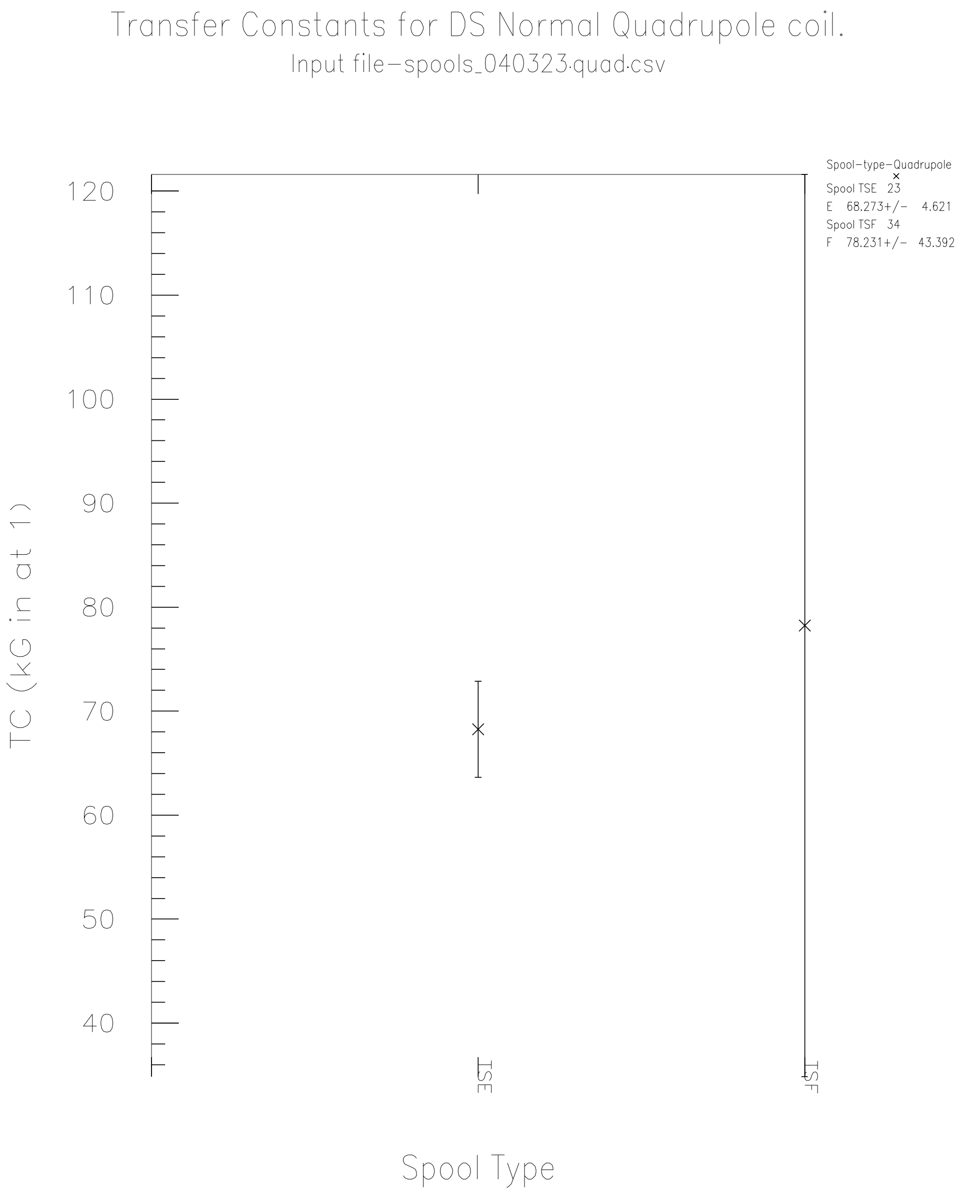

Figure 7: Measured Strength of the Downstream Normal Quadrupole Corrector Coils ($kG \cdot in/in$).

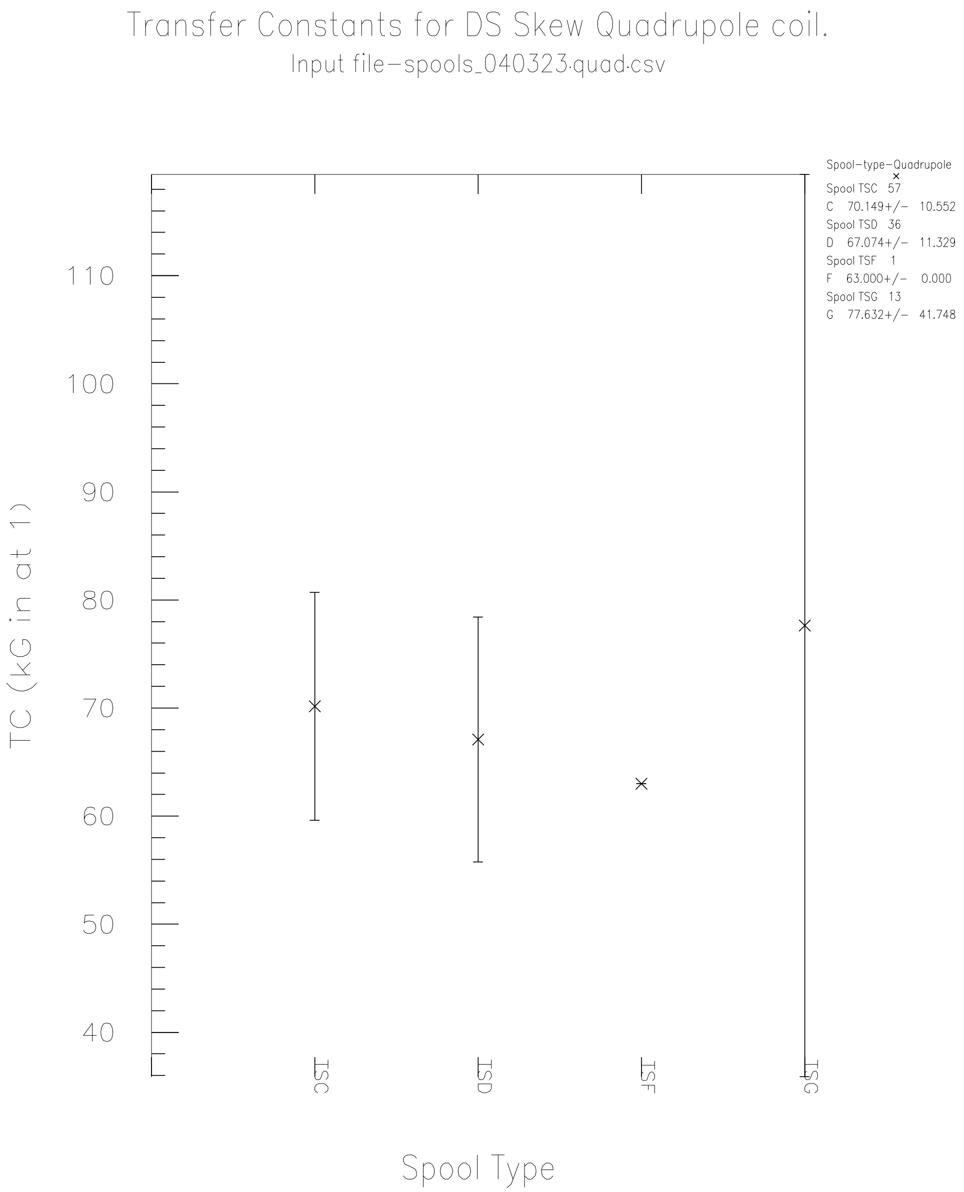

Figure 8: Measured Strength of the Skew Quadrupole Corrector Coils ($kG \cdot in/in$).

Table IIIa
High Order Multipoles for the US Normal Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
A	US	Quadrupole	Normal	b_0	18	11.789	99.203
A	US	Quadrupole	Normal	b_1	18	-1.833	2.494
A	US	Quadrupole	Normal	b_2	18	-6.539	28.887
A	US	Quadrupole	Normal	b_3	18	3.433	7.123
A	US	Quadrupole	Normal	a_0	18	39.172	191.921
A	US	Quadrupole	Normal	a_1	18	-45.272	185.637
A	US	Quadrupole	Normal	a_2	18	-9.156	33.724
A	US	Quadrupole	Normal	a_3	18	-9.056	16.302
A	US	Quadrupole	Normal	TC	18	68.411	2.868
B	US	Quadrupole	Normal	b_0	44	-34.607	192.863
B	US	Quadrupole	Normal	b_1	44	-1.357	4.165
B	US	Quadrupole	Normal	b_2	44	-0.461	37.710
B	US	Quadrupole	Normal	b_3	44	1.427	8.047
B	US	Quadrupole	Normal	a_0	44	-27.764	205.598
B	US	Quadrupole	Normal	a_1	44	-71.759	202.028
B	US	Quadrupole	Normal	a_2	44	-17.580	42.788
B	US	Quadrupole	Normal	a_3	44	-3.459	15.653
B	US	Quadrupole	Normal	TC	44	68.449	3.725
C	US	Quadrupole	Normal	b_0	63	-80.468	183.819
C	US	Quadrupole	Normal	b_1	63	-2.652	7.110
C	US	Quadrupole	Normal	b_2	63	-4.978	33.769
C	US	Quadrupole	Normal	b_3	63	0.625	7.183
C	US	Quadrupole	Normal	a_0	63	24.567	186.032
C	US	Quadrupole	Normal	a_1	63	-5.600	284.384
C	US	Quadrupole	Normal	a_2	63	-7.884	37.727
C	US	Quadrupole	Normal	a_3	63	-0.438	14.020
C	US	Quadrupole	Normal	TC	63	71.899	19.268

