Fermilab

QUADRUPOLES

G.R.Kalbfleisch and R.E.Peters

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(This is a draft - late February we will make a TM from this.)

ABSTRACT

Magnetic measurement data for both QA and QB quadrupoles is summarized. The current "BOTTOM LINE" projects to a very reasonable final QB quadrupole. Fabrication of final collared QB assemblies (≥QB-10) can soon be started.

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Fermilab

21 December 1978

To: W. B. Fowler

From: G. R. Kalbfleisch

Subject: QB-quadrupoles--MAJOR PROBLEMS TO SOLVE before proceeding to construction of final QB's (QB-10 and on).

I. Coils--

1. SHIMMING FOR CORRECT INTEGRATED 12-POLE. This needs
   a. Measurement of QB-2 at 'MTF' for integrated 12-pole (by 10 Jan. 79?).
   b. Measurement at LAB5 (in vertical dewar) of quads QB-6,7,8,9 (by 20 Jan. 79?).

II. Collared Assemblies--

2. NEW DIE FOR KEYED COLLARS. Based on calculations of W. Young. Actual fatigue life will be tested in parallel with construction of first several final QB's.
3. KAPTON GROUND WRAP. Needed for radiation damage lifetime and mechanical strength to provide electrical requirements. First trial batch for one quad may be available early Jan.79.

III. Correction elements/Tune quads--

4. RADIAL SIZE AND CONSTRAINT(banding) CONTROL of correction elements
5. NEW 10-INCH TUNE QUADRUPOLE. Tooling about ready.

IV. Cryostats--

6. T. NICOL's VAST LIST OF CHANGES from experience with QB-2.
7. TESTING OF PRESENT SAFETY LEAD SYSTEM (constantan/stopper).
8. TESTING of new 'flapper' RELIEF VALVES (1 and 2- phase).
9. OPERATION OF CORRECTION ELEMENTS (and tune quads). B12 testing of QB-2 (and later QB-6?) in Feb. 79 (?) by K.K. Should we get five QB's to minisector 25 magnet string for more realistic testing? Much to be learned by Accelerator counterparts about quench protection, beam spills, etc...

Items 1 through 6 look straight-forward, and can be completed in some reasonably predictable schedule.
Items 7,8,9 may entail new solutions etc to be operational sound for real operation. However, based on present designs, we can proceed for first thirty or so QB's; a predictable schedule for production of complete cryostats cannot yet be made, in my opinion, until more information is available on drafting changes, vendor performance and delivery etc, etc...

Copies to: NE/TN/FK/ML/KK/HE/ROrr/Alvin/WHanson/JO'M/JEF/?
DSMITH / D GROSS / E BIRCAS

3. ASSUMPTION

Only INTEGRATED strengths of various multipoles matter!

(i.e., β function, η, $\Delta\phi$ vary so little over 6 foot length of QB that details of Body vs. Ends immaterial.)

4. MEASUREMENTS

Multipoles (Morgan coil)

(Lab 5) VD† - 18" sections → Body and/or End

(Ind.#1) MTF - 1/2 QB length → $\int$1/2 quad

Stretched Wire

(Ind.#1) MTF - Full length → $\int$whole quad

Note: †VD - no Fe, collared assembly only.

5. SPECIFIC MEASUREMENTS - QUAD BY QUAD (dc only; no ac yet)

(Minimum done in order to get maximum information consistent with installing 5 QA's in tunnel.)

Magnet		VD (no Fe) Body	VD (no Fe) End	MTF (+ Fe)
QA: Collared	QA-2	[✓	✓]→∫	-
"	QA-9 (Lost)	✓	-	-
Complete	QA-1R	-	-	1*∫
	QA-2R	-	-	2*∫ (In 25 ministring in tunnel)
	QA-8	✓	-	
	QA-3	✓	-	3*∫ (In 25 ministring in tunnel)
	QA-6	✓	-	
(QA-5 arc down) (destroyed)	QA-7	✓	-	
	QA-4	[✓✓	✓]→∫	-
QB:**Complete	QB-2	✓	-	1/2*∫ 12-pole Morgan
Collared	QB-1 (Lost)*	[✓✓	✓]→∫	-
	QB-3	✓	-	-
	QB-6 in VD*	Jan.'79		-
	-7✓ *	2 Body		-
	-8✓ *	+1 E each		-
	-9 to finish*	(2 Ends some?)		-

*EBONOL (others are STAY-BRITE) cable.
**QB-4/5 shorts, no ramp, → autopsy.

