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Quadrupole Components in Dipoles
- A Review of Problems and their Dispositions -

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October 28, 1982

I. Introduction

The need for a review of the problems associated with quadrupole components in the superconducting dipoles arose when three dipoles were pulled out of the B12 building and remeasured at the MTF in August-September, 1982. These dipoles had experienced more than twenty quenches at various excitation levels in addition to some 1,500 ramps up to 4kA. Since the originally planned tests had been completed at B12, it was felt that these dipoles would provide us unique data on the integrity of magnet field quality after a long period of operation. To everyone's relief, the remeasurement revealed that the changes in multipole field components were generally insignificant and we could expect the field quality of the superconducting ring to remain unchanged for a reasonable period of time. After the first group of these three dipoles, six more have been taken from B12 and their remeasurements at MTF have confirmed the previous findings.* At the same time, the same measurements reminded us once again that there are problems with quadrupole components, the problems that have been with us for almost three years without any of us understanding what causes them. The purpose of this note is to review what we know about them and to try to reassure everyone concerned that although we are not clever enough to solve the problems in a fundamental manner, we have at least been prudent enough to install only few magnets known to have problems in the tunnel, ten or so out of more than five hundred so far. For one type of difficulty, which seems to be common to almost all dipoles so that there is no way we can avoid it in the tunnel.

* W. Cooper will report on this as well as on other related findings.

the correction system we are introducing into the ring turns out to be more than adequate to overcome the difficulty at the highest design energy. Let me repeat the main point of this note: Problems related to quadrupole components b_1 and a_1 in dipoles* are still with us unsolved but they should not cause any serious trouble in running the machine.

II. Three Problems

The earliest of my memos on the quadrupole problems was issued on January 14, 1980, "Is the Field Quality of Doubler Dipoles Deteriorating?". This was followed ten days later by another memo, "A Concerned View of the Field Quality of Doubler Dipoles". Soon after, the smart bolts were introduced primarily to prevent the change in vertical plane angle but also as the solution to the quadrupole problems. Instead of describing the nature of the problems all over again, I have partially reproduced four memos on this subject in the appendix so that interested readers can learn the background. These memos are of course all obsolete by now and they serve no useful purpose except to demonstrate that we have never completely forgotten the existence of the problems. As one can see from them, there are three different types of abnormalities in b_1 and a_1:

1. hysteresis-like behavior in a_1 (but never in b_1),
2. current dependence in b_1 and in a_1,
3. change in a_1 and, to a lesser extent, in b_1 during storage.

We have tried to understand what causes these problems which may or may not be related to each other. As far as I know, nobody has come up with the believable answer to any of them. Meanwhile, since magnets

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* By now it is well-advertised that we use coefficients b_n and a_n to represent the normal and skew multipole components, respectively:

$$B_y(x)|_{y=0} \equiv B_o(1 + b_1x + b_2x^2 + \cdots\cdots),$$

$$B_x(x)|_{y=0} \equiv B_o(a_1x + a_2x^2 + \cdots\cdots).$$

Unless explicitly stated otherwise, the unit 10^{-4}/inch is always understood for quadrupole components b_1 and a_1.

had to be accepted and installed in the tunnel and, luckily, the number of magnets afflicted with the first two problems was not substantial, we decided to accept magnets with what we believed to be "reasonable" criteria,

1. hysteresis in a_1:

   $|a_1$(at 660A and current going up)
   $- a_1$(at 660A and current going down)$| < 1.$

2. current dependence:

   change in b_1 between 660A and 4kA $< 1.$,
   change in a_1 between 660A and 4kA < 1.5