Table IIIa
High Order Multipoles for the US Normal Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
D	US	Quadrupole	Normal	b_0	42	-60.683	181.198
D	US	Quadrupole	Normal	b_1	42	-4.702	8.401
D	US	Quadrupole	Normal	b_2	42	-12.350	27.348
D	US	Quadrupole	Normal	b_3	42	0.933	7.498
D	US	Quadrupole	Normal	a_0	42	35.924	172.688
D	US	Quadrupole	Normal	a_1	42	-75.307	297.026
D	US	Quadrupole	Normal	a_2	42	-0.074	32.955
D	US	Quadrupole	Normal	a_3	42	-1.069	11.590
D	US	Quadrupole	Normal	TC	42	69.211	8.183
E	US	Quadrupole	Normal	b_0	23	-112.274	189.533
E	US	Quadrupole	Normal	b_1	23	-3.383	3.232
E	US	Quadrupole	Normal	b_2	23	2.009	34.213
E	US	Quadrupole	Normal	b_3	23	1.317	8.237
E	US	Quadrupole	Normal	a_0	23	7.183	170.353
E	US	Quadrupole	Normal	a_1	23	-70.122	250.623
E	US	Quadrupole	Normal	a_2	23	-0.735	28.136
E	US	Quadrupole	Normal	a_3	23	-0.613	16.040
E	US	Quadrupole	Normal	TC	23	69.501	2.705
F	US	Quadrupole	Normal	b_0	35	-98.857	128.317
F	US	Quadrupole	Normal	b_1	35	-2.477	3.965
F	US	Quadrupole	Normal	b_2	35	-8.720	29.025
F	US	Quadrupole	Normal	b_3	35	0.366	8.730
F	US	Quadrupole	Normal	a_0	35	76.269	174.965
F	US	Quadrupole	Normal	a_1	35	-53.771	215.877
F	US	Quadrupole	Normal	a_2	35	-8.837	30.806
F	US	Quadrupole	Normal	a_3	35	0.169	11.080
F	US	Quadrupole	Normal	TC	35	71.836	12.975

Table IIIa

High Order Multipoles for the US Normal Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
G	US	Quadrupole	Normal	b_0	13	-1.892	151.250
G	US	Quadrupole	Normal	b_1	13	-2.484	2.529
G	US	Quadrupole	Normal	b_2	13	-41.146	33.615
G	US	Quadrupole	Normal	b_3	13	2.469	7.185
G	US	Quadrupole	Normal	a_0	13	-13.123	214.628
G	US	Quadrupole	Normal	a_1	13	-134.000	177.608
G	US	Quadrupole	Normal	a_2	13	-15.492	42.954
G	US	Quadrupole	Normal	a_3	13	3.031	18.844
G	US	Quadrupole	Normal	TC	13	84.865	58.700
H	US	Quadrupole	Normal	b_0	1	58.800	0.000
H	US	Quadrupole	Normal	b_1	1	-12.900	0.000
H	US	Quadrupole	Normal	b_2	1	7.200	0.000
H	US	Quadrupole	Normal	b_3	1	3.600	0.000
H	US	Quadrupole	Normal	a_0	1	-172.000	0.000
H	US	Quadrupole	Normal	a_1	1	-507.300	0.000
H	US	Quadrupole	Normal	a_2	1	5.900	0.000
H	US	Quadrupole	Normal	a_3	1	2.000	0.000
H	US	Quadrupole	Normal	TC	1	68.590	0.000

Table IIIa
High Order Multipoles for the DS Normal Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
D	DS	Quadrupole	Normal	b_0	1	-172.200	0.000
D	DS	Quadrupole	Normal	b_1	1	-0.200	0.000
D	DS	Quadrupole	Normal	b_2	1	40.400	0.000
D	DS	Quadrupole	Normal	b_3	1	-3.300	0.000
D	DS	Quadrupole	Normal	a_0	1	350.700	0.000
D	DS	Quadrupole	Normal	a_1	1	61.400	0.000
D	DS	Quadrupole	Normal	a_2	1	26.600	0.000
D	DS	Quadrupole	Normal	a_3	1	16.300	0.000
D	DS	Quadrupole	Normal	TC	1	70.170	0.000
E	DS	Quadrupole	Normal	b_0	23	-109.761	221.839
E	DS	Quadrupole	Normal	b_1	23	-2.513	2.560
E	DS	Quadrupole	Normal	b_2	23	-6.648	34.463
E	DS	Quadrupole	Normal	b_3	23	-1.348	5.430
E	DS	Quadrupole	Normal	a_0	23	96.243	150.869
E	DS	Quadrupole	Normal	a_1	23	-99.135	201.369
E	DS	Quadrupole	Normal	a_2	23	-7.674	28.600
E	DS	Quadrupole	Normal	a_3	23	-3.413	8.690
E	DS	Quadrupole	Normal	TC	23	68.273	4.621
F	DS	Quadrupole	Normal	b_0	34	-81.665	172.070
F	DS	Quadrupole	Normal	b_1	34	-2.897	4.071
F	DS	Quadrupole	Normal	b_2	34	-13.706	32.349
F	DS	Quadrupole	Normal	b_3	34	1.271	10.564
F	DS	Quadrupole	Normal	a_0	34	153.559	204.076
F	DS	Quadrupole	Normal	a_1	34	-69.924	230.230
F	DS	Quadrupole	Normal	a_2	34	-9.524	40.959
F	DS	Quadrupole	Normal	a_3	34	-1.903	12.953
F	DS	Quadrupole	Normal	TC	34	78.231	43.392

Table IIIb

High Order Multipoles for the Skew Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
C	DS	Quadrupole	Skew	b_0	57	111.146	201.482
C	DS	Quadrupole	Skew	b_1	57	-0.016	283.372
C	DS	Quadrupole	Skew	b_2	57	-16.721	39.129
C	DS	Quadrupole	Skew	b_3	57	-0.256	7.606
C	DS	Quadrupole	Skew	a_0	57	68.037	170.334
C	DS	Quadrupole	Skew	a_1	57	3.867	6.892
C	DS	Quadrupole	Skew	a_2	57	3.733	28.380
C	DS	Quadrupole	Skew	a_3	57	-1.344	13.500
C	DS	Quadrupole	Skew	TC	57	70.149	10.552
D	DS	Quadrupole	Skew	b_0	36	124.519	224.219
D	DS	Quadrupole	Skew	b_1	36	-91.836	318.477
D	DS	Quadrupole	Skew	b_2	36	-9.442	40.081
D	DS	Quadrupole	Skew	b_3	36	0.317	5.726
D	DS	Quadrupole	Skew	a_0	36	44.850	260.031
D	DS	Quadrupole	Skew	a_1	36	4.920	7.881
D	DS	Quadrupole	Skew	a_2	36	19.008	80.073
D	DS	Quadrupole	Skew	a_3	36	5.172	25.081
D	DS	Quadrupole	Skew	TC	36	67.074	11.329
F	DS	Quadrupole	Skew	b_0	1	559.800	0.070
F	DS	Quadrupole	Skew	b_1	1	-53.400	-0.010
F	DS	Quadrupole	Skew	b_2	1	15.500	0.000
F	DS	Quadrupole	Skew	b_3	1	-9.400	0.000
F	DS	Quadrupole	Skew	a_0	1	-121.300	-0.018
F	DS	Quadrupole	Skew	a_1	1	0.100	0.000
F	DS	Quadrupole	Skew	a_2	1	46.600	-0.007
F	DS	Quadrupole	Skew	a_3	1	-1.700	0.000
F	DS	Quadrupole	Skew	TC	1	63.000	0.000

Table IIIb
High Order Multipoles for the Skew Quadrupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
G	DS	Quadrupole	Skew	b_0	13	26.323	132.936
G	DS	Quadrupole	Skew	b_1	13	-120.023	159.280
G	DS	Quadrupole	Skew	b_2	13	0.185	36.087
G	DS	Quadrupole	Skew	b_3	13	1.215	7.854
G	DS	Quadrupole	Skew	a_0	13	-11.123	246.893
G	DS	Quadrupole	Skew	a_1	13	1.985	2.858
G	DS	Quadrupole	Skew	a_2	13	17.638	32.970
G	DS	Quadrupole	Skew	a_3	13	-0.654	21.019
G	DS	Quadrupole	Skew	TC	13	77.632	41.748
H	US	Quadrupole	Skew	b_0	12	113.317	180.427
H	US	Quadrupole	Skew	b_1	12	-123.658	288.652
H	US	Quadrupole	Skew	b_2	12	5.275	45.030
H	US	Quadrupole	Skew	b_3	12	-1.267	7.466
H	US	Quadrupole	Skew	a_0	12	61.758	230.583
H	US	Quadrupole	Skew	a_1	12	4.925	3.837
H	US	Quadrupole	Skew	a_2	12	-3.533	39.149
H	US	Quadrupole	Skew	a_3	12	2.125	19.901
H	US	Quadrupole	Skew	TC	12	81.289	50.919