6. GENERAL PERFORMANCE OF QB's

STAY-BRITE Wire	I_{max}(kA)*	I(kA) @ $\frac{dI}{dt}\left(\frac{kA}{sec}\right)$
QB-2 (VD 9/28/8)	>5.45	$\geq$5.0 @ $\leq$0.75
QB-3 (VD 9/21/8)	>5.45	$\geq$5.0 @ $\leq$0.6
EBONOL Cable		
QB-1 (VD 12/4/8)	5.2	$\geq$4.9 @ $\leq$2.0
QB-6 (VD 12/29/8)	5.2	$\geq$4.95 @ $\leq$2.0

Notes:

a. EBONOL S.S. lower than STAY-BRITE.

b. AC losses obviously less by ramp rate.

c. Will make 3 quads (as soon as cable available, on order) from 1.25 Cu:1 SC wire (EBONOL) with ~7.0kA S.S.

d. QB-4/5 - Shorts to $\geq$4.0kA only at dB/dt <.01kA/sec. (Burned in on first quenches → autopsy.)

*In Vertical Dewar @ 4.2°K, no Fe.

Operation at 4.7°K	-7%
and with Fe	-6% (Fe adds +6%)
	-13%

$\Rightarrow I_{max}$ ≈4.5kA (without correction elements)

7. INTEGRATED FIELD (with Fe)

a. Need match $\int B'dl|_{Quad}$ with $\int Bdl|_{Dipole}$.

b. 21 Dipoles (E22-55/88) consistent

$\int Bdl$ = 64.0±0.1kG-m/kA (flat ($\leq 10^{-3}$) with current)

vs. Design (35/21 turns) 63.62kGm/kA.

c. QB Design (≥12/17/7)

$\int B'dl$ = 1354kG-in./in. @ "match"

to 45.0kG in dipole(@ 4527 amps).

d. D.E.Johnson 2/1/78 ((LATTICE))

Q: (|B'|= 742.422kG/m) x 1.71704m = 1274.8kG

for D: (|B| = 42.344kG) x 6.4008m = 271.0kGm

(presumably 1000 GeV).

vs.

T.L.Collins - Update June 1978

Q: 68.85" x 19.666kG/in. = 1354.0kG in./in. (SS ok)

for D: 252.0" x 45.00kG = 11340 (SS.V).

(achieved via SS 35/21 @ 4527A.)

e. Actual

Dipole (from b) $\frac{\text{Meas.}}{\text{Design}} = \frac{64.0\pm.1}{63.62} =$ 1.006 (±?)

vs.

Quads QA(4527A) =(1345±5)kG

QB(") = ~1346kG

±?1% Meas. problem?)

$\frac{\text{Meas.}}{\text{Design}}$ ≈0.993

MAGNETS		∫B'dl(4.527kA)*
QA: QA-1R	296.9/kA x 4.527 =	1344kG
1/2(QA-2R+QA-8)	$\frac{596.6}{2}$ x " =	1350kG
1/3(QA-3+QA-6+QA-7)	$\frac{891.6}{3}$ x " =	1345kG
QB: 2 x (1/2QB-2 - MTF)	x 4.527 =	kG
2 x (1/2QB-3-VD) + (Fe Est.) →	(277.1 x 4.527 = +91.3 calc.)	≃"1346"kG
*Used MTF value at 4kA		

(∫B'dl/kA vs. kA shows ~1% variation; "MTF" must fix -- expect <0.2% from 12-pole etc. variations with I).

N.B. VD tests (R.E.Peters)

Body gradient very linear with I(kA).

8. 20-POLE (All Body effect without Fe)

QA (8 meas.) (-10 to -12) x $10^{-4}/in^8$

vs.

Design -11.5 x $10^{-4}/in^8$

and

3 QB (5 meas.) (-0.4 to -1.6) x $10^{-4}/in^8$

vs. Design -1.8 x $10^{-4}/in^8$

This was main redesign QA → QB (reduction of 20-pole to near 0 increases "tuneshift ($x \propto \frac{\Delta p}{p}$) radius" from 0.9" (QA) → 1.3" (QB)).

