UPC 083

Fermilab

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A. Effects of Full Quenches on the Field Quality of Dipoles

B. Hysteresis - Dependence of the Dipole Field quality at Injection on the Base Current of Ramping

A. Effects of Full Quenches on the Field Quality of Dipoles

Effects of "soft" quenches and warm-cool cycles on the field qulity of doubler dipoles have already been reported.[1] The measurement for this was made in December, 1978 on PCA148. During the same period, another dipole, RDA101, went through more than 150 full energy quenches and the multipole components were measured several times after many such quenches. This report is a summary of the results showing that full energy quenches do not seem to affect the field quality in a substantial manner. At the same time, there are a few questions that should be clarified by another series of the same type of measurements. Measurements reported here were all carried out by Karl Koepke, Moyses Kuchnir and members of the Magnet Measurement Group. Raw data without center corrections are available in the PDP-10 file DCH3.DAT[103,122].

The first measurement of RDA101 was made in August, 1978 on the stand #1. The warm bore used was free of magnetization which introduces a spike in the signal and distorts the field, especially below 1,000A excitation. Results from this first measurement are represented by solid circles (●) in Figs. 1 - 3. The magnet was then removed from the stand for a storage until the end of November when it was placed on the stand #2 for the full quench test. Unfortunately, the warm bore on this stand was not free of magnetization. In addition to any effects of moving from a stand to storage to another stand (bumping is not totally excluded), the effect of the magnetized strip on the warm bore is expected to show in the multipole components of the field. This measurement is represented by crosses (X) in Figs. 1 - 3. In mid-December, the magnetized bore was replaced by a new annealed one which presumably is free of magnetization. The third measurement, represented by open circles (O) in Figs. 1 - 3, should therefore be compared with the first one (solid circles) to see the effect of quenches.

	date	stand	warm bore	full quenches
●	August, 1978	1	good	no
X	November, 1978	2	bad	many
O	December, 1978	2	good	many

Fig. 1. Multipole fields (two ends and body combined) at 1" when the dipole field is normalized to 10 kG. Normal 6-, 10-, 14-, 18- and 22-pole components at 500A, 1,000A and 4,000A excitations.

Fig. 2. Same as Fig. 1. Normal and skew components. 4_s = skew quadrupole, 6_s = skew sextupole, etc.

One can see from these figures that the first and the third measurements are in a good agreement with the exception of the skew qudrupole. On the other hand, the second measurement with the bad warm bore definitely shows the effect of magnetization. Typical cases are normal 10, 14, and 18 in Fig. 1, and 8, 12s, 16s, 20, 22s, 24, 26, 26s, 28s and 30 in Fig. 2. In all these cases, the agreement becomes better at higher excitation currents. The effect of the bad warm bore is also evident in the variation of the calculated field center relative to the center of the measuring coil when the excitation current is increased. The standard procedure for finding the center is to assume that the normal and skew 16-pole components are generated by the shifted normal and skew 18-pole components. In most cases, the center coordinates calculated in this way vary not more than five mils or so when the excitation current is increased from 200A to 4,000A. In Fig. 3, center coordinates at 200A, 500A, 1,000A and 2,000A relative to the coordinates at 4,000A are shown for three measurements. It is not clear whether the large vertical shifts (center and upstream end) of the third measurement (open circles) are caused by the new warm bore, which may not be completely free of magnetization, or by something else. At the same time, the abnormal behavior of the second measurement (crosses) is evident.

In order to confirm that the differences of the second measurement from the other two are mostly caused by the bad warm bore and not by the full quenches, three sets of measurements, all with the same bad warm bore, are compared. Each set is a combination of the center and the downstream end fields so that it is not possible to get the full combined field. Nevertheless, the difference among these three sets will indicate the effect of full quenches alone since the warm bore was not moved and the magnet itself never left the stand. Results shown in Fig. 4 are the difference of set 2 and set 3 relative to set 1. (Open and solid circles in this figure are not to be confused with those in Figs. 1 - 3.) With the exception of normal sextupole and 18-pole (normal and skew) fields, the changes are much smaller here. For example, in Fig. 2, the normal 20-pole component of the second measurement (cross) at 500 A is different from the other two measurements (circles) by 1.5 G while there is no difference among three sets in Fig. 4.