Of 546 dipoles already installed or assigned, there are only ten or so that do not meet these criteria. Since these abnormal ones are known to us, it would be a simple matter to replace them with spares in the future even if they were found to cause problems in operation. Our experience at B12 indicates that this is unlikely. It should be emphasized here that the two abnormalities, hysteresis-like behavior and the current dependence, are not at all important as far as the beam in the ring is concerned. The beam will never experience the field at 660A (the injection level) when the excitation current is coming down. The abnormal current dependence is totally insignificant since the correction elements for both b_1 and a_1 must be programmed from the injection to the full energy any way. What we are afraid of is that these two are a manifestation of some very serious problem about which we are totally ignorant, the problem associated with the structural integrity of magnets. Before moving on to the last (and possibly the most serious) problem of "drifting", I should mention two known facts on the hysteresis and the current dependence:

a) The abnormal behaviors are not affected by repeated quenches or thousands of ramps. The "bad" ones are always bad and "good" ones stay that way. This is based on the remeasurement data of B12 dipoles.

b) The problems are not localized at the ends or in the body of magnets. Rather, they are over the entire length. This is in contrast to the third problem of "drifting" which is definitely predominant at ends.

I have always felt that the last of the three problems is the most serious one, especially because the data available in the summer of '81 showed the drifting in a_1 to be always toward the positive direction. If this were true, we would have an impossibly large average value of a_1 in the ring. My feeling at that time can be seen in the following excerpt from the memo issued on July 1, 1981:

C. Change in a_1 during Storage

This is potentially the most serious of three problems discussed in this note. Unfortunately, there have been no systematic studies of this phenomenon; remeasurements of a magnet are almost always done for some different reasons. Besides, one usually is not sure if anything abnormal happened to a magnet during its storage (getting bumped, for example). Certainly each magnet goes through a series of maneuvers and it may not be fair to look at more or less random observations and conclude that the similar change would take place for all magnets in the tunnel. On the other hand, we must understand the cause of this problem since it is truly very serious if universal.

I have compiled all cases I know of in which measurements have been repeated after some period. To the best of my knowledge, no change (such as reshimming) has been intentionally made during the storage period. All quantities are at 4kA so that the effect of hysteresis or the effect of current overshooting (during 3/15 to 4/05) should not affect the result. It seems safe to conclude from this tabulation that the change during storage is

1. *mostly in a_1, but also in b_1 to some extent(?),*

2. *concentrated near the ends of magnet; however, this may be partially caused by the different coil position longitudinally (along the beam direction) on two different measurements,*

3. *the change in a_1 seems to be again always in the positive direction. (#451 is the exception).*

In order to separate the effect of storage from others such as re-yoking and reshimming,* I solicited a help from Ray Hanft who kindly supplied me with the list of all dipoles that nave been mounted on the measurement stands more than once with some time intervals between two successive measurements. In the list, he noted all the changes known to have been made on each magnet. With this information, I have found eighteen dipoles as the "uncontaminated" source of data on drifting. Of these, nine are B12 dipoles (B12), two are the so-called reference magnets (R) stored at MTF for long-term observations and two are the "transportation" magnets (T) which were once used to test the effects of moving a magnet around the ring. In the list given below, numbers following each magnet ID are the interval (in days) between two measurements at MTF.

1.	TB0269	20		
2.	TB0271(R)	359	38	205
3.	TB0347(B12)	659		
4.	TB0349(B12)	652		
5.	TB0376(B12)	744		
6.	TC0393	108		
7.	TC0403(B12)	671		
8.	TC0411	40		
9.	TC0425(B12)	722		
10.	TC0430(B12)	675		
11.	TC0433(B12)	672		
12.	TC0435	69		
13.	TC0451(B12)	30	35	516
14.	TC0470(B12)	562		
15.	TB0478	180	28	
16.	TC0535(R)	268	90	
17.	TC0629(T)	166		
18.	TB0823(T)	125		

"hysteresis" and current dependence:

#269 c.d. in b_1

#425 hyster. in a_1 and c.d. in a_1

#435 hyster. in a_1

#451 hyster. in a_1 and c.d. in a_1

#470 hyster. in a_1 and c.d. in a_1

#478 hyster. in a_1 and c.d. in a_1

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* "Storage" may include, in addition to the usual "moving around", thermal cycles, quenches and field rampings.

