PERSISTENT CURRENT FIELDS IN THE FNAL SUPERCONDUCTING MAGNETS

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ABSTRACT

The size of the fields due to persistent currents in the FNAL magnets is examined. Its effect is small enough so that superconducting magnets can be used over the same dynamic range of as much as 100:1.

Many different considerations go into determining the injection energy of a synchrotron. The FNAL main ring operates over a ratio of about 50, i.e. injection at 8 GeV and extraction at 400 GeV. Superconducting magnets are similar to iron magnets in that persistent currents in the superconductor set up residual fields that are somewhat analogous to the residual fields in a ferro-magnet.

These persistent currents exhibit themselves in two ways. First, they generate a dipole field. The strength of this field is a function of the history of the excitation of

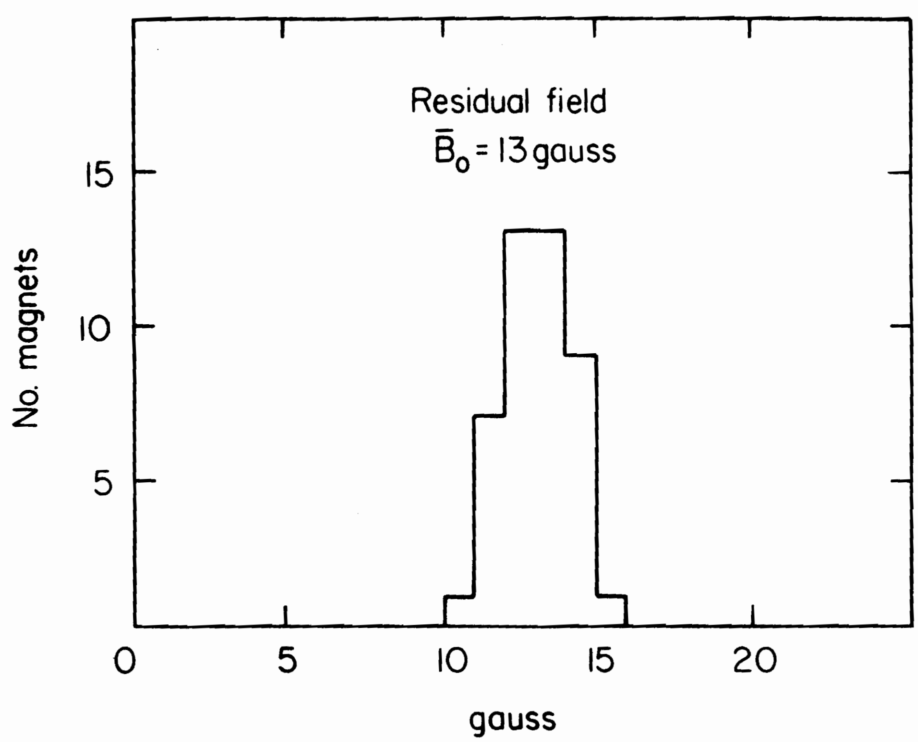

Fig. 1

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the magnet. A histogram of the residual field of 44 magnets is shown in Fig. 1. About half of this dipole field comes from persistent currents and the rest from the yoke. This data is obtained by ramping the coil to 4 Tesla, then reducing the current to zero and measuring the residual with a flip coil. The residual is reasonably independent of the shape of the ramp as long as the $\mathring{B}$ is not high enough to quench the magnet. (If the magnet quenches, the residual is much smaller since some fraction of the wire went normal and thus no longer carries persistent currents.)

A second way that persistent currents show up is through their effect on the sextupole of the magnet. (The effect on the other multipoles is negligible.) A typical curve of b_2 as a function of B_0 is shown in Fig. 2, below.

Here we have:

$$B_y(x) = B_0 \sum_{n=0} b_n x^n \qquad b_n \text{ units} = 10^{-4} \text{ (in.)}^{-n} \tag{1}$$

As there is no simple way to separate out the absolute value of the effect of persistent currents, we will discuss here the quantity δb_2 shown in Fig. 2. The effect of the persistent currents during the increasing ramp is approximately 1/2 of this value.

