FERMILAB-UPC-160

Fermilab

An Interim Report on the Tevatron Quadrupoles

by

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July 12, 1982

As one can see in the Tevatron Design Report (May, 1979), there are six different quadrupoles in the normal lattice.

strength (common to all): $B_0'/(B\rho) = 0.02276\ m^{-2}$

nominal length	number in the ring
66.1"	180
25.5"	4
32.07"	8
82.72"	8
90.19"	4
99.4"	12

At present, the MTF (Magnet Test Facility) data are available for 85 normal (66.1") quadrupoles and for one 32" quadrupole. It is expected that there will be some 220 normal quadrupoles altogether including those for the external beamlines and spares. Some (but by no means all) data are stored in various computer files and they are available to anyone interested in using them. Three files are under my direct control, that is, they are updated by me from time to time:

QDCHD	multipole field components (dc) up to 30-pole field for each quadrupole, at eight different excitation currents between 500A and 4,000A.
TQDATA	quench currents, integrated gradient field, field axis direction relative to yoke, hipot data, various electrical parameters, detector center positions.
QUADS	short comments on each quadrupole including the final disposition.

If you or your colleagues are interested in seeing these files, it is best to print them with the lineprinter we have near the main control room.

When the measurements of a quadrupole is completed at the MTF, their staff members (Ray Hanft and Jay Schmidt) prepare the data summary sheets (an example is attached) and send them to me for evaluation. Dipole data are sent to Leo Michelotti. Based on the data in the summary sheets (and, sometimes, from other sources), I decide whether the quadrupole should be

1) assigned to the ring,
2) designated as a spare for the Tevatron,
3) designated as a beamline magnet,
4) sent back to the magnet factory for necessary repairs,
5) remeasured for confirming some suspicious data.

As of today, the statistics of 85 quadrupoles are as follows:

assigned to the ring	71
Tevatron spares	5
beamline magnets	3
sent back to the factory	3
to be remeasured	2
kept at the MTF as the reference magnet	1

Of 71 assigned to the ring, 30 each in the E and F sectors are installed. Twenty-four quadrupoles in the A sector, which are used together with 92 dipoles for the successful cryo-test, are of the old style; they will come out in January or February to be refitted with new beam detectors and ground insulation.

Quench Test

The maximum quench current is measured in two ways:

1. a straight ramp with dI/dt = between 220A/s and 250A/s.
2. simulated Tevatron (fixed-target mode) ramp; two cycles or more (200A/s, 20s flattop, 2s between two cycles).

The statistics for these are:

	straight ramp	Tevatron ramp	
higher than 4,900A	31	7	out of 85
" " 4,800A	45	19	
" " 4,700A	50	48	
" " 4,600A	69	66	
" " 4,500A	81	74	
" " 4,400A	84	82	
lower than 4,400A	1	3	

The excitation current for 1 TeV/c is expected to be 4,438A (this includes a very small saturation effect).

Hipot

The acceptance criteria are discussed in a memo by H. Edwards. Three different conditions are used to test:

1. cold liq. He, the lowest acceptable voltage 2.2 kV
2. warm He, 1 ATM, the lowest acceptable voltage 0.8 kV
3. warm He, 4 ATM, the lowest acceptable voltage 1.9 kV

The typical leakage current is ∿1μA. When the leakage current is more than ∿5μA, moisture effects on the measuring stand at the MTF are suspect and the magnet is re-tested in the Ind. #4. So far, only one out of 85 failed to pass the criteria.

Field angle and DC Excitation

These are stretched-wire measurements. Data are taken at 500A, 660A (injection at 150GeV/c), 1,000A, 2,000A, 3,000A and 4,000A. A few magnets have been measured beyond 4,000A but the saturation effect is entirely negligible. The fluctuation of the integrated gradient $\int G \cdot d\ell$ from magnet to magnet is less than 0.12% (standard deviation). The statistics for the field angle are:

less than 1 mr	16	out of 85
1 mr to 2 mr	14	
2 mr to 3 mr	15	
3 mr to 4 mr	15	
4 mr to 5 mr	7	
5 mr to 6 mr	11	
more than 6 mr	7	

Magnetic Center (relative to the yoke)

	horizontal	vertical	
less than .005"	30	42	out of 85
.005" to .010"	31	23	
.010" to .015"	15	16	
.015" to .020"	8	2	
.020" to .025"	0	1	

One quadrupole was sent back to the factory because the horizontal position was more than .05" relative to the yoke.