III. Findings

The first observation one can make from the data is the unchanging behavior of hysteresis and current dependence. If a magnet is bad in this respect, it remains bad after a long period of time and after many quenches and thermal cycles. A good magnet never develops these malignant characteristics. This is true not only in a qualitative sense but, to a surprising degree, in a quantitative sense as well. The fact that the abnormalities are over the entire length of magnet has also been reconfirmed. Let me present just one case as a typical example:

TC0425 (B12 magnet) time interval = 722 days

1. hysteresis in a_1:

days	downstream	upstream	center	
0	1.37	1.55	1.61	
722	1.56	1.80	1.71	(*)

2. current dependence in a_1:

days	downstream	upstream	center	
0	0.82	0.92	0.65	
722	0.90	1.18	0.80	(**)

The word "uncanny" might not be totally inappropriate to describe the feeling I experienced when I found out that these two measurements were done with two different probes (A1 and J2).

The overall picture of the drifting in a_1 and b_1 can be seen in Fig. 1 where the amount of drift in b_1 and a_1 at 4kA is plotted as a function of the time interval. For this, three positions (upstream and downstream ends, center) are combined with the proper ratios. For the beam, the combined value is the only quantity of any consequence but it is instructive to see three positions separately in order to confirm the previous observation that the drift is predominantly at two ends. The statistics of 24 samples are:

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* hysteresis in a_1 : a_1(660A, current going down) - a_1(660A, curren going up).

** current dependence in a_1: a_1(4kA) - a_1(660A, current going up).

	skew a_1	normal b_1
downstream	0.29 ±1.70	-0.06 ±1.70
upstream	0.84 ±2.24	-0.12 ±2.14
center	0.19 ±0.30	-0.03 ±0.23
combined	0.41 ±0.95	-0.07 ±0.55

For B12 dipoles alone (9 samples, interval longer than 500 days):

	skew a_1	normal b_1
downstream	-0.13 ±1.93	-0.64 ±1.60
upstream	1.34 ±2.50	-0.56 ±2.10
combined	0.44 ±0.98	-0.41 ±0.57

Observations

1. There is no strong evidence to suggest that the drifting is of a "walk-away" type. The amount of drift after one month could be as large as the amount after two years.

2. For b_1, the change is symmetric. For a_1, it tends to be more to the positive direction. The difference in average values between two groups (all samples vs B12 samples only) may or may not be significant. The standard deviation of the combined value seems to be the same for two groups.

3. The drift is definitely at ends and not at the center. For a_1, the change is larger at the upstream end compared to the other end. Is this somehow "explainable" from the structure?

4. The statistics of the magnets already installed or assigned are as follows:

$$\text{MTF data at 4kA:} \quad b_1 = 0.13 \pm 0.56, \quad a_1 = 0.19 \pm 0.63$$

If these were combined with the results of B12 samples, one would guess as the true situation in the tunnel

$$4\text{kA} \qquad b_1 = -0.28 \pm 0.80, \quad a_1 = 0.63 \pm 1.17$$

If all 24 samples were used instead of 9 B12 samples,

$$4\text{kA} \qquad b_1 = 0.06 \pm 0.78, \quad a_1 = 0.60 \pm 1.14.$$

With these numbers, one can make a very optimistic or a very pessimistic assumptions in evaluating the adequacy of the correction system. As a "reasonable-but-leaned-toward-pessimistic-side" assumption, I propose

	average	std. dev.	
b_1:	between -.8 and +.5	1.0	at 4kA.
a_1:	between 0 and +1.2	1.5	

Readers are welcome to make their own assumptions in accordance with their inclinations.

IV. Correction Systems

Before evaluating the correction systems for b_1 and a_1, it is instructive to see what has happened to the field quality of dipoles in the past three years or so. A report on this subject issued after the change in length from 22' to 21' but before the introduction of the smart bolts covered the measurement of only twenty-two magnets.*

<u>fluctuation of the bend field from magnet to magnet</u>

1979: 12 magnets between -0.06% and +0.05%

1982: 546 magnets, std. dev. = 0.062%

These values should be compared to the original design criterion of "$<\pm 10^{-3}$ about mean @ 2000A", 1979 Design Report, p. 30.