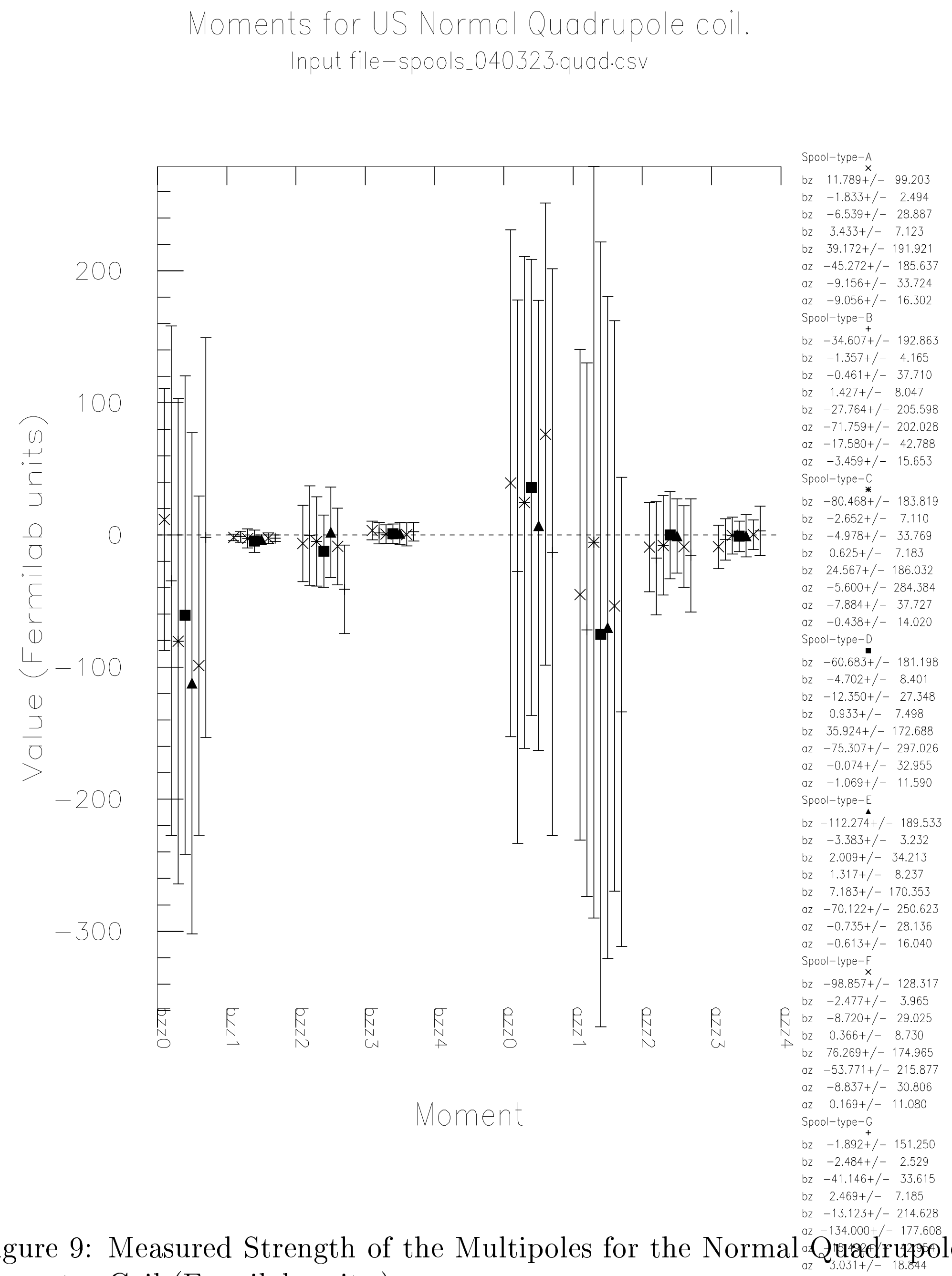

Figure 9: Measured Strength of the Multipoles for the Normal Quadrupole Corrector Coil (Fermilab units.)

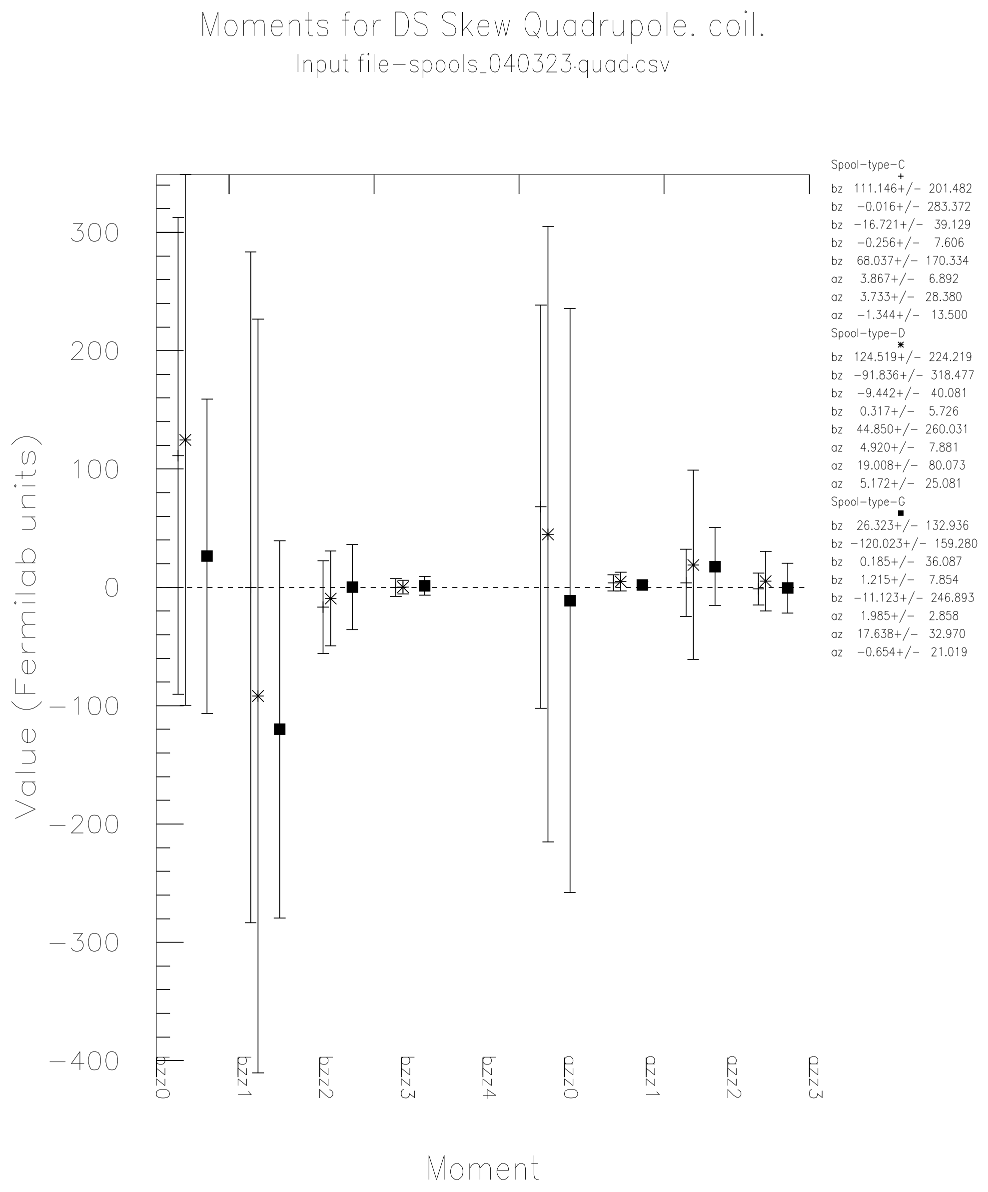

Figure 10: Measured Strength of the Multipoles for the Normal Quadrupole Corrector Coil (Fermilab units.)

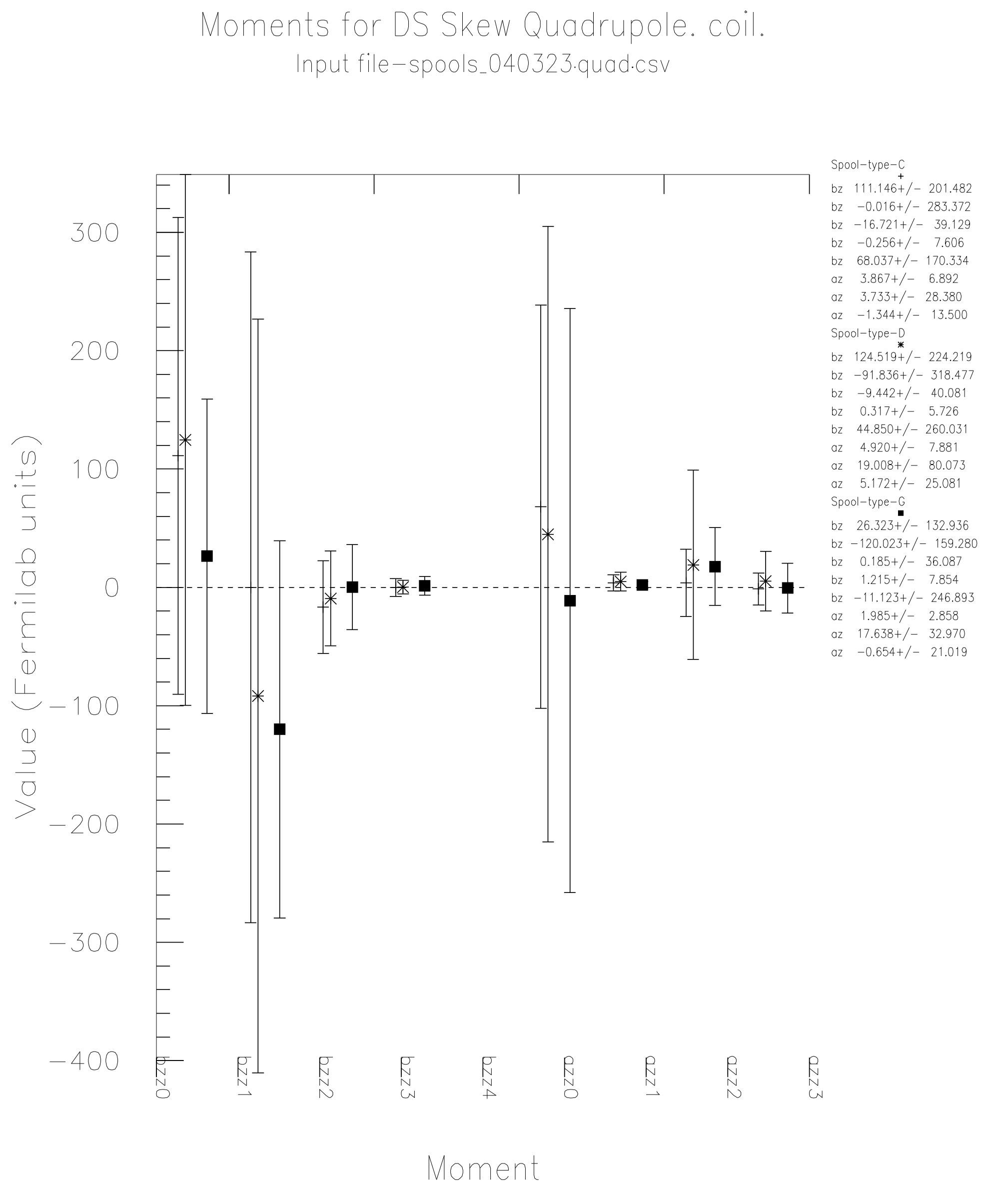

Figure 11: Measured Strength of the Multipoles for the Skew Quadrupole Correction Coils. (Fermilab units.)

