MEASUREMENT AND CALCULATION OF EDDY-CURRENT EFFECTS IN THE B2 MAGNET

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This note describes initial pulsed-field measurements on the main-ring B2 3-foot magnet model. The measurement setup is shown in Fig. 1, and the data flow is shown in Fig. 2(a) and (b). Noise on the current shunt caused an unreliable trigger so instead the integrated voltage from a fixed coil in the magnet was used for a trigger. This signal goes into channel 0 and as shown in Fig. 2, whenever the signal on channel 0 passes one of the desired "current" values, two values each of ΔB, B, and I (in this case the same as B) values are stored on magnetic tape for later linear interpolation. Since a time signal proportional to I is not available, excitation curves cannot be derived from these data.

The procedure insures that from data taken on successive magnet pulses in different positions a graph of spatial distribution at a given current of field value can be produced.

What is measured and plotted in Fig. 3 is $K-K_o$ vs x where $K = 1/B_o \; dB/dx$, B_o = field at x = 0, x is left-right motion across the magnet.

The axes of the differential coil are not parallel, and an error in balance can result from a rotational error in positioning. For this reason the k = 0 axis is displaced to k_o, the value of k at x = 0 in presenting the data in Fig. 3.

These data in Fig. 3 were all obtained with the magnet pulsing from 0 to ~10 kG in a section of the magnet built from a low H_c U. S. Steel. All measurements were taken on the median plane. The results are in qualitative, but not detailed quantitative agrement with dc measurements taken on the same magnet model but with Armco Steel.[1] Of course, since the field is integrated in time, the remanent field is not seen.

Four separate runs were taken and are shown in Fig. 3 from left to right:

a. dB/dt = 6 kG/sec, "normal" acceleration
   cycle 9 kG in 1.6 sec = 5.6 kG/sec

b. dB/dt doubled to 12 kG/sec

c. "Vacuum chamber" inserted dB/dt = 6 kG/sec

d. "Vacuum chamber" inserted and insulated from steel
   dB/dt = 6 kG/sec.

If the low field runs, 500 g and 1 kG, in Fig. 3(a) and (b) are compared, it is seen there is an increase in the (negative) sextupole component for the higher dB/dt run. On Fig. 3(b) two curves are shown: one with smaller sextupole component which is a smoothed representation of the points in Fig. 3(a) and a larger sextupole component obtained by adding in a calculated amount of sextupole due to eddy currents in the copper magnet. These calculations will be described in detail elsewhere[2] but basically consist of a double summation over elements of eddy currents and over a series of image currents in the iron poles ($\mu = \infty$ assumed) due to each current element. The agreement is not spectacular partly due to a large scatter of points due to noise pickup.

The runs shown in Figs. 3(c) and (d) have 0.049 in. thick type 304 stainless steel plates (measured $\mu < 1.01$) inserted top and bottom as shown in Fig. 1. Calculations show that the effect on the field shape over the center ±0.5 in. is about the same as from a "real" vacuum chamber with sidewalls.

The curves superimposed on the 500 g and 1 kG data of Figs. 3(c) and (d) are

1. the smoothed version of 3(a) and
2. superimposed on it the calculated sextupole component of 0.44 kG/m^2.

The measured sextupole component in Fig. 3(c) when the vacuum-chamber plates were shorting the magnet laminations is larger than expected. When the plates are insulated from the magnet poles the agreement shown in Fig. 3(d) is reasonable.

A smooth curve through the 9 kG points from Fig. 3(a) is traced onto the 9 kG runs in Fig. 3(b), (c), and (d) showing agreement at a field level where eddy-current effects are not expected to be important.

An obvious improvement was to repeat each point 10 times. This was done and is shown in Figs. 4 and 5.

In Fig. 4: (a) was run without the vacuum chamber and (b) is with the chamber inserted and insulated from the steel. dB/dt = 6kG/sec. Fig. 4(a) and (b) may be compared to Fig. 3(a) and (d). Although the magnet had been changed to Bethlehem B1 steel by the time these latter runs were made, there is still good agreement between them as may be expected at these low fields.