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* TM-910, "Field Quality of Doubler Dipoles and its Possible Implications", October 15, 1979.

multipole field components at 4kA

	1979 (16 dipoles)	1982 (509 dipoles)*
b_1:	-0.92 ±1.47	0.13 ±0.56
a_1:	0.12 ±1.88	0.19 ±0.63
b_2:	-0.90 ±2.86	1.22 ±3.54
a_2:	-0.11 ±1.11	0.43 ±1.32
b_3:	-0.34 ±0.82	-0.24 ±0.80
a_3:	-0.59 ±2.44	-0.04 ±1.67
b_4:	1.38 ±1.73	-0.76 ±1.51
a_4:	0.00 ±0.56	-0.06 ±0.52
b_6:	7.25 ±0.74	6.98 ±0.94

1979 Design Report, p. 30. Criteria at 2kA for b_n and a_n

b_1 and a_1 :	±2.5
b_2 :	±6.0
a_2 :	±2.0
b_3, a_3, b_4, a_4:	±2.0

The improvements in b_1 and a_1 with the smart bolts are obvious. Even with the expected drift, the standard deviations do not exceed the 1979 values. As for other multipole components, the change from 1979 to 1982 (or from 16 dipoles to more than 500 dipoles) is unbelievably small. At the time of writing the report in 1979, I did not expect this result. In three years, we have not made any substantial improvements in reducing the nonlinear components but, more significantly, there was no deterioration in the field quality and what we said in the Design Report in May, 1979 were not a mere wishful thinking.

In addition to the 1979 Design Report (Chapter 7), there are two reports I know of which are relevant to the question of correction

* These numbers were supplied to me by Don Edwards.

systems for b_1 and a_1:

ref. 1 Design Report, May 1979, Chapter 7 (7.3.2 & 7.3.5).

ref. 2 UPC No. 123, "The Quadrupole Component in Dipoles and the Injection Mismatch", March 6, 1980.

ref. 3 UPC No. 125, "Correction of Skew Quadrupole Field in the Doubler", March 26, 1980.

I believe it is better to cite relevant passages from these reports than to repeat the arguments all over again.

A. Correction of b_1

A.1 tune correction associated with the average value of b_1

There are 180 trim quadrupoles planned, each having B'ℓ = 60kG. With the assumption $-0.8 < (b_1)_{av} < +0.5$ (see p. 8), the tune correction requires only ∿3kG out of 60kG of each trim quadrupole.

ref. 1, p. 125

"*A systematic quadrupole term, b_1, in the dipoles would produce tune shifts $\pm 1.1\times 10^3 b_1$ in the two planes of motion. The magnet-selection criteria require that b_1 for each dipole lie within the range $\pm 2.5\times 10^{-4}$/in. If the systematic component were half that value, 5 kG-in.*(for ∫B·dℓ at 1") *would be required of each trim quadrupole.*"

A.2 39th harmonic component associated with the standard deviation of b_1

The effect of 39th harmonic from b_1 is considered in ref.1 and in ref.2. In ref.1, the standard deviation of b_1 is assumed to be 2.5 which is more than twice the value assumed on p. 8 of this report as my guess.

ref.1, p.125

"*For half-integer extraction, a typical value of the total strength on the 39th harmonic is 170 kG-in., to be distributed among a suitable distribution of trim quadrupoles. Contributions to this harmonic from quadrupole fields in the dipoles* *must be compensated. The measurements alluded to in the preceeding paragraph indicate a standard deviation for b_1 comparable to the bounds of the magnet-selection criterion. If so, the driving term on either the sine-like or cosine-like phase of the 39th harmonic due to b_1 in the dipoles would be 23 kG-in. at the rms."*

There are sixteen trim quadrupoles for controlling, predominantly, the 39th harmonic term of the resonance $2\nu_x = 39$, again with $B'\ell$ = 60 kG. Ref. 2 was written when the role of smart bolts for controlling b_1 and a_1 was not established. It was felt at that time that we would have to relax the acceptance criterion of ±2.5 in order to prevent the disastrous side effect of reshimming.