In conclusion, one can probably say that full quenches do not affect the field quality of dipoles in a substantiall manner. At the same time, there are some questions that are raised in the results presented here and these should be answered in the near future by another series of measurements:

1. Large changes in the skew quadrupole component, Fig. 2.

2. Large changes in the normal sextupole and 18-pole (normal and skew) fields in Fig. 4. However, note that the fractional changes are still small (5% or less).

3. Large current dependence of the vertical center coordinates in the third measurement (see Fig. 3). Does this imply that the new warm bore is not totally free of magnetization?

Reference

1. S. Ohnuma, UPC No. 29 (with an added note), December 26, 1978.

B. Hysteresis - Dependence of the Dipole Field Quality at Injection on the Base Current of Ramping

For the measurement of multipole components, the excitation current is reduced to zero from the highest possible value, then raised to various values where the measurement is made. In the actual operation of the doubler, the lowest (base) current of the ramp may be close to the injection value. For example, if the injection is at 150 GeV/c, the corresponding excitation current is 635A and the base current of the ramp may be as high as 500A. Since the field is sufficiently higher (4.2 kG) than the filament penetration field, which is 1 kG or so, one does not expect a large change arising from the hysteretic magnetization of the superconductor.[1] In order to test this, M. Wake of the magnet measurement group has made a series of measurements on PCA135. The base current of the ramp was varied from zero to 50, 100, 150, 200, 300, 400, 500 and 625A. The measurement is in dc mode and, strictly speaking, the result is applicable only for injections with a front porch. For an injection "on fly", there will be eddy current effects with time delay and this requires an additional test.

The present measurement was made only for the body field to see if there are any substantial effects caused by the change in the base current. The following table gives changes in some multipole components when the base current is varied. All field values are in Gauss at 1" when the dipole field is normalized to 10 kG.

1. <u>500 A</u> (118 GeV/c injection)

pole	standard value*	base current (in A)			
		50	100	150	300
6	-14.2	-0.2	0.8	0.9	0.4
10	8.1	0.1	-0.1	-0.1	0.5
14	3.1	0.0	0.1	0.3	0.2
18	-16.4	0.1	0.0	0.1	0.2
22	6.4	0.0	0.1	0.1	0.1

*) Two edges and body combined, base current zero.

2. <u>625 A</u> (148 GeV/c injection)

pole	standard value	base current			
		100	300	400	500
6	-12.0	0.2	0.1	0.3	1.0
10	8.1	0.1	0.2	0.3	0.6
14	3.5	0.0	0.1	0.2	0.3
18	-16.5	0.0	0.1	0.2	0.2
22	6.4	0.0	0.0	-0.1	-0.1

