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EDDY CURRENT LOSSES AND SYNCROTRON RADIATION IN THE PULSE MAGNET'S BEAM PIPE

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The objective of this experiment was to determine the amount of Eddy current losses that would occur when metal was placed in the gap of the model pulsed magnet. The model magnet pulser was used to run these tests.

The dissipated power in the metal plate was measured two different ways:

(a) Measuring directly the increased power supplied by the power supply.

(b) Measuring the temperature rise in the metal plate and calculating from this the dissipated power.

(a) In this test the power put into the magnet was measured by recording the voltage and current supplied by the power supply. A piece of stainless steel (Inconel) .065" x 2.5" x 10" was then placed in the air gap of the pulsed magnet and the power supply adjusted to bring the peak magnetic field back to the same value as before. The power from the power supply was measured again. The difference in the measured power was assumed to be the power dissipated in the steel plate. (The result of the measurement is plotted in Fig. 1).

(b) In this test, in order to record the temperature rise in the metal slab, two holes were drilled in the plate from the sides, and thermocouples were glued in place to give good thermal contact with the plate. The plate was then wrapped in "Tipersul" thermal insulation material to get good insulation in the relatively narrow air gap. The thermocouples were hooked up to a millivolt recorder for registering the temperature rise. Ice water was used on the cold junction of the thermocouples to record 0 millivolts at 0° C. To determine the energy absorbed in the plate, pulses with the same voltage and repetition rate were maintained until the temperature in the plate reached a steady state. The pulser was then turned off, and the immediate rate of cooling was found. This rate of cooling must be the same as the rate of energy being created in the plate due to eddy currents. When the plate was cold (close to ambient temperature) the initial heat rate was also found. No heat leak to the surrounding was then assumed. The two ways to find the energy rate created by the eddy currents gave very much the same result. (The data for different repetition rates and energy pulses are shown in Fig. 1).

To estimate the eddy current loss in the metal plate, one might calculate the Joule heat which is generated by the changing flux in the plate.