Sextupole Correctors

Normal sextupole correctors are found in the upstream coil packages in all but **H** spool types, viz, in the **A, B, C, D, E, F** and **G** spools. There are also sextupole coils in the downstream package of the **E, F** and **G** correctors.

Skew sextupole correctors are in the downstream package of the **C, D,** and **G** type correctors.

Figure 12 gives the values of the transfer constants (in $kG \cdot in/in^2$) for the upstream normal sextupole coils, and in Figure 13 are plotted the transfer constants of the sextupole coils in the downstrem package.[11]In Figure 14 are plotted the transfer constants for the skew sextupole coils.

The average strength of the sextupole coil in the upstream package in the **A, B, C, D, E, F** and **G** spools is $56.2 \pm 12.4 kG \cdot in/in^2$. The nominal value in $50 kG/in$. For the sextupole coils in the downstream package of the **E, F** and **G** the average strength is $46.4 \pm 21.8 kG \cdot in/in^2$. The large variance is indicative of inconsistent data. The strength of the skew sextupoles in the downstream package of the **E, F** and **G** spools is $43.8 \pm 10.0 kG \cdot in/in^2$.

The measured sextupole strengths are with $\approx 10\%$ greater than the nominal values. Again the results must be used with some caution if we want to apply them to spools operating in the tunnel.

The measured high order multipoles (HOM) for the sextupole coils are displayed in Table IVa and are plotted in Figure 15 for the different types of upstream spools with normal sextupole. The moments for the sextupoles in the downstream package are plotted in Figure 16. Figure 17 is the plot of the measured multipoles for the skew sextupole coils. The only statistically significant moments are the b_2 for the normal Sextupoles and the a_2 for the skew Sextupoles. All the other HOM are smaller than the variance on the multipole.

Table IVa
High Order Multipoles for the Normal Sextupole Coils.

[11]Sextupoles in the downstream package are used in the feed down circuits. The are weaker than the sextupoles in the upstream package.

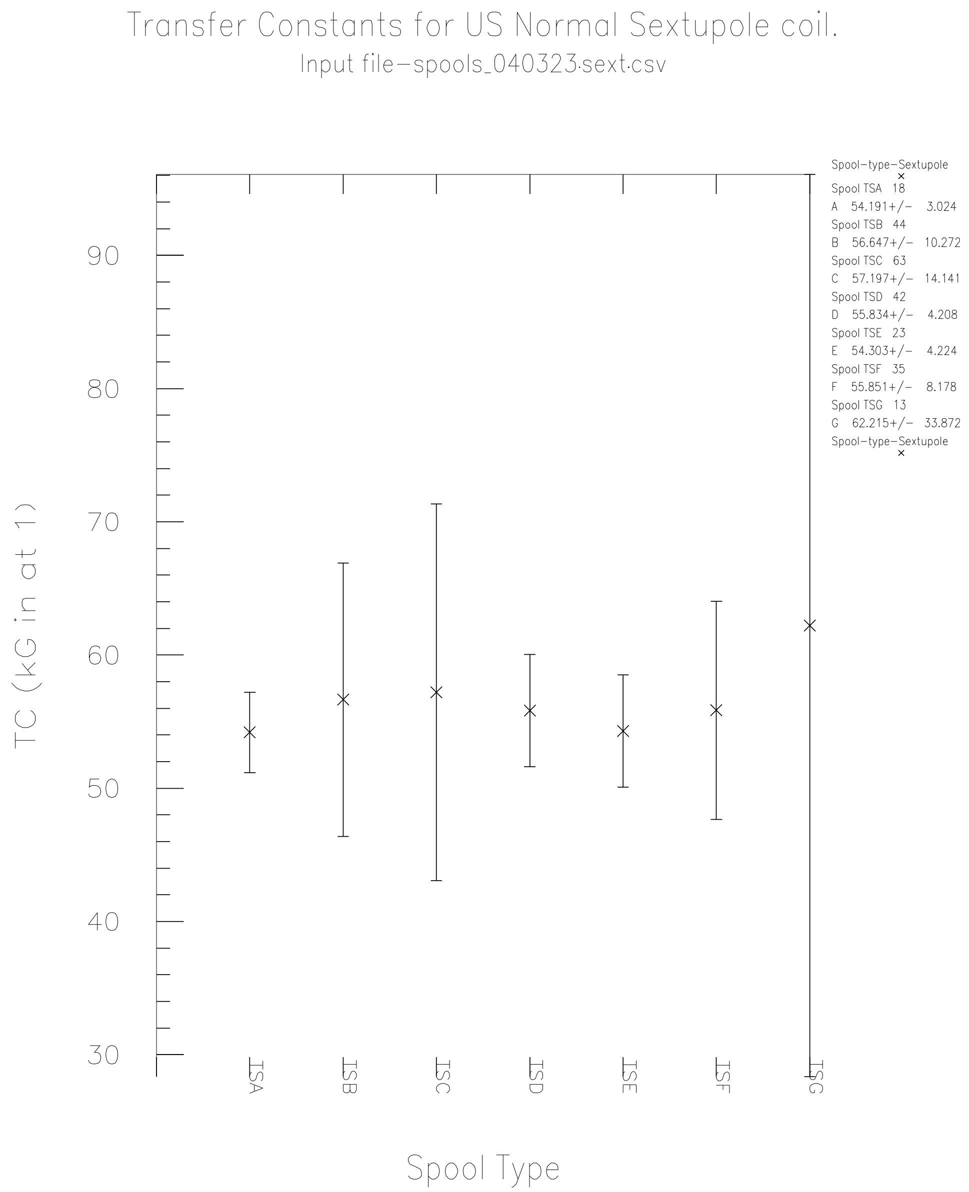

Figure 12: Measured Strength of the Normal Sextupole Corrector Coils ($kG \cdot in/in$).

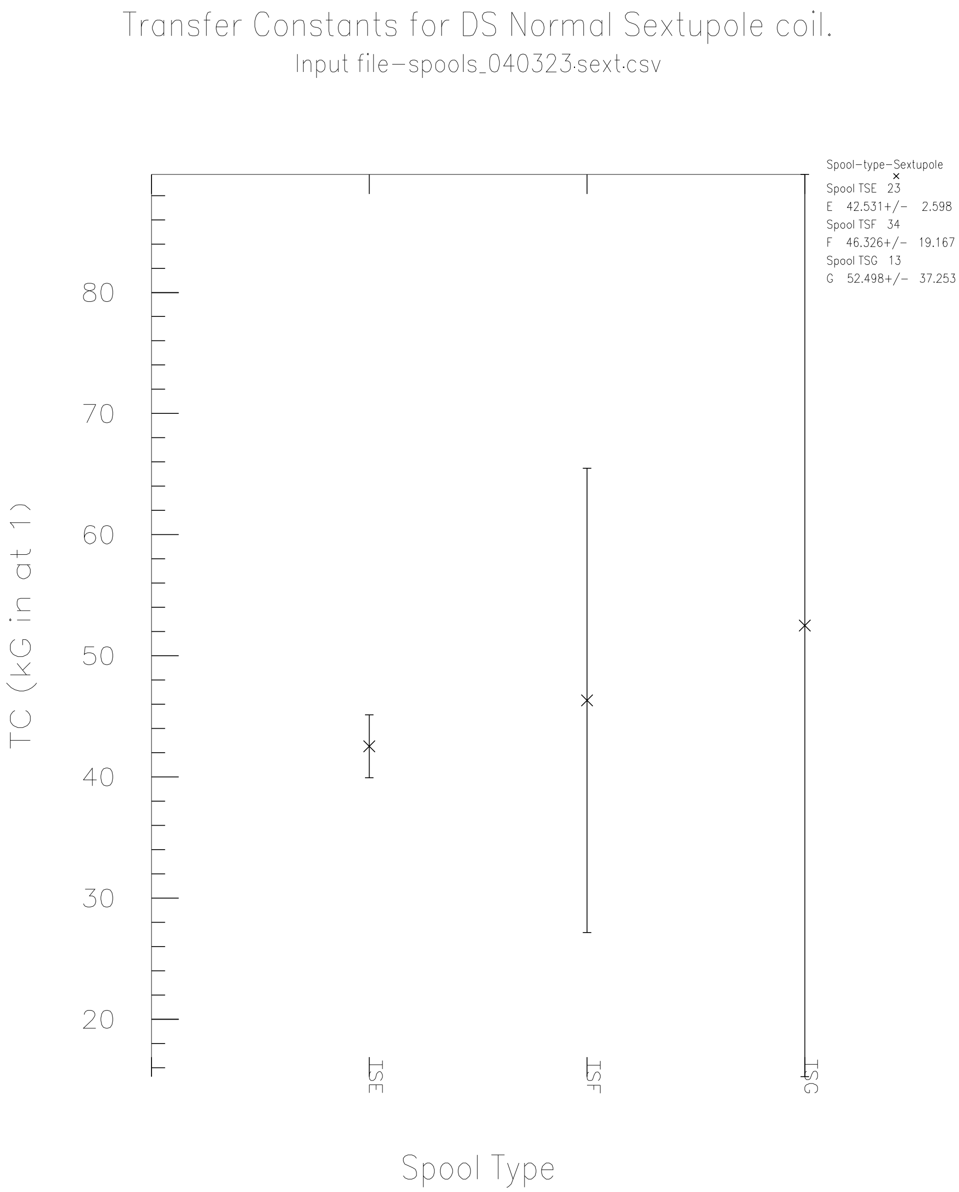

Figure 13: Measured Strength of the Normal Sextupole Corrector Coils ($kG \cdot in/in$).