Figure 5 shows a least-squares fit to the data in Fig. 4 over the central inch (±1/2 inch from center) of the magnet and a plot of the resultant sextupole component as a function of the field. From Fig. 5 it is easily seen what portion of the sextupole field is due to the magnet and/or the vacuum chamber. The sextupole for the vacuum chamber obtained by subtracting the component due to the magnet agrees with calculations.

Since this is the first written description of results obtained with new magnet-field measuring fast-data-acquisition system[3] it seems worthwhile to list dates to give an idea of the time scale needed to develop such a system.

February 1, 1968: Conceptual design started

March 26, 1968: Proposal for a small digital computer for use in magnetic-field measurements, FN-122. System works essentially as outlined in that note.

May 14, 1968	Request for proposals sent to vendors
June 18, 1968	Closing date for proposals
July 9, 1968:	Choice of computer based on responses to RFP
August 26, 1968:	Contract with Varian signed
November 30, 1968:	Delivery of equipment at NAL (Promised: 90 days; actual: 96 days)
January 15, 1969	First dc magnet measurements obtained
March 5, 1969	First pulsed magnet measurements

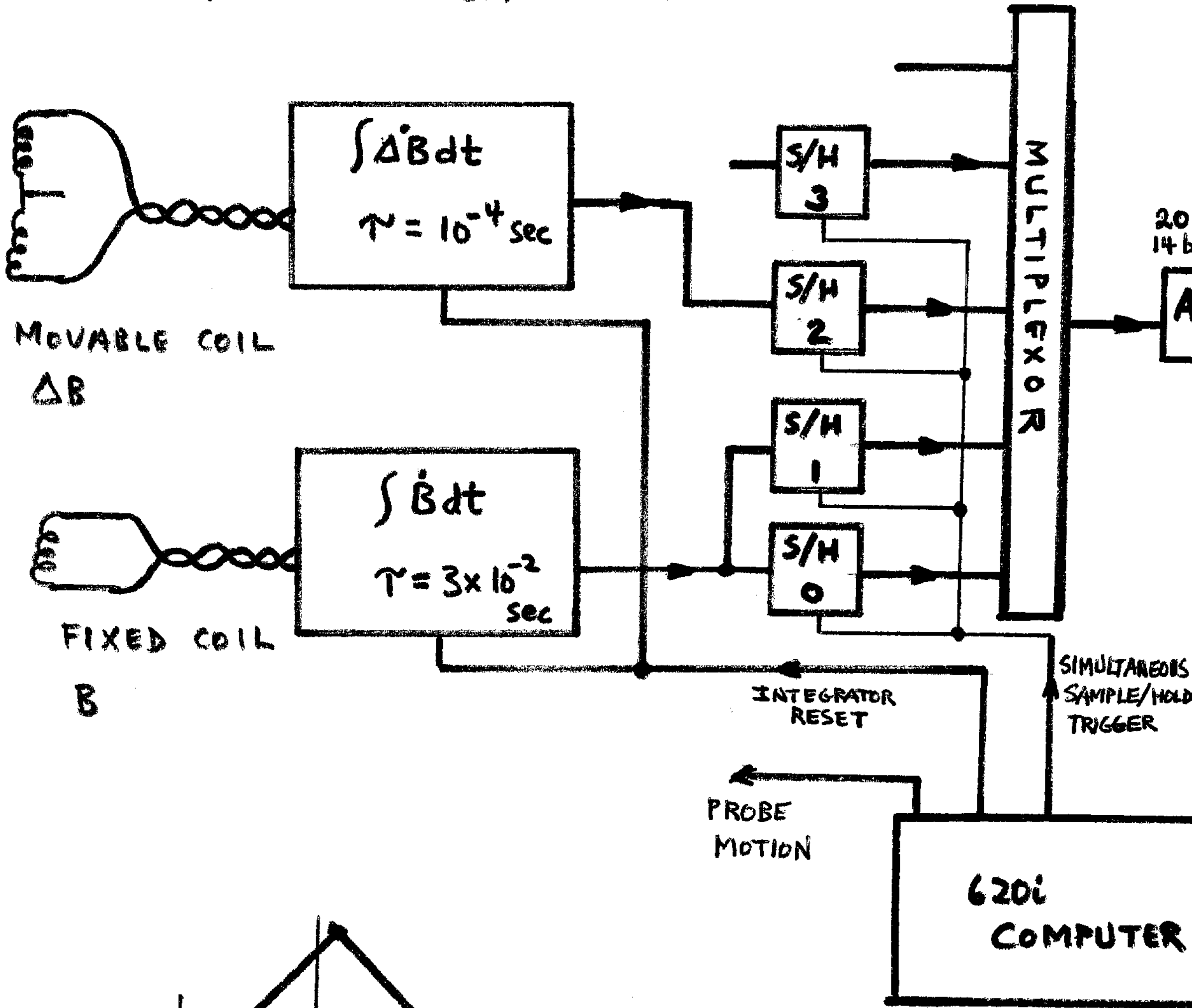
REFERENCES

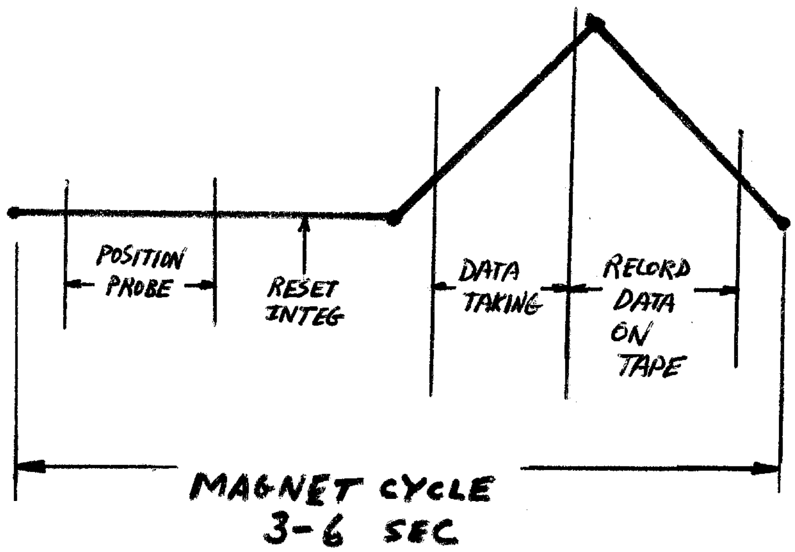
[1] R. Yamada, DC Field Measurements on No. 2 Model Magnet, National Accelerator Laboratory Internal Report TM-82, September 27, 1968.

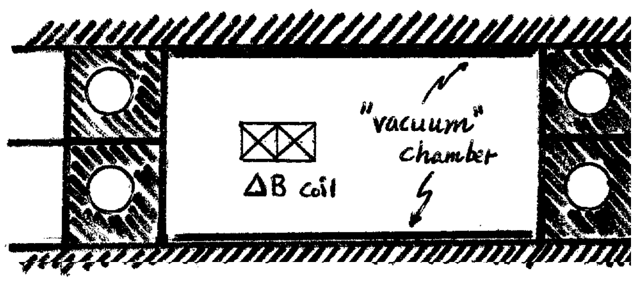
[2] E. Malamud, Eddy Current Effects at Injection Field in the Main-Ring Bending Magnets.

[3] H. Feng and E. Malamud, Fast Data Acquisition and Processing System for 200-BeV Synchrotron Magnetic-Field Measurements, (to be described later).