9. 12-POLE

a. The 12-pole is to be adjusted by shimming; it is sensitive to key angle changes and 0^{th} iteration hits desired value only approximately.

b. The 12-pole changes under excitation (varying Lorentz forces) if adequate preload not provided. Heat cured collar cannot be preloaded (coils creep, reform); room temperature cured collared assemblies ok (see Fig. 1). Mechanical measurements plus derivatives by calculation agree quantitatively with changes observed on average.

c. Various shimming has been used to produce various 12-pole contents (and variations agree with calculations). Shimming of QA's, QB's shown in Table I.

$$\left(\frac{\text{12-pole}}{\text{4-pole}}\right): \quad \begin{matrix} \text{Various QA/s} & (-12 \text{ to } +12) \times 10^{-4}/\text{in}^4 \\ \text{Various QB/s} & (-1 \text{ to } +5) \times 10^{-4}/\text{in}^4 \end{matrix}$$

d. What counts is REPRODUCIBILITY

Set shims → & $\int$ 12-pole$\approx$0 .

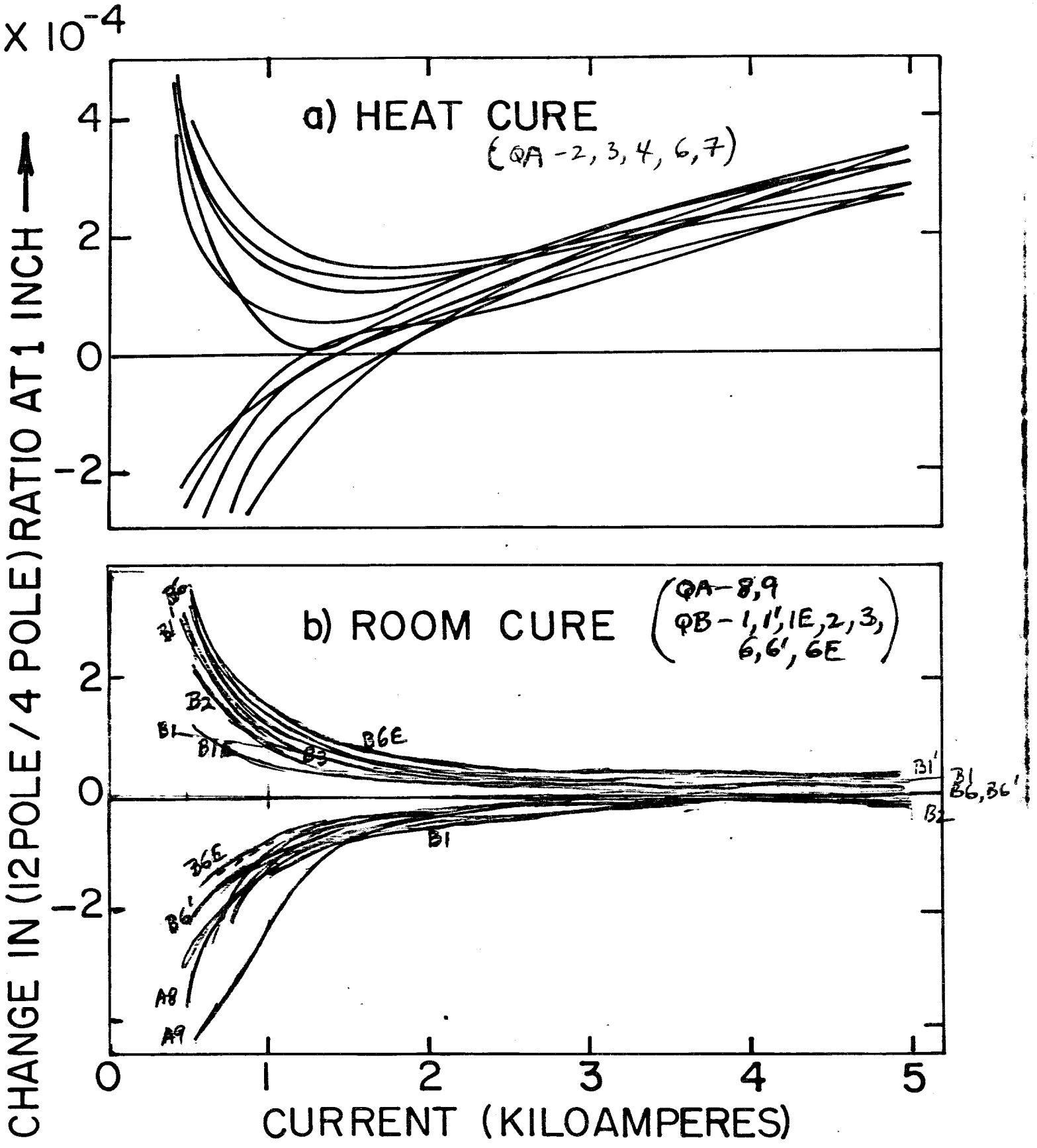

Fig. 1 QA/QB QUADRUPOLES - VARIATION OF 12-POLE WITH CURRENT

TABLE I

SHIMS

Heat cured (not clamped) (180°F several hours).

		Key	Part. Plane
QA:	QA-1R, 2, 3	0	63 mils (under shimmed)
	QA-2R, 4	0	93 mils
	QA-5(Lost), 6, 7	13 mils	93 mils

Room temperature cured (all clamped/preloaded).

	QA-8, 9R(Lost)*	16(1), 13(2,3)	84 mils
		Spacer	Key
QB:	QB-2,3	+2x5 mils	20 mils
	QB-1, 6, (7,8,9)**	+2x10 mils	10 mils

*Same for QA - got 5×10^{-4} vs. 5 desired.

**Shims set to give approximate Body 12-pole to design ($2 \times 10^{-4}/in^4$); got ≈0; but see "Ends" effect (Section 10).

10. REPRODUCIBILITY OF (12-POLE/4-POLE)

Various pairs (or sets, case of QB) of Quads were built the same (see Section 9, Table I) to check this.

a. Body 12-Pole	Δ(12-Pole)