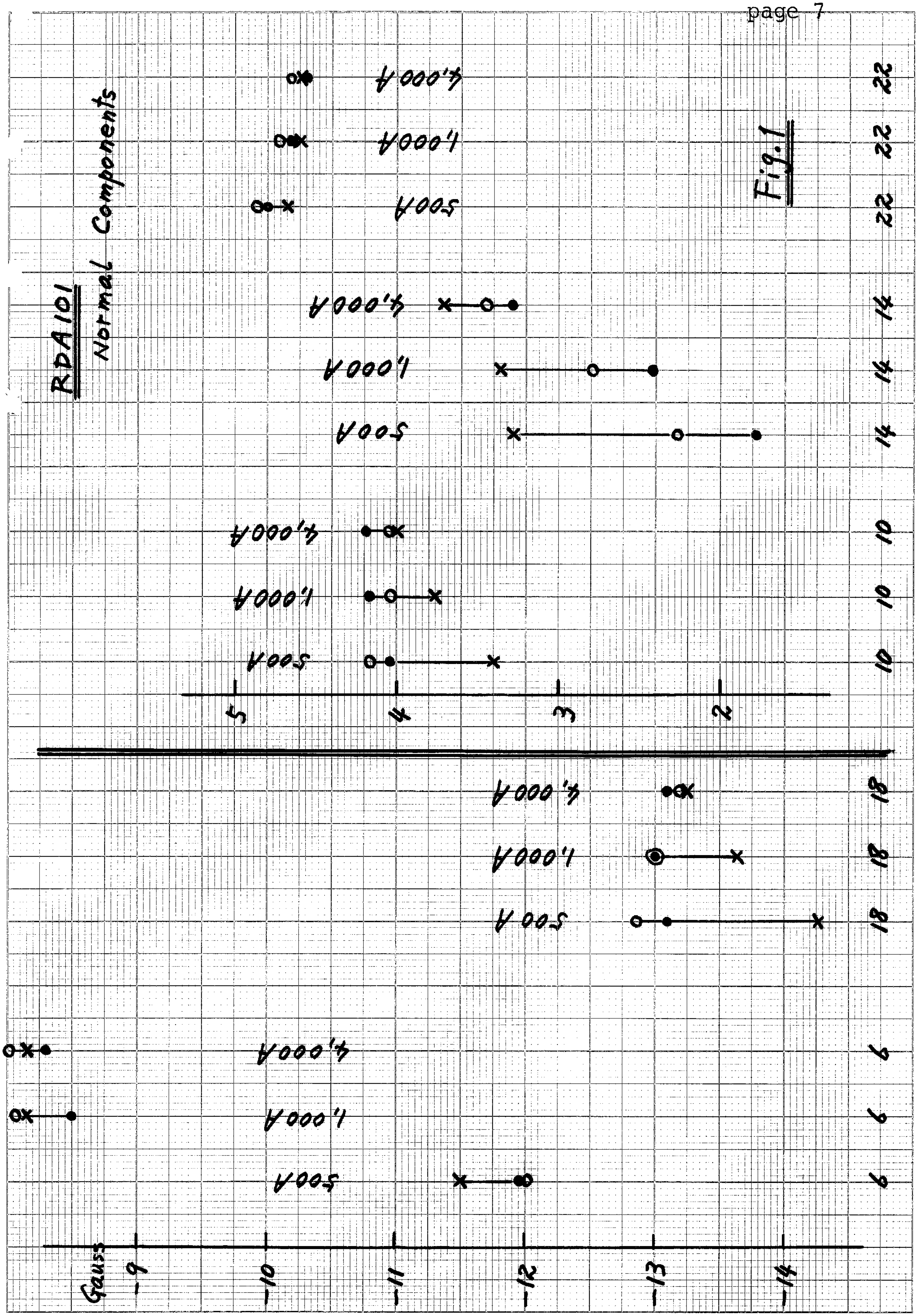
3. 800 A (189 GeV/c injection)

pole	standard value	base current 100	300	400	500
6	-9.5	0.1	-0.4	0.1	1.0 (?)
10	8.1	0.1	0.2	0.1	-0.1
14	3.8	0.0	0.0	0.1	0.3
18	-16.5	0.1	0.1	0.1	0.1
22	6.3	0.2	0.1	-0.1	-0.1

From these results, one sees that the base current should be 400A or less when the injection is at 150 - 200 GeV/c. Changes in other harmonic components are in general very small.

Reference

1. H. Ishimoto, R. E. Peters, M. E. Price and R. Yamada, IEEE Trans. Nucl. Sci. NS-24 (1977), 1303.


RDA101
Normal Components
Fig. 1
500A
1,000A
4,000A
22
14
10
18
6
5
4
3
2
Gauss
-9
-10
-11
-12
-13
-14

