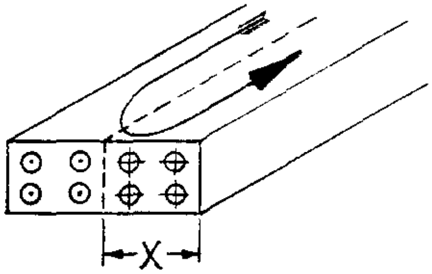
Subject

EDDY CURRENTS IN MAIN RING MAGNET CONDUCTORS

To the extent that the coils of the bending magnets fill the gap, there is no first order effect of eddy currents in the copper. However, there must be some allowance for insulation, and there is a perturbation in the field caused by the resulting re-distribution of the current. L. C. Teng has made use of this effect to compensate the field shape. In the B-2 magnet, a 0.01" gap between the conductor and the iron nearly perfectly compensates for the fall-off in field caused by the finite width of the magnet pole. This thickness is, of course, much too small for groundwall insulation. In addition, some insulation is needed at the mid-plane. The lowest order term in the expansion of the field perturbation has the opposite sign for these two insulation layers, so that mid-plane insulation compensates for additional groundwall insulation. Unfortunately, the second order term in the field perturbation has the same sign for both layers, so that the compensation is not perfect. There are therefore two effects to consider: the magnitude of field error caused by this imperfect compensation, and the further field error caused by the re-distribution of the current in the conductors due to the rising magnetic field through them, i.e., eddy currents.

To a reasonable approximation, one can calculate the magnitude of the eddy currents by assuming that the eddy currents, themselves, do not affect the rate of change of the flux through the conductors. Since the conductors under study account for only 10% of the ampere turns in the magnet, this results in little error. Assume that the conductor is long compared with its width, and neglect end effects. Also assume that B is uniform over the conductor, and equal to the field in the aperture. The flux enclosed in a loop of length