QA-2, QA-3	$3 \times 10^{-4}/in^4$
(QA-4 2 places)	?
QA-6, QA-7	1×10^{-4}
QA-8, QA-9R	1×10^{-4}
QB-2, QB-3	0.3×10^{-4}
and QB-1	1.0×10^{-4}

RMS $1.5 \times 10^{-4}/in^4$

b. End 12-Pole - Return End		∫(2 Ends, 12-Pole) (By diff.)
QA-2	(2.2x)	-8.3×10^{-4}
QA-4	(2.7x)	-10.2×10^{-4}
[QB-2 VD Body; MTF∫]	(2.3x)	-6.1×10^{-4}
QB-1 B,E (VD)	(2.0x)	$-(5.4 \pm 0.5) \times 10^{-4}$

Variation $\approx 1 \times 10^{-4}$

vs. Design End - 12*

QA	-3.8×10^{-4}
QB	$-2.7 \times 10^{-4}/in^4$

"Ends" too strong by factor = 2.3±0.3 (like Sext in Dipole).

11. GOAL OF $\int$ 12-POLE $\approx$0!

a. QA-8, 9R and QB1, 6, ... etc. had $\int$ body 12 $\tilde{}$design

b. but ends too strong (2.2±.3 x)

$\therefore$ → condition $\int$ 12-pole $\approx$0 not yet met!

~~//~~ α. want Jan '79 meas. B_1, B_2, E_{return}, E_{LEAD} ~~(plus $E_{lead\ end}$ and [some L])~~

β. For values and reproducibility,

γ. QB-8, 9 better ends etc

before final adjustment, which can be hit closely, I think.

12. NORMAL ("ASYMMETRY") POLES (6, 8, 10, ...)

a. Poles 2, 18 due to "off-center" ~~R~~ess of probe (4→2, 20→18) 2,18→0 by determining magnetic center, set by "MTF" survey marks (N.B. some QA's were equipped with SURVEY BUTTONS but no magnetic centerline were ever brought out to adjust them -- for P.Koehler and "MTF" yet to do!).

b. Pole 10 has some contribution from off-center 12-pole feed-down; but when $\int$ 12-pole → $\approx$0, 10-pole will have no feed-down component. Will take 10-pole (raw) meas as 10-pole (ignore feedown) ~~conservative~~.

c. 14, 16, 22, 24, 28, 30-poles not measured. Should be small and negligible.

d. QB mechanical design - sector blocks, armor, fewer plastic pieces. Is vastly superior to QA. EXPECT BETTER VALUES FOR QB.