ref.2, p. 9

"1. *New criteria for the normal quadrupole component b_1 in doubler dipoles:*

660A to 4000A	$(b_1)_{rms}$	<	3×10^{-4}/inch
	$\|(b_1)_{av}\|$	<	1×10^{-4}/inch
	$\|b_1\|$	<	6×10^{-4}/inch

2. *There should be a plan to have at least twelve harmonic trim quadrupoles with four "knobs". If the price is not prohibitive, it is desirable to consider a system with twenty-four trim quadrupoles."*

The planned correction system is composed of four groups, eight trim quadrupoles for each group making a total of thirty-two. It is inconceivable that, even with drifting, b_1 in the ring may deteriorate to this outrageous condition. The desire to have twenty-four trim elements came about because of a possible emittance dilution caused by the injection mismatch. As for the half-integer resonances, we see in ref.2.

ref.2, p.2

"A. *Half-integer resonances $2\nu_{x,y} = 39$. This is driven by the 39th harmonic. If the criterion for b_1 is relaxed to*

$$(b_1)_{rms} < 3\times10^{-4} \quad \text{and} \quad |b_1| < 6\times10^{-4},$$

the total resonance width $(\Delta\nu)_{rms} = 0.026$. *In addition, from the fluctuation* $(\Delta B'/B')_{rms} = 1.5\times10^{-3}$ *of quadrupole magnets, we have* $(\Delta\nu)_{rms} = 0.011$ *and from the sextuple component in dipoles* $(b_2)_{rms} = 3\times10^{-4}/\text{inch}^2$ *coupled with the horizontal closed-orbit distortion of 1 cm at* $\beta_x = 100m$, $(\Delta\nu)_{rms} = 0.012$. *Altogether, we expect* $(\Delta\nu)_{rms} = 0.031$. *Taking twice the rms value as "safe", one should be able to avoid the stopband by operating the doubler at* $\nu < 19.47$ *or* $\nu > 19.53$. *This is not a very severe restriction."*

Note that the above situation is when we have no harmonic correction for the half-integer resonances. We can safely conclude that the correction of b_1 is more than adequate under any conceivable situation.

B. Correction of a_1

From the beginning, the plan for the skew quadrupole correction system emphasized the flexibility:

ref.1, p.129

"The skew-quadrupole coefficient in the main dipoles will be closely monitored in order to review the number and distribution of the skew quadrupoles as construction proceeds."

Ref.3 was an attempt to define quantitatively the requirements in the strength as well as in the distribution of correction elements. Note that the report was written very shortly after ref.2, UPC No. 123, when the outlook for b_1 and a_1 was rather gloomy:

ref.3, p.2

"There are reasons to believe that the present criteria for normal and skew quadrupoles in dipoles are unrealistically tight and a new criterion for the normal quadrupole component has been proposed. It is suggested here that the new criteria for a_1 *should be*

660A to 4,000A $(a_1)_{rms} < 3\times10^{-4}$/inch,
$|a_1| < 6\times10^{-4}$/inch,
$(a_1)_{av}$ *for all dipoles* $< 0.5\times10^{-4}$/inch.

The criteria for θ_q *are*

$(\theta_q)_{rms} < 3$ mrad,
$|\theta_q| < 6$ mrad,
$(\theta_q)_{av}$ *for all quadrupoles* < 0.5 mrad.

The purpose of this note is to study the consequence of these criteria on the necessary correction system."