FIG 1 MEASURING SETUP







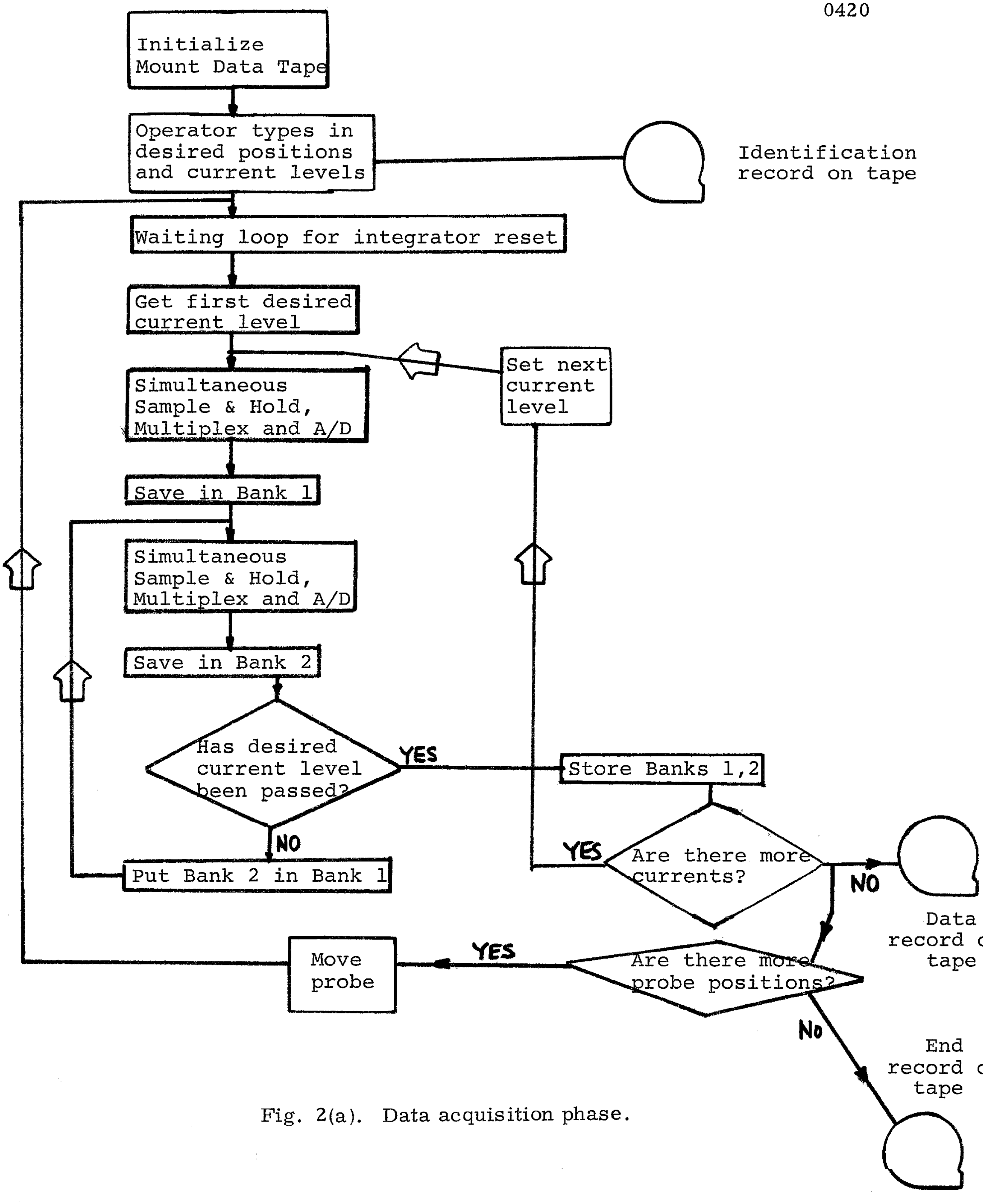


Fig. 2(a). Data acquisition phase.