Harmonic (Multipole) Components, DC

These are measured with a long (spanning the entire quadrupole length) rotating coil and the signal is fast-Fourier-analyzed. In order to find the field center relative to the center of the measuring coil, two methods are used and results are compared.

1. Eliminate dipole component,
2. *Minimize the decapole hysteresis (which arises from the* natural 12-pole hysteresis when the center is shifted).

In general, two methods give the same results within the expected measurement accuracy. Multipole components are defined by the expressions

$$B_y(y=0) = B_o' \left(b_1 + b_2 x + b_3 x^2 + \ldots \right), \qquad \text{normal field}$$

$$B_x(y=0) = B_o' \left(a_1 + a_2 x + a_3 x^2 + \ldots \right) \qquad \text{skew field}$$

where, <u>by definition</u>, $b_1 = 1$. The unit of length for <u>x</u> is inches and all b's and a's are usually given in units of 0.0001. Measurements are done at 500A, 660A, 1,000A, 2,000A, 3,000A and 4,000A. In addition, when the current is coming down from 4,000A, the measurement is repeated at 2,000A and 660A to see the natural hysteresis effects in b_5 (12-pole). The statistics of 85 quadrupoles are:

(average, std. dev.) in 10^{-4} at 1"

<u>4,000A</u>		normal	skew
	1.	1.0000	(.30, .49)
	2.	(2.78, 3.44)	(2.63, 3.39)
	3.	(1.21, 0.99)	(-0.61, 1.89)
	4.	(-.39, .72)	(-.61, .74)
	5.	(-3.77, .95)*	(.34, .37)
		(-1.02, .69)	
	9.	(-1.65, .31)	

* Two classes of quadrupoles were made intentionally.

<u>500A</u>		normal	skew
	1.	1.0000	(.25, .46)
	2.	(2.39, 3.42)	(2.49, 3.33)
	3.	(1.07, 1.10)	(-.52, 1.96)
	4.	(-.47, .80)	(-.60, .78)
	5.	(-6.13, 1.02)	(.70, .60)
		(-4.09, .84)	
	9.	(-1.60, .44)	

hysteresis of b_5 (12-pole)

$$b_5(\text{660A, going up}) - b_5(\text{660A, coming down})$$

$$= -3.88 \pm 0.33 \qquad 10^{-4}/\text{inch}^4$$

Electrical Properties (statistics of 85 quadrupoles)

DC resistance, coil & bus	1.61±.011	ohms
inductance (1 kHz)	5.91±.026	mH
Q (")	3.65±.077	
resistance (")	10.15±.11	ohms
capacitances (1 kHz)		
coil-cryostat	20.0 ±.78	nF
coil-bus	1.68±.094	nF
bus-cryostat	.33±.027	nF

Beam Detector Center (relative to the magnetic center)

Each magnet has two values, one for the proton beam and the other for the anti-proton beam. Since the difference is not significant, the data sheet usually gives the average of two.

less than 0.010"	27	out of 85
0.010" to 0.020"	17	
0.020" to 0.030"	13	
0.030" to 0.040"	13	
0.040" to 0.050"	5	
more than 0.05"	10	

Magnet No. TQ 168 D

Date Measured 5-JUNE-82

On Stand # 6

Summary Date 16-June-82

Prepared by R H.

MTF QUADRUPOLE SUMMARY
(Version of 2/15/82)

1. Quench Tests
(MTF can only ramp up to 5000A - reported quench currents above 4990A are probably not true quenches).

(a) Quench on ramp: Max I at ramp rate of 244 A/sec: 4696 A

Available stand cooling data taken prior to initiating ramp:

	Pressure		Temp.		Subcooling
1Ø in	9.6 PSIG	1Ø in	4.71 °K	1Ø in	1.6 PSI
1Ø out	9.9 PSIG	1Ø out	4.73 °K	1Ø out	1.5 PSI
2Ø in	4.0 PSIG	2Ø in	4.55 °K		
2Ø out	5.1 PSIG	2Ø out	4.55 °K		

(b) Fixed target endurance test with "saver cycle":
(If magnet runs test successfully at 4800A, no higher current run is made).