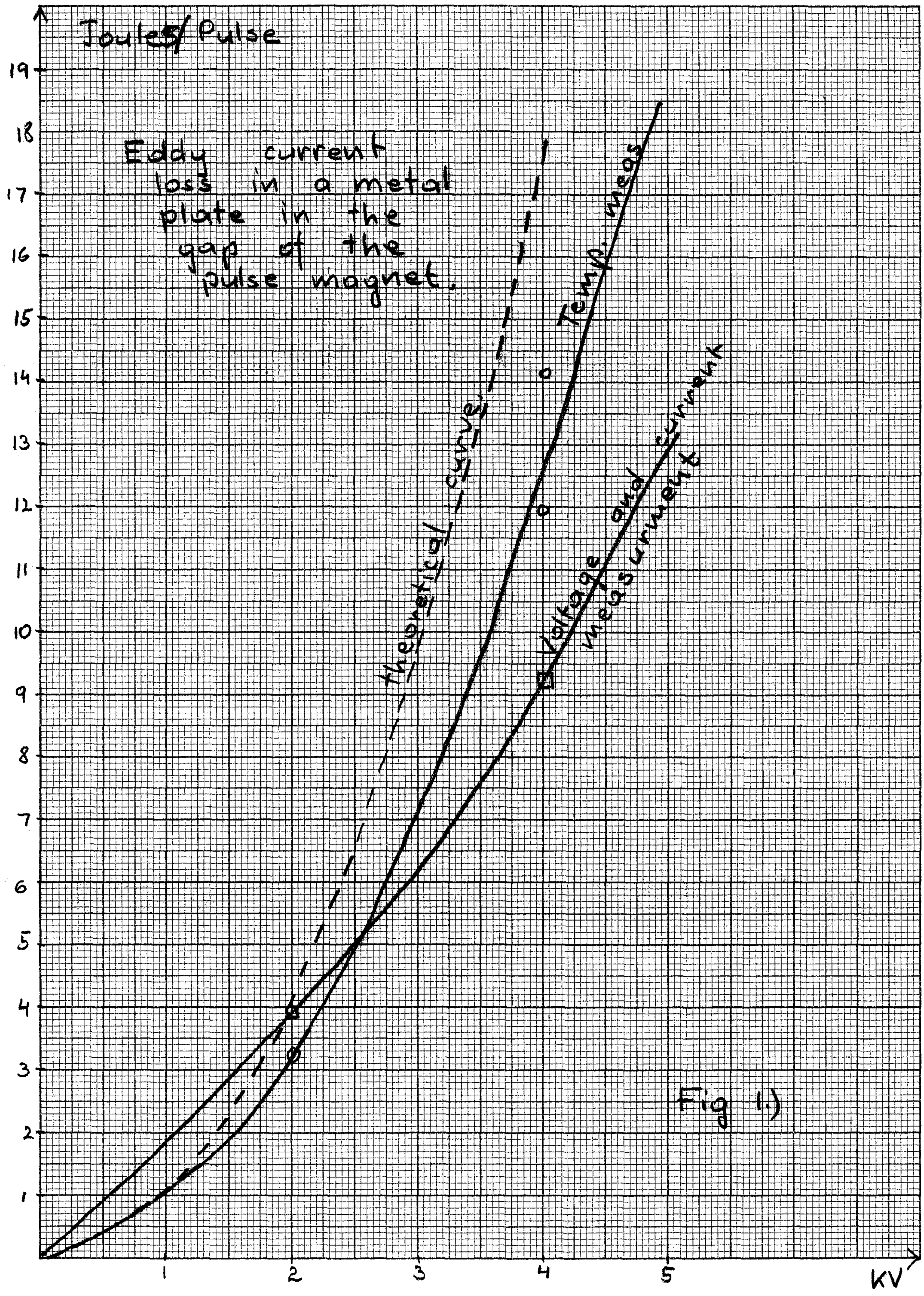
The induced voltage can be expressed as

$$V = A \frac{\partial B}{\partial t} \approx A \frac{\Delta B}{\Delta t}$$

where A is the "average area" of the plate, ΔB is the field change during the pulse, and Δt is the rise time of the pulse. The power loss can then be expressed as

$$P = \frac{V^2}{R} = \frac{A^2}{R} \left(\frac{\Delta B}{\Delta t} \right)^2$$

and the energy loss per pulse is



Joules/Pulse
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Eddy current loss in a metal plate in the gap of the pulse magnet.
theoretical curve
Temp. meas
Voltage and current measurement
1
2
3
4
5
KV

Fig 1.)

$$\frac{\text{Energy loss}}{\text{pulse}} = P\,T = \frac{A^2}{R}\left(\frac{\Delta B}{\Delta t}\right)^2 T \approx 1.8\ \frac{\text{Joules}}{\text{per pulse}}$$

at a peak field $B = .14$ Weber/m^2, 1 KV capacitor voltage with a pulse length of $T = 5 \times 10^{-4}$ sec. The theoretical energy loss per pulse is plotted in Fig. 1, where one point (1 KV) is matched with the experimental value. The difference between the calculated and measured values can be explained by the inaccuracies in the measurement and the calculation. For example, the resistance change with the rising temperature is not accounted for. The important conclusion is that the energy loss per pulse is proportional with $A^2\,B^2$. Therefore, in the actual pulse magnet* this loss can be as high as 25% of the total power (i.e. 40 KW). The cooling of such a metal tube would be a serious problem too. The simplest solution of this problem is to build the beam pipe in the pulse magnet from insulating materials such as ceramic, epoxy or glass. However, to choose such a material for the beam pipe one should worry about radiation damage which could be quite serious even in the case of normal operation. The most intense radiation field in this pipe comes from the synchrotron radiation of the deflected electron beam.

<u>Synchrotron radiation in the pulsed magnet.</u>

The energy loss per turn for an electron moving in a circle of radius R under the influence of a magnetic field B can be expressed** as

$$\delta E = \left(\frac{4\pi}{3}\right)\left(\frac{e^2}{R}\right)\left(\frac{E}{m\,c^2}\right)^4$$

* J. L. Cole, B. Hedin, J. J. Muray - TN-63-3

** J. Schwinger Phys. Rev. 75, 1912 (1949) or

$$\delta E_{kev} = \frac{88.5 \, (E_{BeV})^4}{R_{met}}$$

where E_{BeV} is the electron energy in units of 1 BeV, R_{met} is the radius of the electron orbit in meters, and δE_{kev} is the energy radiated per revolution in units in 1 kev.

For $.6^{o}$ deflection in the pulsed magnet, R is 478 meters. For 25 BeV electrons the radiation loss would be

$$\delta E_{kev} = \frac{88.5 \, (25)^4}{478} = 7.2 \times 10^4 \frac{\text{(KeV)}}{\text{per turn}}$$

However, the actual length of electron trajectory is only 1.67×10^{-3} times $2 \pi R$. Therefore, the radiation loss per deflection per electron is

$$\frac{\delta E_{kev}}{\text{per turn}} \times 1.67 \times 10^{-3} = 120 \frac{\text{KEV}}{\text{deflection}}$$

To calculate the average number of radiated photons, one should calculate the average quantum energy which is given by

$$\bar{\epsilon} = \frac{3}{2} \frac{\hbar c}{R} \left(\frac{E}{m c^2} \right)^3 = 7.35 \times 10^4 \text{ e V}$$

Then the number of equivalent quantum per electron per deflection is

$$\frac{N}{\bar{\epsilon}} = \frac{\text{Number of equivalent quantum}}{\text{DEFLECTION ELECTRON}} = \frac{120}{73.5} = 1.63 \frac{\text{Photon}}{\text{electron deflection}}$$

Then the total number of photons radiated per second is the order of magnitude of 1.63×10^{14} when the number of electrons is $\_ 10^{14}$ per second. This relatively low energy photon flux might liberate electrons from the chamber wall with a quantum efficiency of 10^{-5} - 10^{-6}. This low energy electron flux might cause breakdown effects in the chamber when a surface charge sheet developed.

If one adds to this photon flux the scattered electron and photon flux from the collimator (which is unknown now) then one can see that the epoxy, plastics, and glass are ruled out as possible materials for the beam pipe in the beam switching magnet. The only candidate which remains is some kind of ceramic which has a low secondary electron emmission coefficient.