Ray Hanft and Thornton Murphy assure me that the numbers given above for θ_q, the vertical-plane angle of quadrupoles, are all unrealistically large. With all sorts of uncertainties included (MTF measurement, MTF lug setting, transportation, thermal cycling, installation and survey in the tunnel), their guess is $(\theta_q)_{rms}$ no more than 1 mrad. The same comment applies to $(a_1)_{rms}$ which is twice my guess given on p. 8 of this report. The only exception is the average value of a_1; one cannot exclude the possibility of having $(a_1)_{av}$ larger than 1 which is twice the average assumed in ref.3. For the complete discussion of the skew quadrupole correction, I may have to reproduce ref.3 in its entirety here. Since this is impractical, I stress instead that the following description of the system is far from satisfactory.* The correction system studied in ref.3 is

ref.3, p.6

"B. *correction elements*

1. For $\nu_x - \nu_y = 0$: *set A* — *All and D11*

set B — *two normal stations in each sector, all 12 in series*

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* Don't forget to look up a report by Mike Harrison, UPC No. 115, October 26, 1979. He investigated the vertical oscillation induced by a_1 in dipoles during the slow resonant extraction.

2. For $\nu_x + \nu_y = 39$: *set A B18, C18, E18, F18*
set B A43, B43, D43, E43"

ref.3, p.7

"More than 1,500 samples of random distribution with the parameters specified on p. 6 have been used to find the necessary gradient strength for four sets of correction elements. In order to cover $\gtrsim$ *90% of the cases, we need*

$$|B'_s \ell| \text{ for set } 1A = 49\text{kG } (\times 2),$$
$$1B = 57\text{kG } (\times 12),$$
$$2A = 42\text{kG } (\times 4),$$
$$2B = 43\text{kG } (\times 4)."$$

The requirement found here should be compared with the presently planned system, keeping in mind that the system in ref.3 was for a very much worse condition:

1A = 60kG ×12 (all stations #11 and #49),
1B = 60kG ×48,
2A = 60kG ×4,
2B = 60kG ×4.

The possibility of having a large value of $(a_1)_{av}$ is adequately taken care of by the increased total strength in set 1B. From p.7 of ref.3, we see that the total requirement for set 1B is

$$|B'\ell| \text{ in kG } < 804|a_1,av| + 490\ |\theta_{q,av} \text{ in mrad}|$$

This means, with 48 elements in set 1B,

$$16.8\ |a_{1,av}| + 10.2|\theta_{q,av}| < 60.$$

This is indeed a very comfortable situation for any conceivable combinations of $a_{1,av}$ and $\theta_{q,av}$. Under different circumstances, we would certainly be accused of indulging in yet another overdesigning.

V. Final Thought

Some of us, including myself, would be nagged for a long time to come by the problems we could not understand. Perhaps others would show us that the problems are ovbious. Meanwhile, I strongly suggest that we leave this topic behind us and not waste our time in fruitless speculations.

Fig. 1

The change in b_1 and a_1, the normal and skew quadrupole components in dipoles, respectly, during "storage". Data are at 4kA and they are "shifted and combined" in the usual manner. Points beyond 500 days are all from B12 dipoles. These dipoles have experienced more than twenty quenches and some 1,500 ramps up to 4kA.

Appendix (pp. 17 - 20)

Memos written in the past regarding the quadrupole problems are partially reproduced here. Contents are of course mostly obsolete but I cannot deny their nostalgic values to the writer of them.