☐ FIXTAR data or ☒ CYCLE data

Ramp rate 201 A/sec; flat top 20 sec; dwell between cycles 2 sec.

Maximum current (2 Complete cycles): 4726 A

(Quench occurred in 1st ramp cycle when attempting test at 4773 A)

Available stand cooling data taken prior to initiating ramp:

	Pressure		Temp.		Subcooling
1Ø in	9.3 PSIG	1Ø in	4.72 °K	1Ø in	1.2 PSI
1Ø out	9.4 PSIG	1Ø out	4.73 °K	1Ø out	1.1 PSI
2Ø in	4.5 PSIG	2Ø in	4.52 °K		
2Ø out	4.6 PSIG	2Ø out	4.53 °K		

2. Hi-Pot
(V=Maximum DC voltage; under "T/µA" a "T" indicates there was a sudden rise in leakage current at voltage V, otherwise there is reported the leakage current observed after holding voltage V for about 1 minute.)

☐ This measuring stand was not hi-pot qualified.

Cold Liquid He 3.3 KV limit		Warm He 1 ATM 1.2 KV limit		Warm He 4 ATM 2.5 KV limit	
V(KV)	T/µA	V(KV)	T/µA	V(KV)	T/µA
3.3	4.5	1.2	0.5	2.5	1.8

Magnet No. TQ 168D

7. Field Angle and

9. DC Excitation, rising current

Current	$\int G \cdot d\ell$/KA	θ(mr)
500 A	-286.35	+1.29
660 A	-286.67	1.31
1000 A	-287.00	1.33
2000 A	-287.34	1.32
3000 A	-287.48	~~1~~.32
4000 A	-287.58	1.35

8. Quad Center (stretched wire is electrically centered - then its position relative to yoke is determined by optical survey).

Δx = -8 mils (+ means magnetic axis displaced from yoke center toward outside of ring)

Δy = -9 mils (+ means magnetic axis higher than center of yoke)

Remarks The loop width correction factor for $\int G \cdot d\ell$ = 1.00032

If this factor is reliable, $\int G \cdot d\ell$/I at 4000 A becomes

-287.67 (kg/in.)·in/KA

Field angle measurements @ 4000 A during the only cooldown —

5-June-82 13:40 +1.35 mr, reported above

15:20 +1.25

********* QUADRUPOLE HARMONICS ********* V 2.0

SHIFTING DONE BY DIPOLE ELIMINATION.

MAG NUMBER 168., DATE MEAS 820605., MEAS PROG 4.90, TIME MEAS 104805

XSHIFT= -19., YSHIFT= -45. (IN MILS)

HARMONIC COEFFICIENTS ARE FOR EXPANSION IN INCHES.
COEFFICIENTS (EXCEPT B1) HAVE BEEN MULTIPLIED BY 10**4.
CURRENT IS IN AMPS.