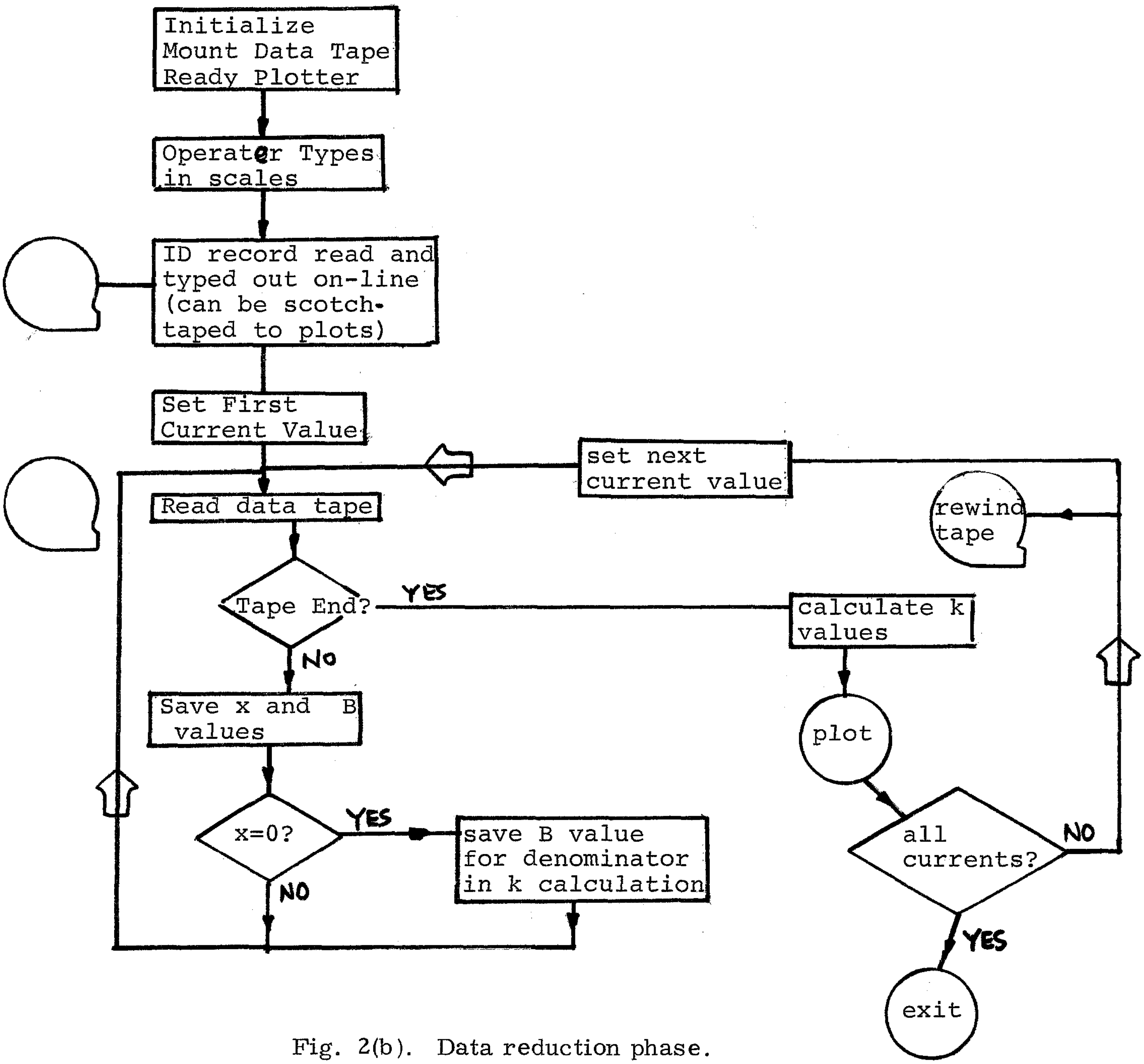
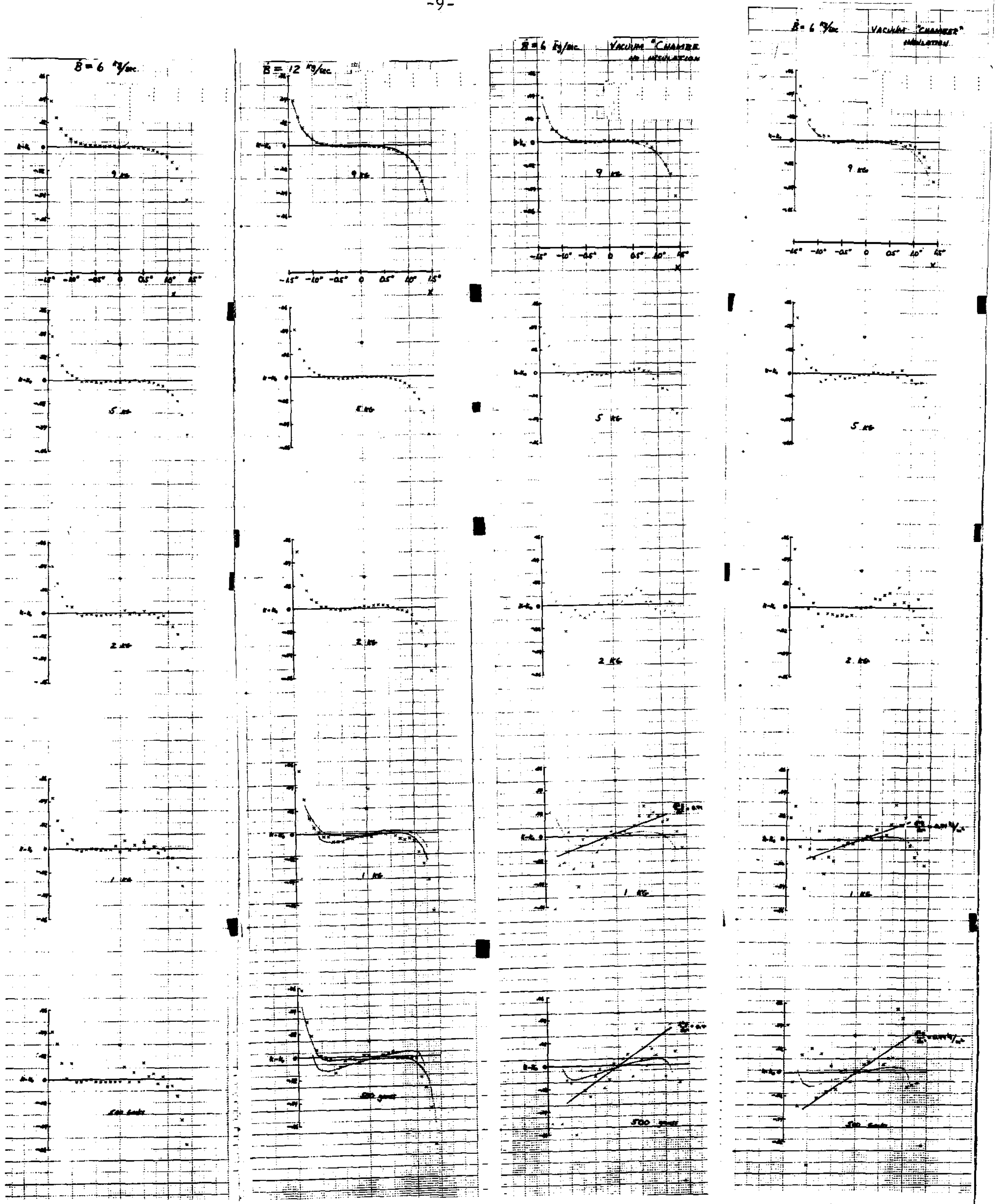