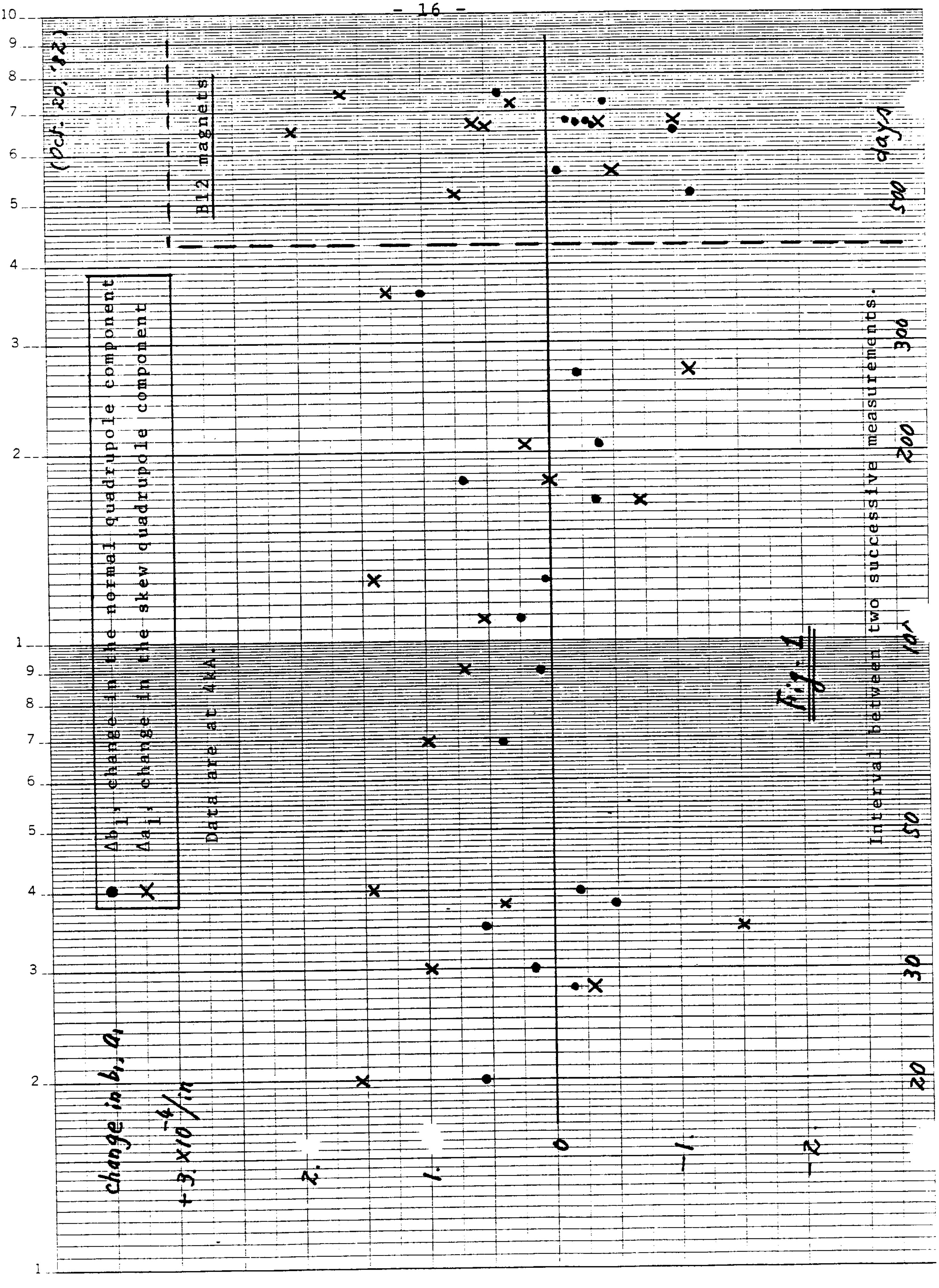
(Oct. 20, '82)
B12 magnets
Δb1: change in the normal quadrupole component
Δa1: change in the skew quadrupole component
Data are at 4kA.
Interval between two successive measurements.
500 days
300
200
100
50
30
20
Change in b1, a1
+3. ×10-4/in
2.
1.
0
-1
-2

Fig. 1

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April 29, 1981

APPENDIX

To: Distribution

From: Sho Ohnuma *Sho.*

Hysteresis-like Behavior of the Skew Quadrupole Component

It has been speculated by some people that the hysteresis-like behavior of the skew quadrupole component a_1 in some dipoles may be related to the normal sextupole component b_2. In order to see this, I have tabulated a_1 at 660A and b_2 at 4,000A for 15 dipoles. These dipoles are all from two groups, one from #411 to #428 and the other from #429 to #469. In order to avoid any ambiguities, measurements made during the second half of March were excluded.