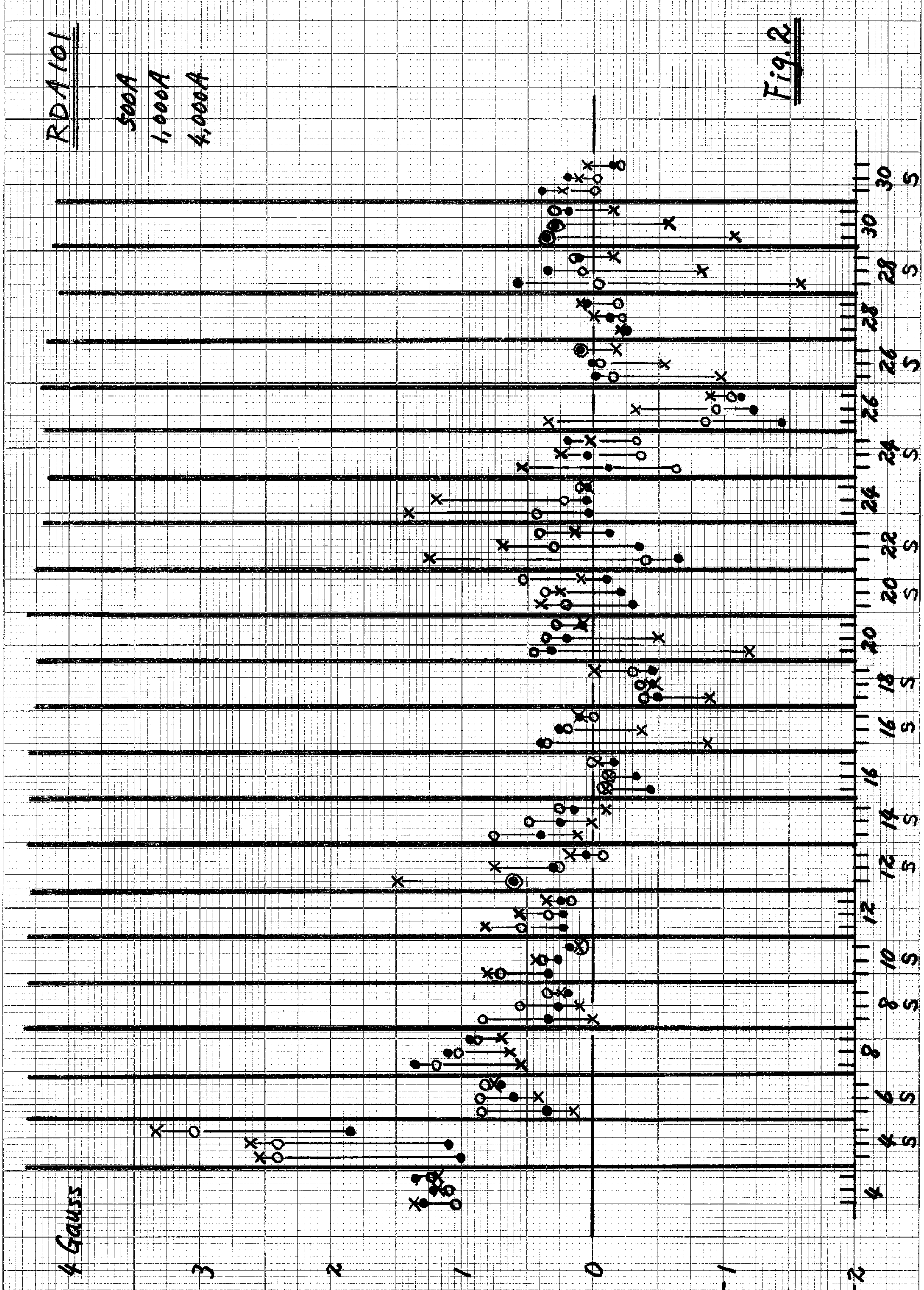

RDA 101
500A
1,000A
4,000A
4 Gauss
3
2
1
0
-1
-2
4
4 S
6 S
8
8 S
10 S
12
12 S
14 S
16
16 S
18 S
20
20 S
22 S
24
24 S
26
26 S
28
28 S
30
30 S

Fig. 2

Calculated distance from the rotating coil center to the field center. 200A, 500A, 1,000A and 2,000A relative to 4,000A.