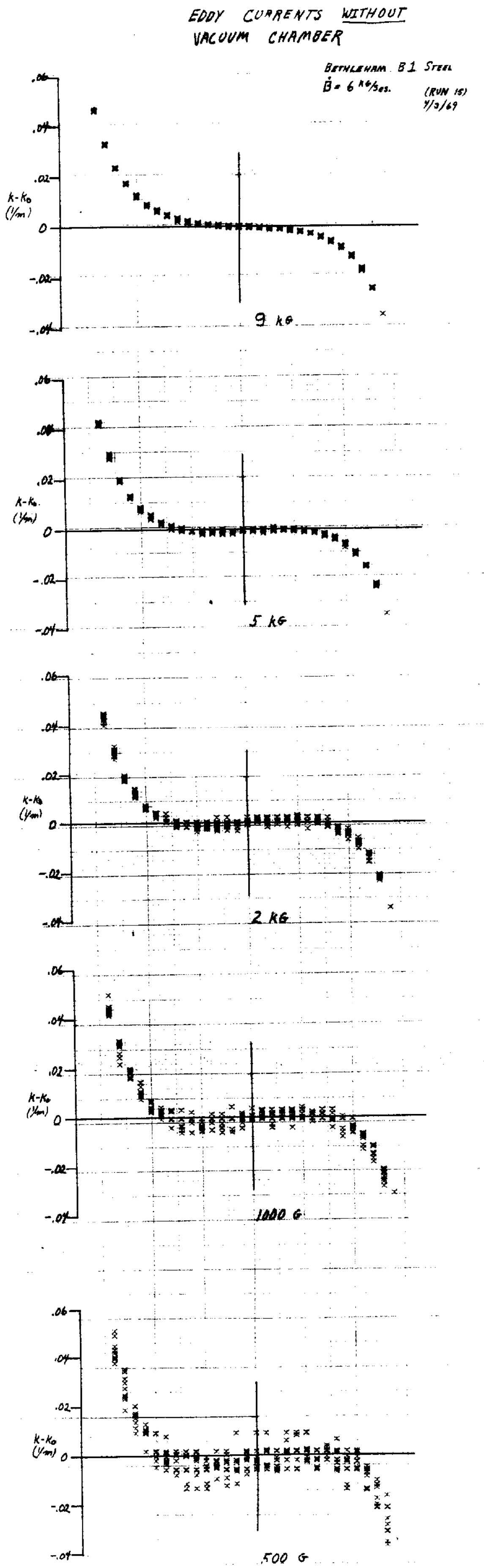