CUR	502.	663.	1005.	2011.	3017.	4024.	2012.	663.
A1	.42	.42	.43	.44	.45	.46	.45	.43
A2	4.44	4.43	4.47	4.53	4.60	4.75	4.52	4.32
A3	-1.75	-1.85	-2.01	-2.20	-2.25	-2.29	-2.21	-2.12
A4	-.40	-.38	-.53	-.65	-.69	-.75	-.69	-.50
A5	-.03	-.01	-.01	.05	.08	.11	-.03	-.60
A6	-.44	-.27	-.26	-.07	-.03	.03	-.11	-.63
A7	-.04	-.03	-.07	-.13	-.14	-.14	-.16	-.18
A8	.44	.45	.27	.14	.08	.04	.14	.56
A9	.70	.69	.59	.55	.54	.52	.52	.72
A10	-.18	-.22	-.10	.08	.11	.13	.05	-.29
A11	-.76	-.61	-.42	-.29	-.22	-.17	-.28	-.53
A12	-.07	-.01	.06	.01	.08	.08	.06	.08
A13	.17	.10	.10	-.07	-.09	-.09	-.04	.06
A14	.13	.07	-.06	-.16	-.15	-.21	-.15	.03
B1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B2	2.96	2.96	3.03	3.19	3.24	3.28	3.20	3.08
B3	-.31	-.16	-.00	.12	.13	.15	.10	-.20
B4	.33	.18	.14	.00	-.03	-.05	.00	.12
B5	-3.42	-2.22	-1.23	-.48	-.31	-.29	.23	2.18
B6	-.21	-.19	-.04	.19	.25	.29	.16	-.16
B7	-1.11	-.84	-.62	-.28	-.18	-.10	-.26	-.81
B8	-.69	-.62	-.50	-.30	-.24	-.20	-.30	-.56
B9	-1.34	-1.45	-1.64	-1.65	-1.67	-1.68	-1.69	-1.59
B10	.19	.19	.05	.15	.14	.15	.11	.06
B11	-.64	-.70	-.62	-.30	-.26	-.20	-.34	-.79
B12	-1.12	-1.00	-.84	-.48	-.39	-.33	-.51	-.95
B13	-.03	.11	.37	.46	.57	.64	.54	.20
B14	-.41	-.48	-.23	-.19	-.18	-.14	-.15	-.35

********* QUADRUPOLE HARMONICS ********* V 2.0

SHIFTING DONE BY MINIMIZING DECAPOLE HYSTERISIS.

MAG NUMBER 168., DATE MEAS 820605., MEAS PROG 4.90, TIME MEAS 104805

XSHIFT= -19., YSHIFT= -46. (IN MILS)

HARMONIC COEFFICIENTS ARE FOR EXPANSION IN INCHES.
COEFFICIENTS (EXCEPT B1) HAVE BEEN MULTIPLIED BY 10**4.
CURRENT IS IN AMPS.

CUR	502.	663.	1005.	2011.	3017.	4024.	2012.	663.
A1	.44	.44	.44	.46	.46	.47	.46	.44
A2	4.43	4.43	4.47	4.53	4.59	4.75	4.52	4.31
A3	-1.75	-1.85	-2.01	-2.20	-2.25	-2.29	-2.21	-2.12
A4	-.42	-.40	-.54	-.65	-.69	-.75	-.69	-.49
A5	-.03	-.02	-.01	.05	.09	.11	-.03	-.60
A6	-.45	-.28	-.26	-.07	-.03	.02	-.11	-.69
A7	-.05	-.04	-.08	-.13	-.14	-.14	-.16	-.19
A8	.42	.44	.25	.12	.06	.02	.12	.54
A9	.70	.69	.59	.56	.55	.52	.52	.72
A10	-.19	-.23	-.11	.07	.11	.13	.04	-.31
A11	-.78	-.63	-.43	-.30	-.22	-.17	-.29	-.55
A12	-.07	-.01	.06	.02	.09	.10	.07	.09
A13	.16	.09	.10	-.07	-.10	-.10	-.04	.05
A14	.13	.07	-.06	-.16	-.15	-.21	-.15	.03
B1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
B2	2.97	2.97	3.04	3.20	3.25	3.29	3.21	3.09
B3	-.30	-.16	.00	.12	.13	.15	.10	-.20
B4	.33	.18	.14	-.00	-.04	-.05	.01	.13
B5	-3.41	-2.22	-1.22	-.48	-.31	-.29	.23	2.18
B6	-.21	-.19	-.04	.19	.26	.29	.16	-.16
B7	-1.11	-.85	-.63	-.28	-.18	-.10	-.26	-.82
B8	-.71	-.63	-.51	-.31	-.25	-.21	-.31	-.58
B9	-1.34	-1.44	-1.64	-1.65	-1.67	-1.68	-1.69	-1.58
B10	.20	.20	.06	.15	.14	.15	.12	.06
B11	-.64	-.71	-.63	-.30	-.26	-.21	-.34	-.80
B12	-1.12	-1.00	-.83	-.48	-.39	-.32	-.50	-.95
B13	-.04	.11	.37	.46	.57	.64	.54	.20
B14	-.41	-.48	-.23	-.19	-.18	-.14	-.15	-.35