13. NORMAL (BODY) 6, 8, 10 VALUES (DESIGN = 0)

relative to 4-pole

$x10^{-4}/in^{1,2,3}$

	6QA(7 Values)	3QB (4 Values)
6-Pole		
Range	-6 to +7	-4 to +3
RMS	(4.0)	(2.6)
8-Pole		
Range	-3 to +3	0 to +3
RMS	(1.8)	(1.7)
10-Pole		
Range	-3 to +1	-1 to +1
RMS	(1.5)	(0.9)

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14. SKEW BODY 6, 8, 10 VALUES (DESIGN = 0)

relative to normal 4-pole

$x10^{-4}/in^{1,2,3}$

	6QA (7 Values)	3QB (4 Values)
6-Pole		
Range	-1 to +10	-13 to +5
RMS	(4.8)	(7.2)
8-Pole		
Range	-4 to +2	-4 to +2
RMS	(2.4)	(2.6)
10-Pole		
Range	0 to +2	-2 to +2
RMS	(1.1)	(1.5)

15. ∫ 6, 8, 10-POLE (QA-2/4; QB-1)

Parts ∫ 10^4 at 1 Inch

QB-1	6 Norm +2.4	6 Skew +1.0
	8 Norm +1.0	8 Skew +1.0
	10 Norm +1.0	10 Skew -1.6
QA-2/QA-4	6 Norm	6 Skew
	8 Norm	8 Skew
	10 Norm	10 Skew

need final data analysis

16. CURRENT ESTIMATE "UNWANTED" HARMONICS

Thus RMS over (QA/QB, Norm/Skew) At 1 inch

$\times 10^{-4}$	BODY	INTEGRATED
6-Pole	5.0	
8-Pole	2.2	
10-Pole	1.3	

NOTE: QB-1, 6, 7, 8, 9 are mechanically symmetric, whereas most others are not (QA's, QB-2, 3)

17. SKEW 12 AND 20 (AND 4)

These are essentially negligible

$$\left|\frac{12(20)}{4}\right| \lesssim 1 \times 10^{-4} \text{ at 1 inch}$$

NOTE: Skew 4 is "rotation", to be set to 0 via "MTF survey" buttons

(P.Koehler again)

18. NONLINEARITY, APERTURE, TUNE SHIFT

Taking (relative to 4-pole)

a. 20-pole = design = $-1.8 \times 10^{-4}/\text{in}^8$
b. $(0 < 12\text{-pole} < 4) \times 10^{-4}/\text{in}^4$
   (∫ or B+E)
c. RMS 6-pole = $5 \times 10^{-4}/\text{in}$
d. RMS 8-pole = $-2.2 \times 10^{-4}/\text{in}^2$, and
e. RMS 10-pole = $1.3 \times 10^{-4}/\text{in}^3$

(Worst case: 6/10 some sign // 8 negative)

We obtain, as function or radius (see FIG.2, next page)