Fig. 2(b). Data reduction phase.

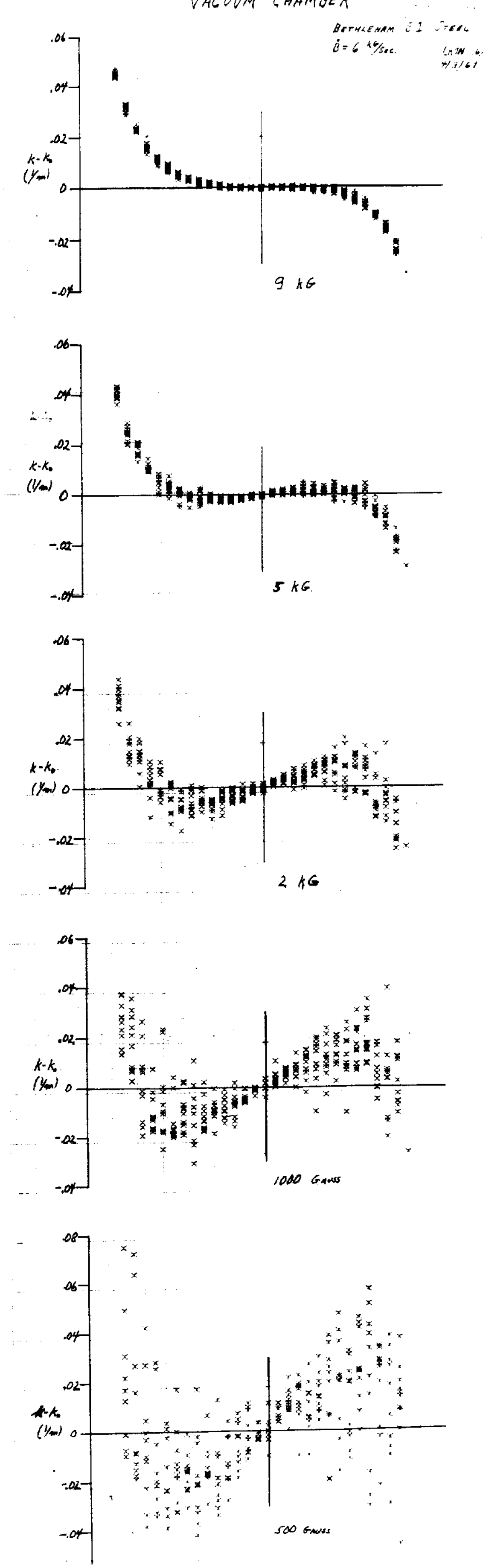


(a) (b) (c) (d)

Figure 3


EDDY CURRENTS WITHOUT
VACUUM CHAMBER
BETHLEHAM B1 STEEL
Ḃ = 6 KG/sec.
(RUN 15)
4/3/69
k-k₀ (1/m)
9 kG
5 kG
2 kG
1000 G
500 G

(a)


EDDY CURRENTS WITH
VACUUM CHAMBER
BETHLEHAM B1 STEEL
Ḃ = 6 KG/sec.
k-k₀ (1/m)
9 kG
5 kG
2 kG
1000 GAUSS
500 GAUSS

(b)