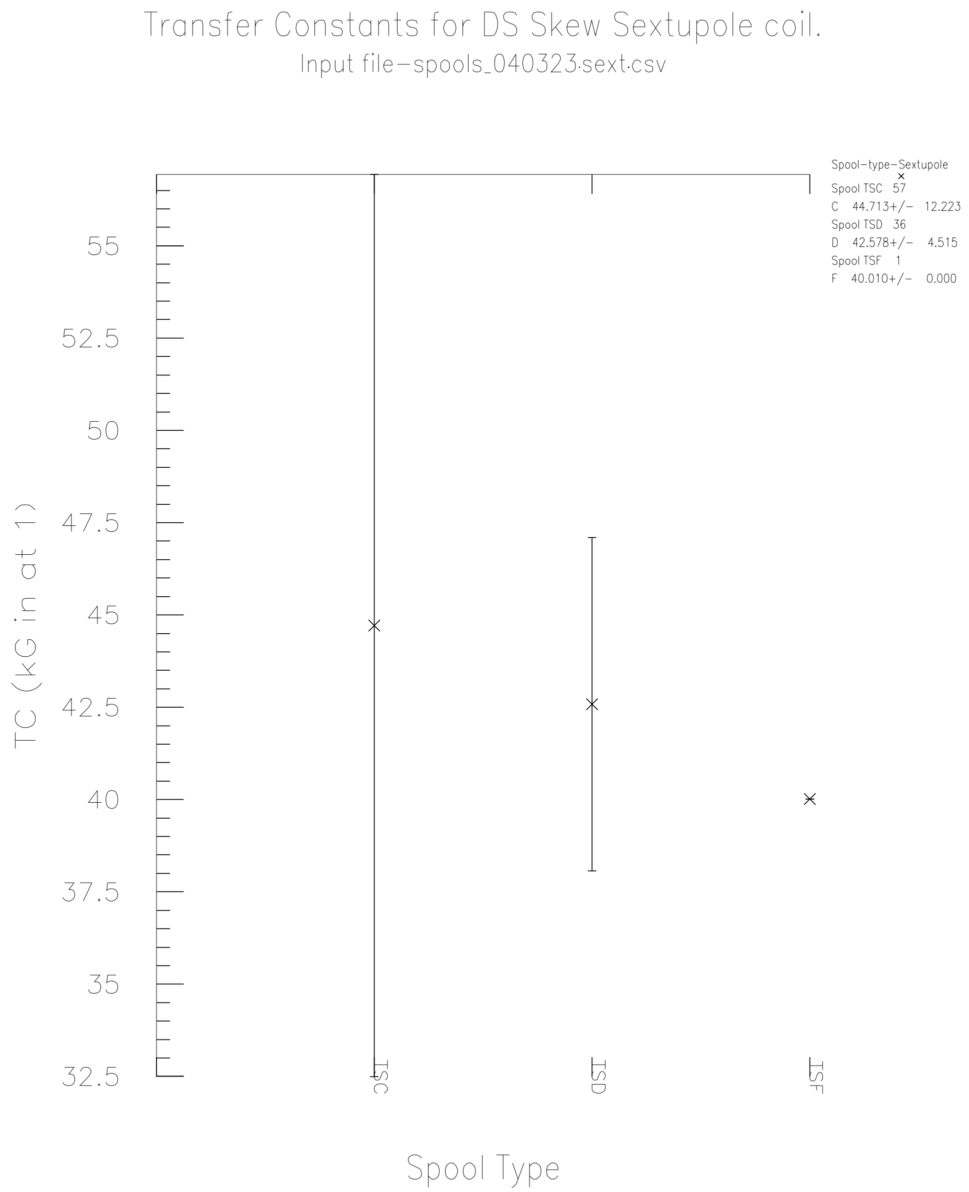

Figure 14: Measured Strength of the Skew Sextupole Corrector Coils ($kG \cdot in/in$).

Type	Loc	Coil	N/S	Moment	#	Ave	σ
A	US	Sextupole	Normal	b_0	18	56.678	93.856
A	US	Sextupole	Normal	b_1	18	8.056	270.520
A	US	Sextupole	Normal	b_2	18	-3.472	5.261
A	US	Sextupole	Normal	b_3	18	-4.789	59.018
A	US	Sextupole	Normal	a_0	18	-15.706	106.598
A	US	Sextupole	Normal	a_1	18	29.228	314.205
A	US	Sextupole	Normal	a_2	18	-6.339	263.546
A	US	Sextupole	Normal	a_3	18	-25.250	33.858
A	US	Sextupole	Normal	TC	18	54.191	3.024
B	US	Sextupole	Normal	b_0	44	-121.223	130.839
B	US	Sextupole	Normal	b_1	44	-93.523	347.841
B	US	Sextupole	Normal	b_2	44	-5.000	8.220
B	US	Sextupole	Normal	b_3	44	18.900	48.458
B	US	Sextupole	Normal	a_0	44	-47.930	115.589
B	US	Sextupole	Normal	a_1	44	-83.480	407.810
B	US	Sextupole	Normal	a_2	44	-18.602	318.338
B	US	Sextupole	Normal	a_3	44	-23.714	45.941
B	US	Sextupole	Normal	TC	44	56.647	10.272

Table IVa
High Order Multipoles for the Normal Sextupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
C	US	Sextupole	Normal	b_0	63	18.487	110.939
C	US	Sextupole	Normal	b_1	63	-162.457	322.911
C	US	Sextupole	Normal	b_2	63	-10.157	16.979
C	US	Sextupole	Normal	b_3	63	-11.397	34.879
C	US	Sextupole	Normal	a_0	63	-54.756	117.623
C	US	Sextupole	Normal	a_1	63	46.917	362.400
C	US	Sextupole	Normal	a_2	63	-25.213	449.577
C	US	Sextupole	Normal	a_3	63	-11.373	47.399
C	US	Sextupole	Normal	TC	63	57.197	14.141
D	US	Sextupole	Normal	b_0	42	-92.114	139.022
D	US	Sextupole	Normal	b_1	42	-213.407	301.627
D	US	Sextupole	Normal	b_2	42	-7.050	22.186
D	US	Sextupole	Normal	b_3	42	9.976	41.866
D	US	Sextupole	Normal	a_0	42	-101.712	124.798
D	US	Sextupole	Normal	a_1	42	-17.355	400.023
D	US	Sextupole	Normal	a_2	42	29.564	507.149
D	US	Sextupole	Normal	a_3	42	-24.271	47.556
D	US	Sextupole	Normal	TC	42	55.834	4.208
D	DS	Sextupole	Normal	b_0	1	119.100	0.000
D	DS	Sextupole	Normal	b_1	1	-262.100	0.000
D	DS	Sextupole	Normal	b_2	1	-5.200	0.000
D	DS	Sextupole	Normal	b_3	1	60.000	0.000
D	DS	Sextupole	Normal	a_0	1	116.300	0.000
D	DS	Sextupole	Normal	a_1	1	595.100	0.000
D	DS	Sextupole	Normal	a_2	1	321.400	0.000
D	DS	Sextupole	Normal	a_3	1	-102.100	0.000
D	DS	Sextupole	Normal	TC	1	43.200	0.000
E	US	Sextupole	Normal	b_0	23	58.730	153.149
E	US	Sextupole	Normal	b_1	23	-196.396	360.201
E	US	Sextupole	Normal	b_2	23	-7.952	8.395
E	US	Sextupole	Normal	b_3	23	-20.326	39.772