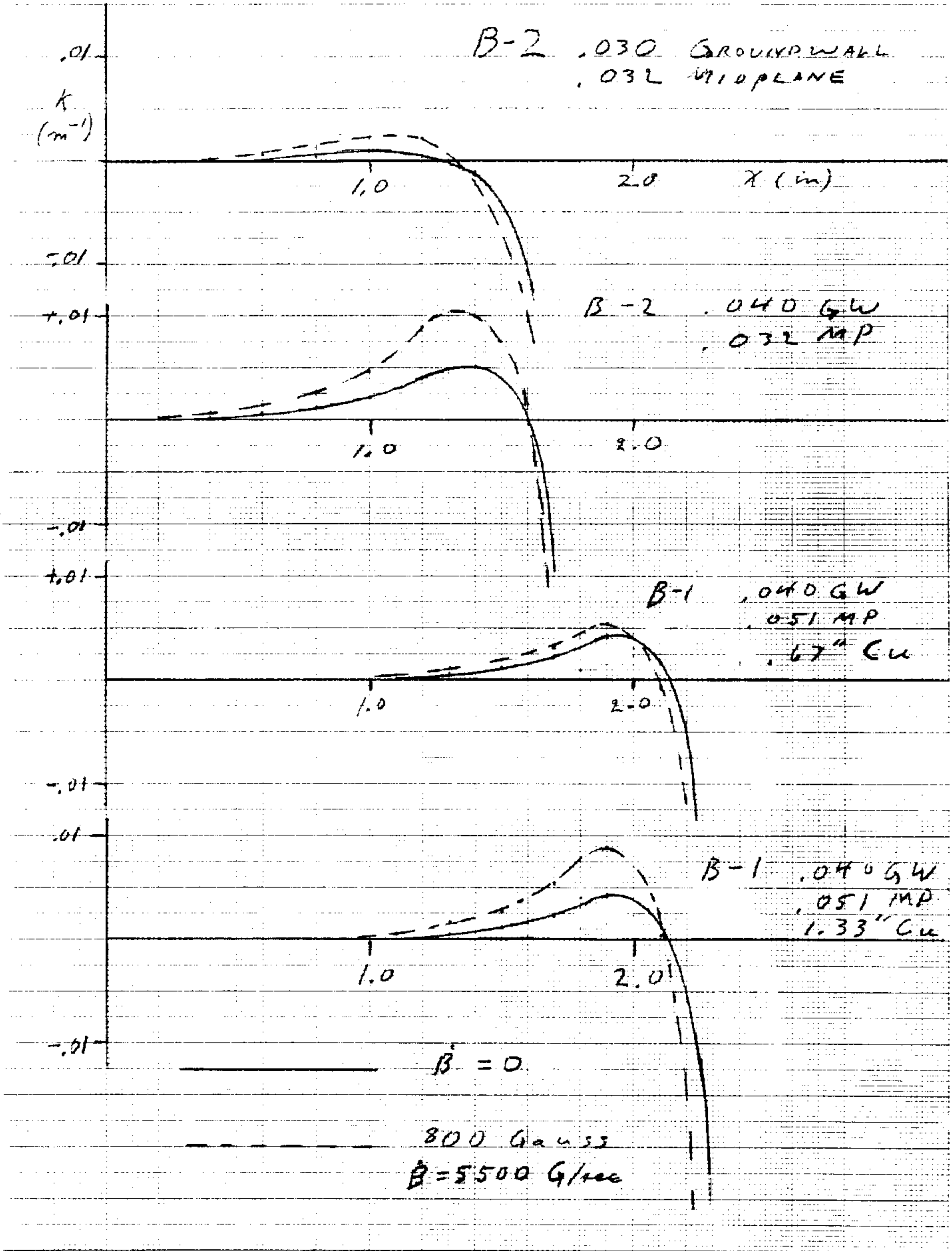


ℓ and width x, where one edge of the loop passes down the centerline of the conductor is $\phi = B\ell x$. The emf $= \oint E d\ell$ $= 10^{-8}\dot{B}\ell x$ where the numerical factor allows B to be expressed in gauss and E to be in volts/cm. The current density, J, is then given by $J = \frac{E}{\rho} = 10^{-8} \frac{\dot{B}x}{\rho}$. Substituting $\dot{B} = 5500$ gauss/sec, $\rho = 1.7 \times 10^{-6}$ cm, $J = 32$ x amps/cm^2, where x is the distance from the centerline of the conductor.

A conductor 0.67 in. wide thus has eddy current density at its edges equal to 24 amps/cm^2. If this conductor is carrying 1/12 of the total ampere turns, and if it fills (vertically) the gap of a B-1 magnet, (the conductor consisting of two bars in parallel) then the current density at 800 gauss (the lowest B field at which $\dot{B}$ has its full value) is 17 amps/cm^2. The current density in the edge closest to the aperture is seen to more than double and the current in the opposite edge actually reverses.

The effects of added insulation gaps, both for high fields where the effects of eddy currents on the current density distribution are negligible, and for lower fields where they might be important, may be calculated (treating them as thin current sheets) by summing the field from the series of "images" in the poles. The series converges slowly, but the GE computer gives one complete curve in about 20 seconds. In a B-2 magnet, the effect of the eddy currents turns out to very nearly equal the effect of the incomplete cancellation of the effects due to additional groundwall and mid-plane insulation gaps. These reduce the useful aperture in a B-2 magnet to 3.1-3.4 inches. The calculated values of k without eddy effects and with eddy effects at 800 gauss are shown on the attached graph. The conductor size used for these calculations was 1" × 1" (nominal). There is a range of values from which one could choose the thicknesses of the insulation. Two choices are shown.

Also shown are plots for the B-1 magnet, calculated for 25% of the ampere-turns in the gap and a 9" pole width. The two cases shown represent different aspect ratios of the conductor. The wider conductor shows the greater eddy effect, as expected.


B-2 .030 GROUNDWALL
.032 MIDPLANE
.01
K
(m⁻¹)
1.0
2.0
X (m)
-.01
B-2 .040 GW
.032 MP
+.01
-.01
B-1 .040 GW
.051 MP
.67" Cu
+.01
-.01
B-1 .040 GW
.051 MP
1.33" Cu
.01
-.01
Ḃ = 0.
800 Gauss
Ḃ = 5500 G/sec