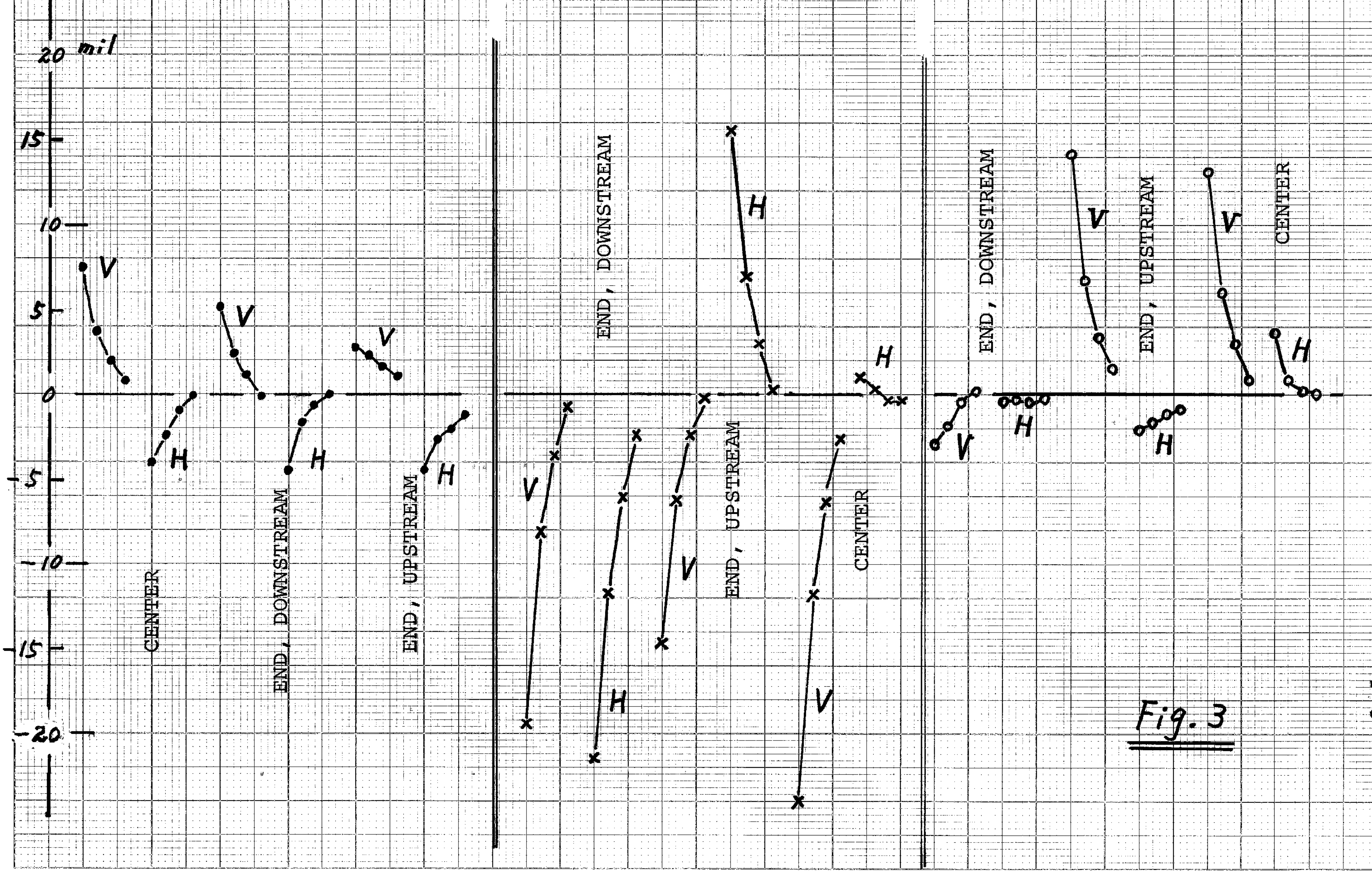


Fig. 3

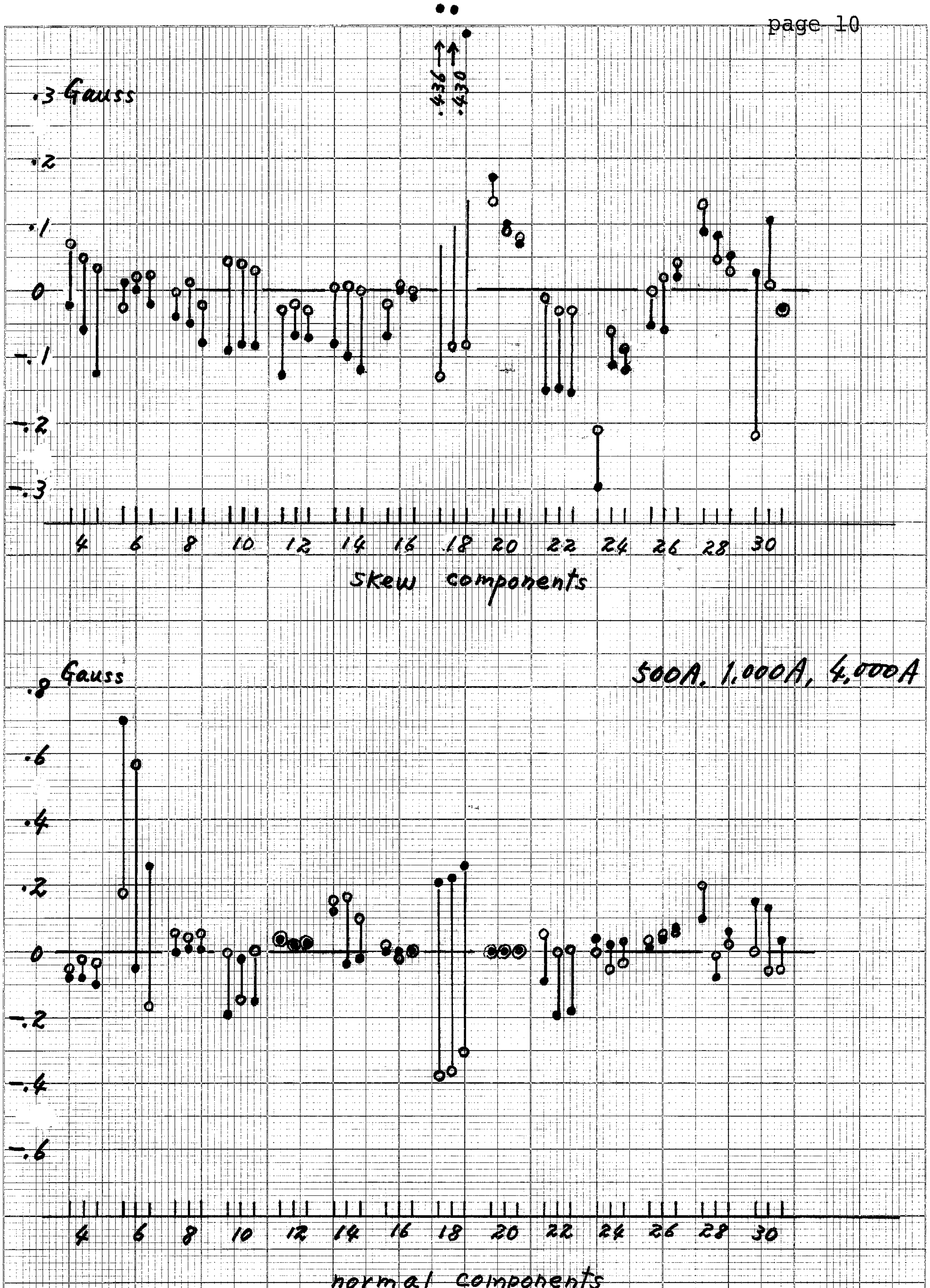

.436
.430
.3 Gauss
.2
.1
0
-.1
-.2
-.3
4
6
8
10
12
14
16
18
20
22
24
26
28
30
skew components
.8 Gauss
500A, 1,000A, 4,000A
.6
.4
.2
0
-.2
-.4
-.6
4
6
8
10
12
14
16
18
20
22
24
26
28
30
normal components

Fig. 4