Table IVa
High Order Multipoles for the Normal Sextupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
E	US	Sextupole	Normal	a_0	23	-23.630	134.452
E	US	Sextupole	Normal	a_1	23	29.000	329.214
E	US	Sextupole	Normal	a_2	23	-91.196	388.146
E	US	Sextupole	Normal	a_3	23	-0.970	46.614
E	US	Sextupole	Normal	TC	23	54.303	4.224
E	DS	Sextupole	Normal	b_0	23	1.104	104.499
E	DS	Sextupole	Normal	b_1	23	-256.265	386.675
E	DS	Sextupole	Normal	b_2	23	-5.674	6.287
E	DS	Sextupole	Normal	b_3	23	3.770	45.889
E	DS	Sextupole	Normal	a_0	23	-52.917	139.581
E	DS	Sextupole	Normal	a_1	23	224.283	312.417
E	DS	Sextupole	Normal	a_2	23	-24.983	338.446
E	DS	Sextupole	Normal	a_3	23	10.517	42.312
E	DS	Sextupole	Normal	TC	23	42.531	2.598
F	US	Sextupole	Normal	b_0	35	-65.537	125.850
F	US	Sextupole	Normal	b_1	35	-230.394	365.914
F	US	Sextupole	Normal	b_2	35	-5.906	11.450
F	US	Sextupole	Normal	b_3	35	8.803	48.826
F	US	Sextupole	Normal	a_0	35	-47.546	134.345
F	US	Sextupole	Normal	a_1	35	70.917	377.293
F	US	Sextupole	Normal	a_2	35	9.254	347.620
F	US	Sextupole	Normal	a_3	35	-18.100	28.852
F	US	Sextupole	Normal	TC	35	55.851	8.178
F	DS	Sextupole	Normal	b_0	34	20.600	163.379
F	DS	Sextupole	Normal	b_1	34	-132.426	386.309
F	DS	Sextupole	Normal	b_2	34	-32.327	148.525
F	DS	Sextupole	Normal	b_3	34	-5.485	44.835
F	DS	Sextupole	Normal	a_0	34	-39.268	129.585
F	DS	Sextupole	Normal	a_1	34	278.871	343.126
F	DS	Sextupole	Normal	a_2	34	-157.229	1060.056
F	DS	Sextupole	Normal	a_3	34	2.432	42.262
F	DS	Sextupole	Normal	TC	34	46.326	19.167

Table IVa
High Order Multipoles for the Normal Sextupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
G	US	Sextupole	Normal	b_0	13	85.292	108.756
G	US	Sextupole	Normal	b_1	13	-151.715	334.035
G	US	Sextupole	Normal	b_2	13	-5.569	4.738
G	US	Sextupole	Normal	b_3	13	-7.454	43.782
G	US	Sextupole	Normal	a_0	13	29.615	94.290
G	US	Sextupole	Normal	a_1	13	-58.569	361.245
G	US	Sextupole	Normal	a_2	13	-194.554	271.233
G	US	Sextupole	Normal	a_3	13	-28.762	50.940
G	US	Sextupole	Normal	TC	13	62.215	33.872
G	DS	Sextupole	Normal	b_0	13	-15.677	149.791
G	DS	Sextupole	Normal	b_1	13	-74.546	425.396
G	DS	Sextupole	Normal	b_2	13	-5.154	5.856
G	DS	Sextupole	Normal	b_3	13	-21.515	36.324
G	DS	Sextupole	Normal	a_0	13	-82.708	174.352
G	DS	Sextupole	Normal	a_1	13	-43.862	260.493
G	DS	Sextupole	Normal	a_2	13	-139.931	289.383
G	DS	Sextupole	Normal	a_3	13	-11.885	38.588
G	DS	Sextupole	Normal	TC	13	52.498	37.253

Table IVb
High Order Multipoles for the Skew Sextupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
C	DS	Sextupole	Skew	b_0	57	68.107	163.620
C	DS	Sextupole	Skew	b_1	57	187.842	403.032
C	DS	Sextupole	Skew	b_2	57	-59.663	448.074
C	DS	Sextupole	Skew	b_3	57	-20.011	54.576
C	DS	Sextupole	Skew	a_0	57	-41.177	198.223
C	DS	Sextupole	Skew	a_1	57	42.346	377.179
C	DS	Sextupole	Skew	a_2	57	10.044	14.526
C	DS	Sextupole	Skew	a_3	57	22.614	61.540
C	DS	Sextupole	Skew	TC	57	44.713	12.223
D	DS	Sextupole	Skew	b_0	36	-6.567	195.616
D	DS	Sextupole	Skew	b_1	36	120.356	403.143
D	DS	Sextupole	Skew	b_2	36	-139.131	453.532
D	DS	Sextupole	Skew	b_3	36	-27.283	47.775
D	DS	Sextupole	Skew	a_0	36	-33.917	164.862
D	DS	Sextupole	Skew	a_1	36	61.117	331.534
D	DS	Sextupole	Skew	a_2	36	11.267	13.463
D	DS	Sextupole	Skew	a_3	36	36.067	49.717
D	DS	Sextupole	Skew	TC	36	42.578	4.515
F	DS	Sextupole	Skew	b_0	1	59.300	0.009
F	DS	Sextupole	Skew	b_1	1	1040.100	0.202
F	DS	Sextupole	Skew	b_2	1	-12.100	-0.002
F	DS	Sextupole	Skew	b_3	1	20.900	0.004
F	DS	Sextupole	Skew	a_0	1	10.300	0.000
F	DS	Sextupole	Skew	a_1	1	-261.400	-0.061
F	DS	Sextupole	Skew	a_3	1	41.800	0.007
F	DS	Sextupole	Skew	TC	1	40.010	-0.006

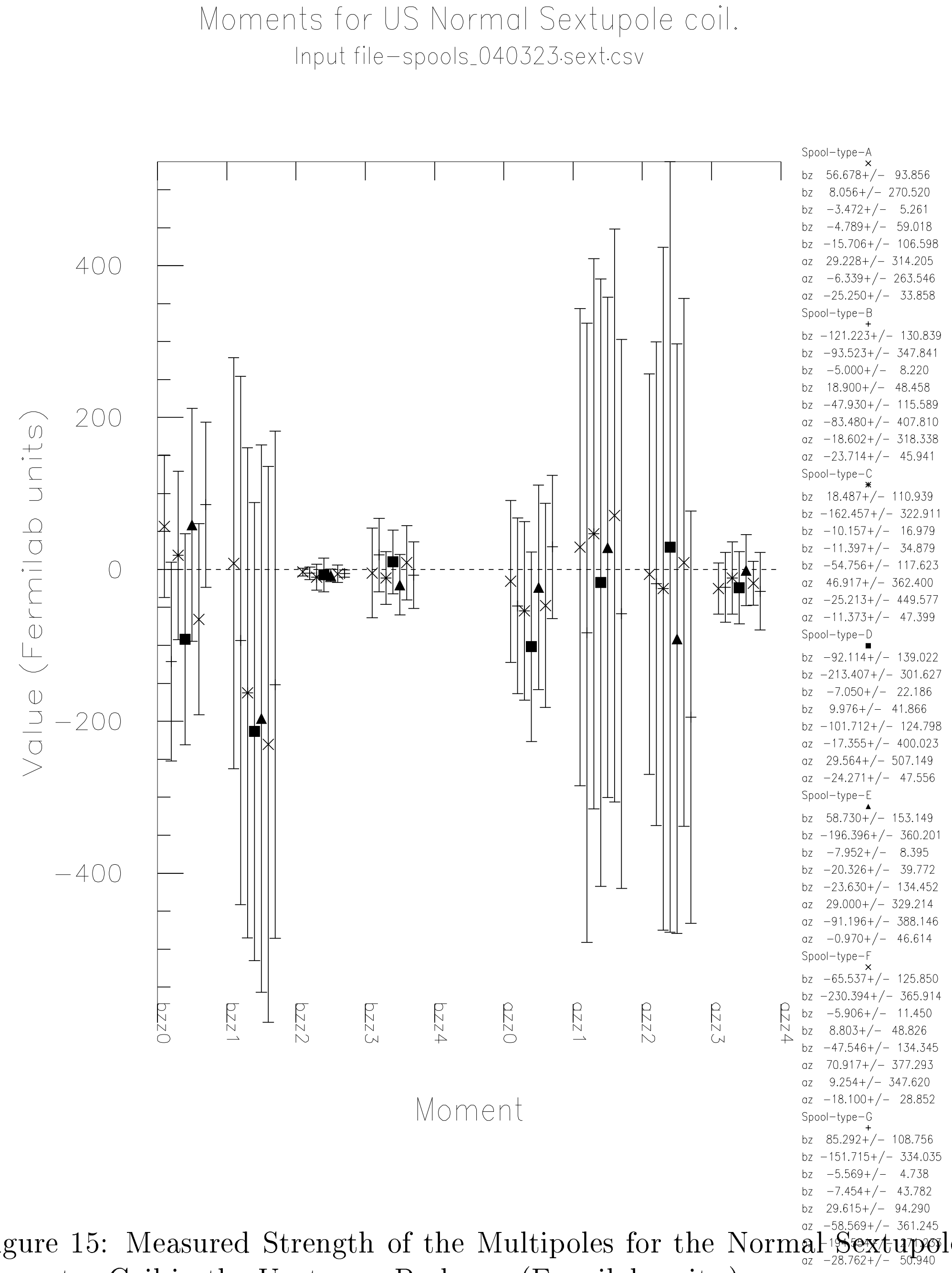

Figure 15: Measured Strength of the Multipoles for the Normal Sextupole Corrector Coil in the Upstream Package. (Fermilab units.)