Form Revised 7-17-81

AFTER MTF

Quadrupole Summary

MAGNET NO. TQ168D

DATE JUNE 15, 1982

1. HiPot (flush with N_2 before HiPot) Accept <5μa

Bus to Coil	.05 μa	5 kV
Bus to Ground	.05 μa	5 kV
Coil to Ground	.10 μa	5 kV

2. Resistance DC

Coil & bus 1.62 ohms at 75 °F 1.58-1.64

3. Magnet Test Box Measurements (at 1KHz, coil floating)

(V2)	(V3)	(V4)	(V5)	(V6)	(V7)	(V8)
4.294	1.655	4.298	1.657	.0657	.0700	.0064

L = 5.91 mH (5.74-5.94) Q = 3.58 (3.24-3.64) R = 10.37 ohms (10.2-11.1)

Capacitances:

coil-cryostat = 20.6 nF (19.6-21.0) coil-bus = 1.70 nF (1.35-1.75) bus-cryostat = .33 nF (0.20-0.44)

4. Vacuum Leak Check

Insulating Vac.	Pressure	Min Det Leak (atm cc/sec^{-1})
1φ	30 psig	3.02×10^{-9}
2φ	30 psig	↓
N_2	30 psig	↓
Vac Shell	Atm.	↓
Bore tube		↓

Quadrupole Summary

MAGNET NO. TQ168D

DATE JUNE 15, 198_

5. Crossover Pipe Offsets

	Upstream Horiz.	Vertical	Horiz.	Vertical
N_2	-3/64	1/64	1/32	-1/64
Bore	-1/32	1/64	1/16	1/64
2φ	0	3/64	1/16	0

6. Beam Detector offset relative to magnetic center .0006 inches

Remarks: Production ______

MTF ______

Damage found to bellows and/or sealing surfaces during post-MTF inspection Yes ______ No ✓

Leads or lead insulation short: Yes ______ No ✓

Lugs set correctly: Yes ______ No ______

Holds over-ridden

Description	Person to over-ride

Coil traveller located: Yes ✓ No ______

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

WRITTEN BY G. CZOP

DATE JUNE 15, 1982

QUALITY CONTROL REPORT NO. № 5730

TYPE OF DISCREPANCY (check one)

- [ ] Purchase Item — to document discrepant purchased material (fill out Section 1, route and approve per Box A).
- [ ] Internal Fabrication — to document discrepant material, assembly or procedure (fill out Section 2, route and approve per Box B).
- [x] Customer Report — to document discrepant final product (fill out Section 3, route and approve per Box C).

SECTION 1

Part No. ______ Part Name ______

Purchase Order No. ______ Batch Receiving Date ______

Batch Quantity Received ______ Qty. Inspected ______

SECTION 2

Assembly Name ______ Traveler No. ______

Traveler Operation No. ______ Assembly Serial No. ______

SECTION 3

Magnet No. TQ168D Traveler No. ______

Traveler Operation No. ______

Item No.	Discrepancy Details (For measurements, list print requirement and tolerance followed by "Reads" followed by actual measurement.) Fill out "Red" hold tags.
	CROSSOVER PIPE OFFSET: UPSTREAM X-BORE $-1/64 \leq$ READS $-1/32$ (After completion of above, send copy to Quality Control Office for logging file and route per boxes below).

Final Disposition (completed by signatories below)

Procurement Officer is: ______

BOX A Hand carry completed form to procurement officer			BOX B Give completed form to production supervisor			BOX C Give completed form to Facility Manager		
Do copies go with with Parts Yes____ No____	Signature Accepted	Rejected		Signature Accepted	Rejected		Signature Accepted	Rejected
Production Officer			Production Officer			Customer		
Engineering Officer			Engineering Officer					

(After signature, route copies as follows:)

Original — Quality Control Facility Manager Parts (inventory) Production Officer Engineering Officer	Original — Quality Control Facility Manager Traveler Production Officer Engineering Officer	Original — Quality Assurance Facility Manager Traveler Accelerator Officer