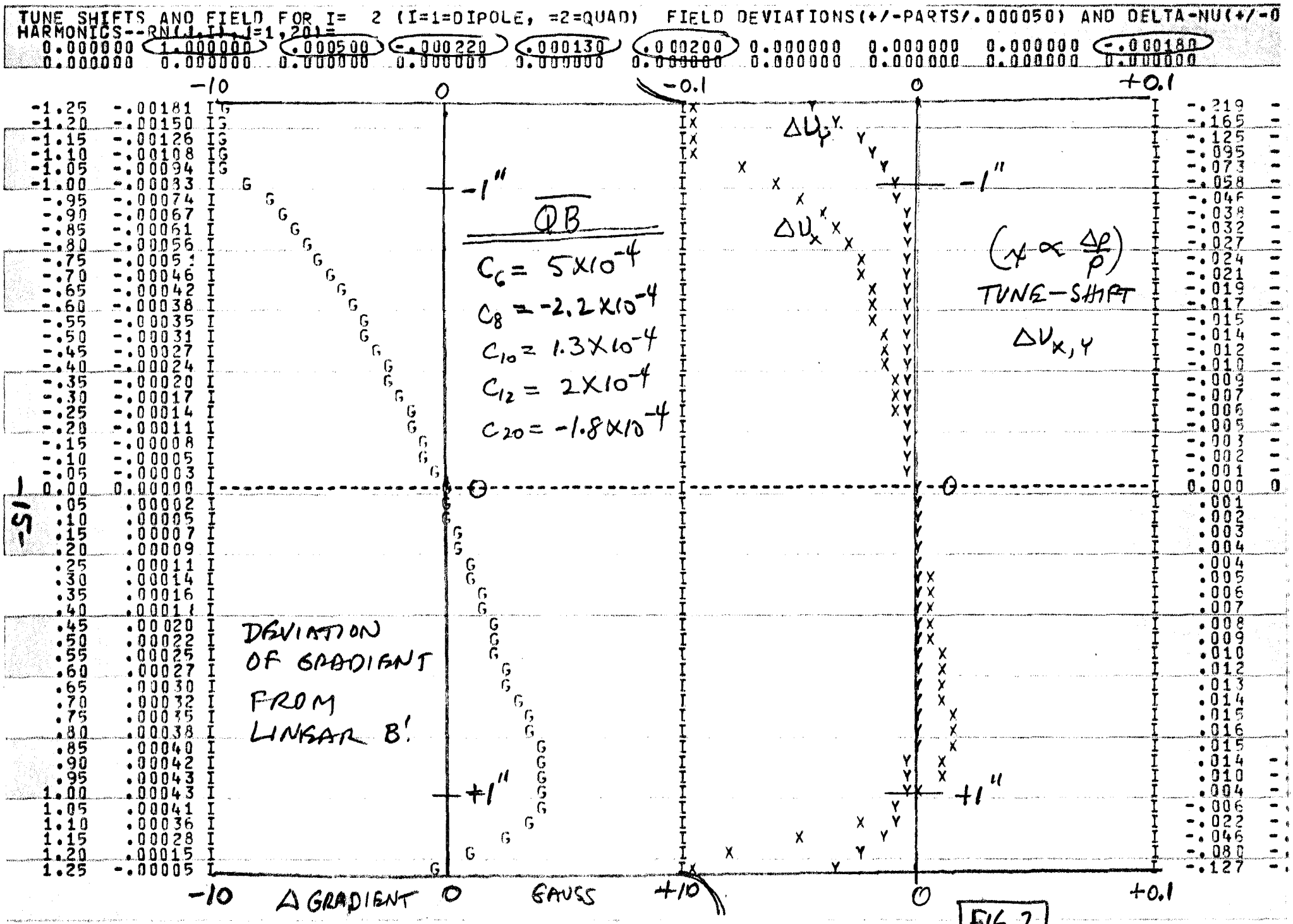
TUNE SHIFTS AND FIELD FOR I= 2 (I=1=DIPOLE, =2=QUAD) FIELD DEVIATIONS(+/-PARTS/.000050) AND DELTA-NU(+/-0
HARMONICS--RN(J,I),J=1,20)=
0.000000 1.000000 .000500 -.000220 .000130 .000200 0.000000 0.000000 0.000000 -.000180
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
-10
0
-0.1
0
+0.1
-1"
-1"
QB
$C_6 = 5\times10^{-4}$
$C_8 = -2.2\times10^{-4}$
$C_{10} = 1.3\times10^{-4}$
$C_{12} = 2\times10^{-4}$
$C_{20} = -1.8\times10^{-4}$
$\Delta\nu_y$
$\Delta\nu_x$
$\left(\nu \propto \frac{\Delta p}{p}\right)$
TUNE-SHIFT
$\Delta\nu_{x,y}$
DEVIATION OF GRADIENT FROM LINEAR B'
+1"
+1"
-10
Δ GRADIENT
0
GAUSS
+10
0
+0.1

FIG. 2

19. THE CURRENT "BOTTOM LINE"

Unless January '79 meas QB-6, 7, 8, 9 ... are unexpectedly disastrous we should have,

a. reasonably reproducible QB. Gradient linear to $\lesssim 5\times10^{-4}$ for radius out to ~1 inch giving "tuneshift" $\Delta\nu \lesssim 0.02$,

b. magnetization effect (especially 12-pole "up") affects injection, early acceleration. Some "history" path to minimize this???, see Fig. 1,

c. "Tune quad" harmonics will downgrade somewhat (6 inches badly; new 10 inch tune quad, harmonic comparable to main QB?).

"UPC" (AND OTHERS) FEEDBACK DESIRED.

>QB-10 = final quads soon!