Looking at the table, it seems unlikely that the abnormal behavior is related to the sextupole component. The quantity Δ which is the extent of hysteresis is , in each dipole, remarkably similar in all three positions (two ends and center). Does this mean the abnormal behavior is related to something which is constant over the entire length of dipole? For example, iron?

Distribution

J. Carson	W. Cooper	D. Edwards	H. Edwards
D. Gross	R. Hanft	P. Limon	R. Lundy
J. Malko	F. Nezrick	R. Orr	A. Tollestrup

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May 20, 1981

To: R. Lundy

From: S. Ohnuma *SOhn*.

Subj: Current dependence of harmonic components

I thought we solved this problem when we introduced bolts. Until quite recently, I have not seen any magnet exhibiting abnormal current dependence. There are, however, six magnets which are all measured recently and show the dependence. Of these six, four were measured during the second half of March when there was something wrong at the MTF. One might question the measurement except for the fact that there are ten more magnets measured during the same period and not showing any abnormal current dependence. I hope someone in your group can explain why these magnets are abnormal. Otherwise, we may have to reject impossible number of magnets soon.

		660A↑	1000A	2000A	4000A	660A↓	
TB0269 (4/14/81)							
	b_1	2.41	2.10	1.77	1.19	2.45	
	a_1	2.06	2.20	2.41	2.82	1.94	
	b_3	-1.89	-1.54	-1.20	-0.94	-1.85	
TB0272 (2/12/81)							
	b_1	0.97	0.85	0.63	-0.02	0.88	
	a_1	-0.85	-0.50	-0.03	0.29	-0.84	
	b_3	-1.67	-1.33	-1.00	-0.72	-1.54	
TB0441 (3/28/81)							
	a_1	-2.16	-1.02	0.09	0.23	-5.72	("hysteresis")
	a_3	-0.79	-0.42	-0.02	0.18	-2.84	(")
TC0451 (3/24/81)							
	a_1	1.35	0.96	-0.08	-0.32	-3.38	("hysteresis")

Measurements on 1/19/81 and on 2/17/81 show the same abnormal dependence.

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July 1, 1981

To: Distribution

From: Sho Ohnuma

Abnormal Behaviors of the Quadrupole Components - Compilation of Data

There are three different types of abnormal behavior in b_1 and a_1 which have been worrisome to some of us in the past few months. This document is simply a (partial) compilation of the relevant data known to us at present. I am distributing this with the hope that experts can find the cause (causes?) of these problems and cure them soon. So far, it is not catastrophic; I have about ten dipoles which I would not introduce into the tunnel because of these problems. On the other hand, if the trouble continues, I may have to reject $\sim$ ten percent of all dipoles received. Three types of abnormal behavior are:

A. Hysteresis-like behavior in a_1 (but never in b_1).

B. "Ordinary" current dependence in b_1 and in a_1.

C. Change in a_1 (also in b_1 ?) during storage of some duration.

These three may or may not be related to each other. Many people suspected the shifted sextupole field as the source of troubles. I have tried to see if sextupoles are somehow related to the problem but so far have not found any clear correlation. Perhaps other people would be more successful in this detective work and the fact that I doubt the sextupole as the origin of trouble should not deter others to pursue the similar direction in their investigation.

Fermilab

May 6, 1982

To: Distribution

From: S. Ohnuma *Sho*.

Current Dependence and Hysteresis in a_1

column 1 : magnet numbers

column 2 : sample numbers

column 3 : number of magnets with $|a_1(4kA)-a_1(660A)| > 1$

column 4 : number of magnets with $|a_1(660A, up) - a_1(660A,down)|$ greater than 1.

#200 - #410	130	2	2
#411 - #519	83	6	23
#520 - #727	157	9	14
#728 -	145	28	8

Note: At #411, there was a change in collared coil geometry.
At #520, there was a change in inner coil mold size.
At #728, there was a change in inner coil mold size.

Does this tell us anything? The increase in column 3 from 9 to 28 in almost equal number of samples is alarming to me.

D. Edwards H. Edwards R. Hanft
R. Lundy L. Michelotti A. Tollestrup
F. Turkot