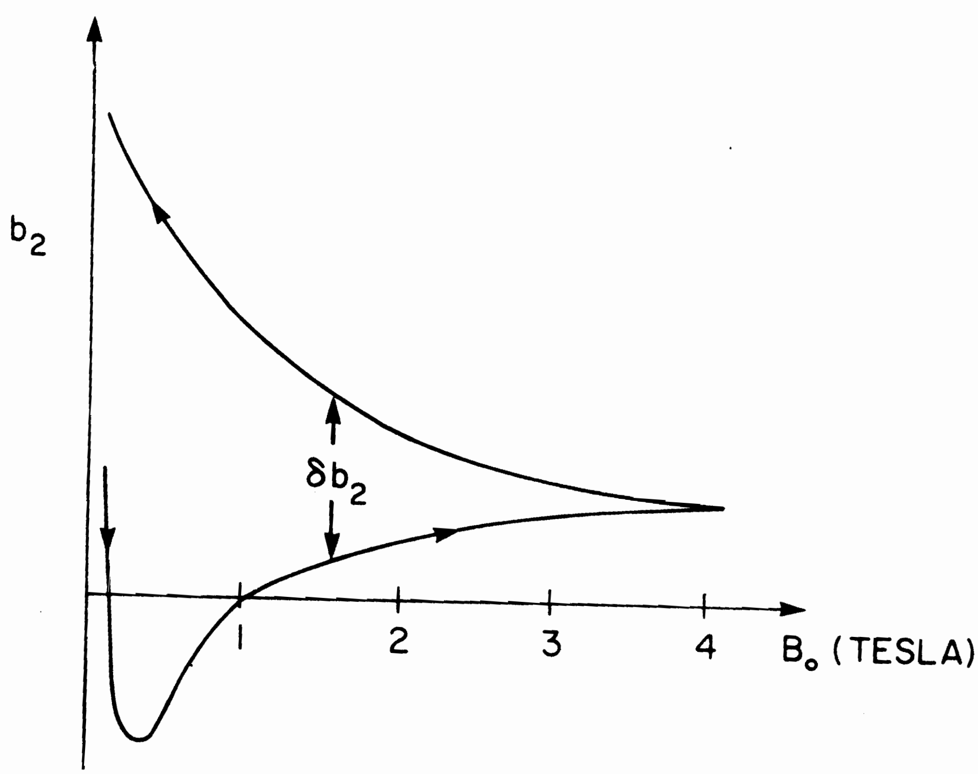

Fig. 2

The rapid deviation seen at low excitation is due to the fact that the actual field from the persistent currents is not changing much and, hence, is becoming a bigger fraction of the central field as this field gets smaller. Two quantities are shown in Table I.

Table I

B_o (Tesla)	0	.5	1.0	2.0	3.0
Av δb_2		14.99×10^{-4}	4.97×10^{-4}	1.63×10^{-4}	0.77×10^{-4}
σ		$\pm 1.29 \times 10^{-4}$	$\pm 1.0 \times 10^{-4}$	$\pm .32 \times 10^{-4}$	$\pm .20 \times 10^{-4}$
δB (sex)	7.5	7.50	4.97	3.26	2.31
Gauss	± .5	± .65	±1	± .64	± .60

The first, δb_2, is defined above. The second is $\delta B_{(sex)} = B_o \, \delta b_2$ or the actual value of the sextupole field in gauss. A plot of δB_{sex} is shown in Fig. 3, below.

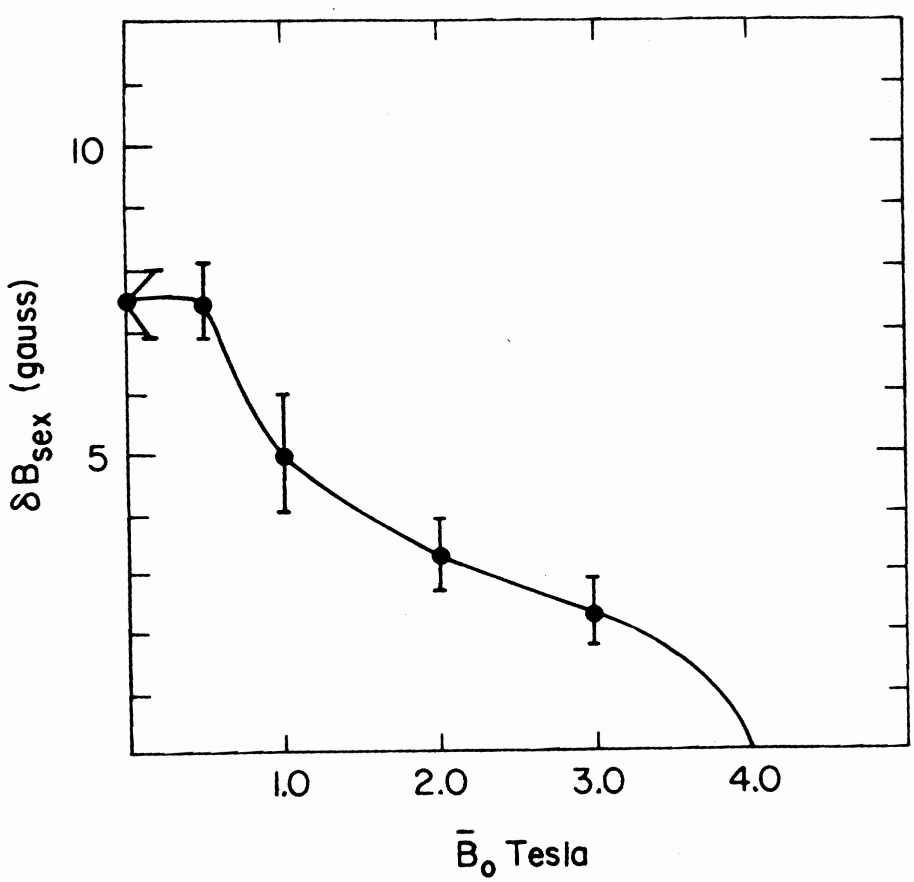

Fig. 3

The spread in both the residual dipole and sextupole fields is rather small. Furthermore, they do not depend on the accuracy with which the magnet is constructed, but rather the quality control of the superconducting wire manufacturing process. Since this has to be rather well controlled in order to ensure reaching a given short sample limit, one can expect the fluctuations shown here to be typical. Presumably in a 10 T magnet, these fields will be somewhat stronger.

Since the actual value of the fields is rather small, and since there must be a set of dynamic corrections in the machine anyway, these results would seem to indicate that the field could be controlled rather well from 0.1 T to 10 T - perhaps as well as 2 parts in 10^4 in so far as the effects of persistent currents are concerned. This is comparable to the mechanical accuracy achievable in the coils. Hence, a useful momentum range of $\sim$ 100:1 may be possible for a future machine. It is, of course, true that other considerations than field quality enter into choice of the injection energy. The point of this note is to indicate that persistent currents in superconducting magnets are not a controlling factor.