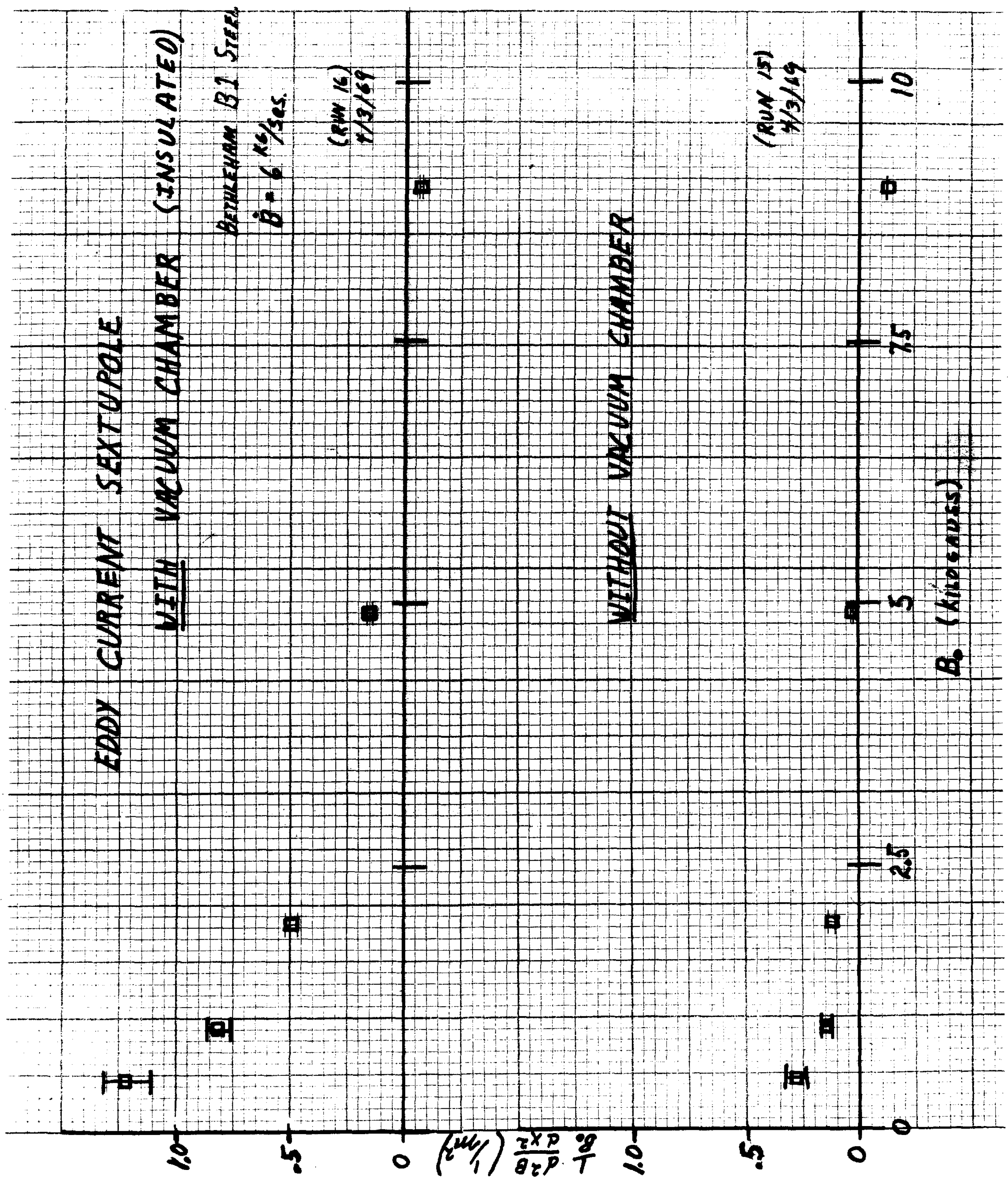

EDDY CURRENT SEXTUPOLE
WITH VACUUM CHAMBER (INSULATED)
BETHLEHAM B1 STEEL
Ḃ = 6 KG/SEC.
(RUN 16)
4/3/69
WITHOUT VACUUM CHAMBER
(RUN 15)
4/3/69
B₀ (KILOGAUSS)
0
2.5
5
7.5
10
1.0
.5
0
1.0
.5
0

Figure 5