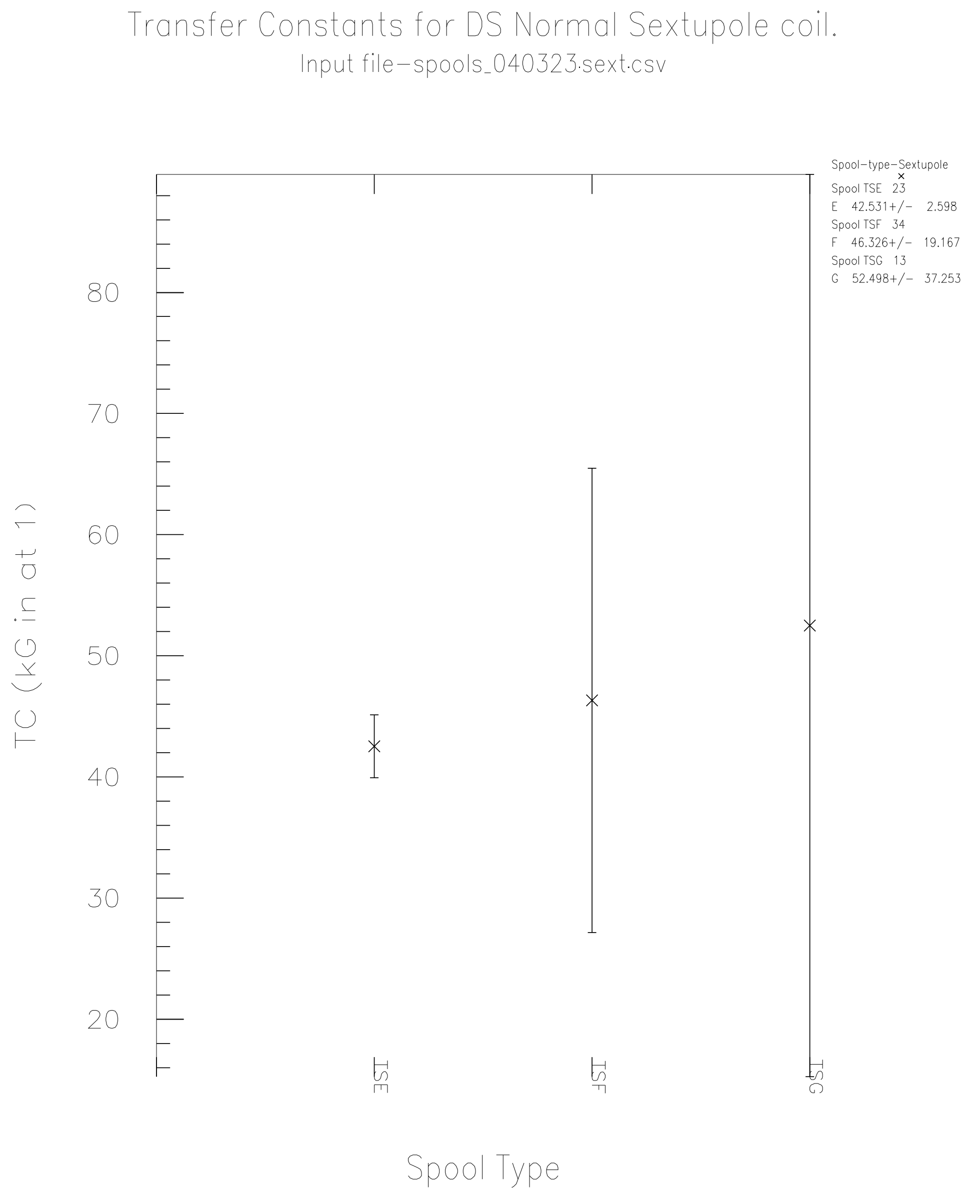

Figure 16: Measured Strength of the Multipoles for the Normal Sextupole Corrector Coil in the Downstream Package. (Fermilab units.)

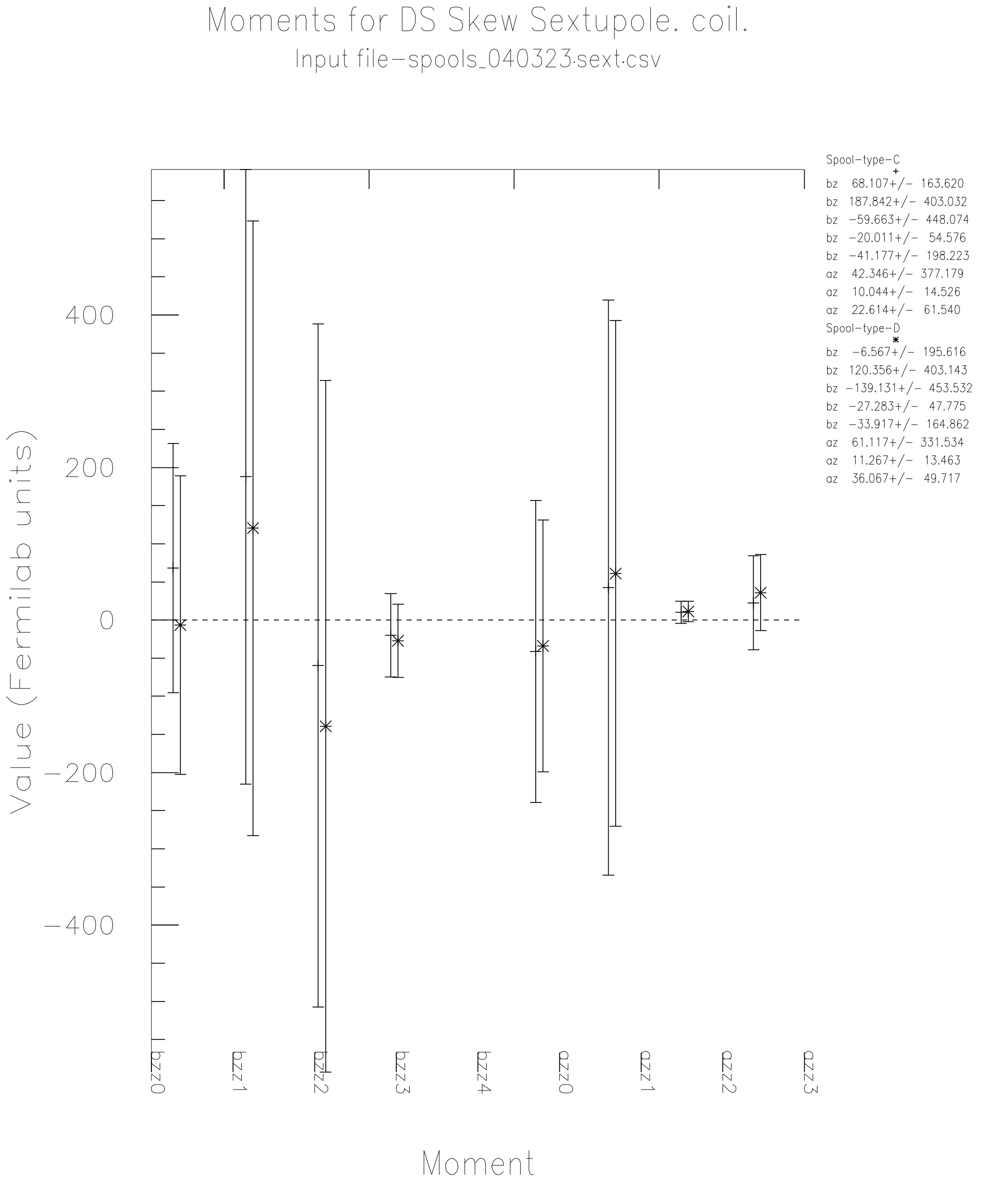

Figure 17: Measured Strength of the Multipoles for the Skew Sextupole Correction Coils. (Fermilab units.)

Octupole Correctors

Normal octupole correctors are found in the downstream coil packages the **C, D, E, F** and **G** spools.

Figure 18 gives the values of the transfer constants (in $kG \cdot in/in^2$) for normal octupole coils.

The average strength of the octupole coil in the downstream package in the **C, D, E, F** and **G** spools is $56.2 \pm 12.4 kG \cdot in/in^2$. The nominal value in $50kG/in$ so the strengths agree fairly well.

The measured high order multipoles (HOM) for the octupole coils are displayed in Table V and are plotted in Figure 19 for the different types of spools with normal octupole.

Table Va
High Order Multipoles for the Normal Octupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
C	DS	Octupole	Normal	b_0	57	37.961	208.134
C	DS	Octupole	Normal	b_1	57	-48.225	174.554
C	DS	Octupole	Normal	b_2	57	-117.421	556.056
C	DS	Octupole	Normal	b_3	57	-20.726	26.106
C	DS	Octupole	Normal	a_0	57	42.977	175.466
C	DS	Octupole	Normal	a_1	57	21.433	159.567
C	DS	Octupole	Normal	a_2	57	345.449	549.574
C	DS	Octupole	Normal	a_3	57	-19.730	642.684
C	DS	Octupole	Normal	TC	57	32.790	6.974
D	DS	Octupole	Normal	b_0	37	17.676	160.143
D	DS	Octupole	Normal	b_1	37	-20.411	180.978
D	DS	Octupole	Normal	b_2	37	-189.922	549.946
D	DS	Octupole	Normal	b_3	37	-21.981	26.748
D	DS	Octupole	Normal	a_0	37	-4.743	206.734
D	DS	Octupole	Normal	a_1	37	-2.200	193.601
D	DS	Octupole	Normal	a_2	37	184.800	561.324
D	DS	Octupole	Normal	a_3	37	-251.089	612.668
D	DS	Octupole	Normal	TC	37	32.025	2.171

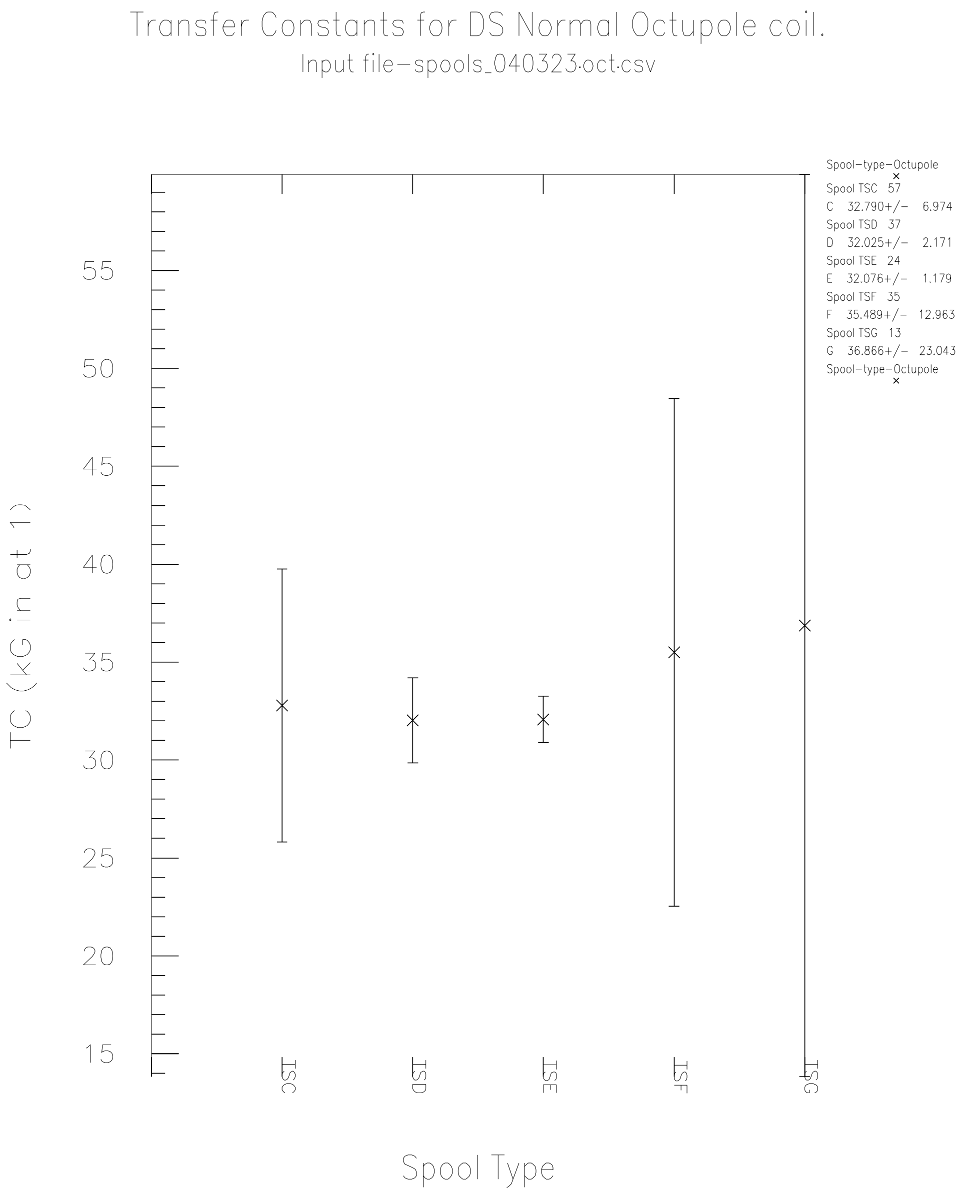

Figure 18: Measured Strength of the Normal Octupole Corrector Coils ($kG \cdot in/in^3$).

Table Va
High Order Multipoles for the Normal Octupole Coils.

Type	Loc	Coil	N/S	Moment	#	Ave	σ
E	DS	Octupole	Normal	b_0	24	-17.408	189.395
E	DS	Octupole	Normal	b_1	24	-73.671	143.387
E	DS	Octupole	Normal	b_2	24	-313.854	626.911
E	DS	Octupole	Normal	b_3	24	-11.533	9.840
E	DS	Octupole	Normal	a_0	24	58.617	151.162
E	DS	Octupole	Normal	a_1	24	43.588	125.064
E	DS	Octupole	Normal	a_2	24	176.679	579.164
E	DS	Octupole	Normal	a_3	24	-154.992	459.885
E	DS	Octupole	Normal	TC	24	32.076	1.179
F	DS	Octupole	Normal	b_0	35	23.026	181.082
F	DS	Octupole	Normal	b_0	35	23.026	181.082
F	DS	Octupole	Normal	b_1	35	-61.734	197.460
F	DS	Octupole	Normal	b_2	35	-187.971	518.637
F	DS	Octupole	Normal	b_3	35	-9.543	26.308
F	DS	Octupole	Normal	a_0	35	16.369	154.432
F	DS	Octupole	Normal	a_1	35	18.949	190.096
F	DS	Octupole	Normal	a_2	35	332.751	613.460
F	DS	Octupole	Normal	a_3	35	-54.854	484.420
F	DS	Octupole	Normal	TC	35	35.489	12.963
G	DS	Octupole	Normal	b_0	13	83.008	121.788
G	DS	Octupole	Normal	b_1	13	-181.100	136.455
G	DS	Octupole	Normal	b_2	13	-160.315	754.420
G	DS	Octupole	Normal	b_3	13	-10.154	13.564
G	DS	Octupole	Normal	a_0	13	-77.854	180.566
G	DS	Octupole	Normal	a_1	13	162.185	172.304
G	DS	Octupole	Normal	a_2	13	-231.046	338.726
G	DS	Octupole	Normal	a_3	13	-329.092	307.391
G	DS	Octupole	Normal	TC	13	36.866	23.043

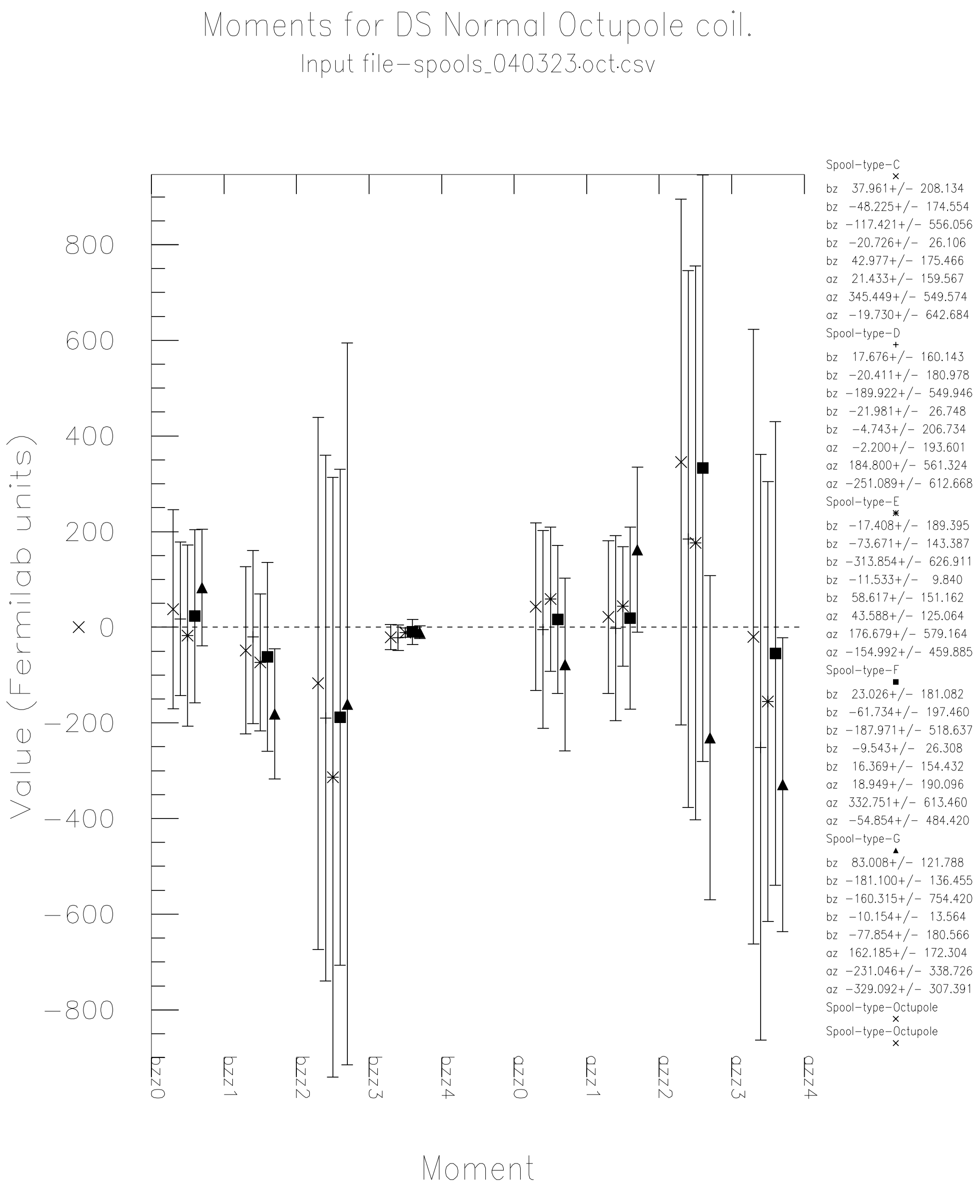

Figure 19: Measured Strength of the Multipoles for the Normal octupole Corrector Coil (Fermilab units.)

Conclusions

It is quite obvious that a large effort went into obtaining, processing and preserving the data on the TeVatron spools. Additional effort went into making these data available to an audience outside of the Technical Division. This work should be recognized and it is appreciated.

There is much work that needs to be done clean up the data however. There are anomalous (i.e. wrong) values in the data tables as well as errors in the identification of the coils. This major effort, even if it could be done, is hardly justified. The reason for that is that I do not see how the data can be put to a useful purpose.

The transfer constants are the most obvious values of interest in operating the TeVatron and yet as as Ray Hanft as shown, at least in the case of the dipole correctors, the values measured at RT at 11Hz are not appropriate to the cold DC conditions in the TeVatron. The frequency and temperature dependence of the transfer constants of the other coils has not been measured but I must regard them as suspect. I am not sure that the measured values of the TC are superior to their nominal values. It is reassuring to note that the HOM of the coils are generally small so that the lack of good measurements is not of any import in the operation of the TeVatron.

I would well any suggestions of how the data could be used.