DESIGN AND PERFORMANCE OF THE DAMPING SYSTEM FOR BEAM STORAGE in the CAMBRIDGE ELECTRON ACCELERATOR

A. Hofmann
R. Little
J. M. Paterson
K. W. Robinson
G. A. Voss
H. Winick

In the CEA the damping rates due to synchrotron radiation are

$+\frac{2U}{E}$ for the synchrotron or phase oscillations

$+\frac{U}{2E}$ for vertical betatron oscillations

$-\frac{U}{2E}$ for horizontal betatron oscillations

(U = energy loss/sec due to synchrotron radiation
E = particle energy)[1]

The minus sign in the case of horizontal betatron oscillation indicates that these oscillations are antidamped. The sum of all damping rates is a constant for a given energy and increases with the third power of the energy.

In order to store particles in the CEA one must transfer an amount $\frac{U}{E}$ from the damping rate of synchrotron oscillations to that of horizontal betatron oscillations to provide positive damping for all modes of oscillation.[1] This is done with damping magnets in synchrotron straight sections, which are characterized by a strongly increasing vertical field strength for decreasing particle orbit radius. This provides larger radiation losses for particles of lower energy, thereby reducing the amount of damping of phase oscillations. At the same time particles with positive (negative) betatron oscillation amplitudes in the damping magnet will suffer smaller (larger) radiation losses as particles which make no oscillations. This in turn redefines an off momentum equilibrium orbit for these particles in such a way as to reduce the betatron oscillation amplitude with repsect to the new orbit.

In order to achieve the proper amount of radial damping the field in the damping magnet B_D has to satisfy the condition[2]

$$\int B_D \frac{\partial B_D}{\partial r} \, ds = -\frac{B_s^2 \ell_s}{\alpha_p R}$$

where B_s is the field strength in the synchrotron, ℓ_s is the total length of the synchrotron magnets, α_p is the momentum compaction factor, R is the radius of the synchrotron and s is the path length. By introducing the characteristic length of the damping field $r_{ch} = \frac{B}{\partial B/\partial r}$ one derives

$$B_D = B_s \sqrt{\frac{\ell_s \, r_{ch}}{\ell_D \, \alpha_p \, R}}$$

ℓ_D being the effective length of the damping magnet.

Using 2 damping magnets, mounted in two successive synchrotron straight sections, each having an effective length of ~34 cm and a characteristic length of 1.65 cm, B_D becomes 1.9 times B_s. At 3 GeV, B_D is 7200 gauss.

In order to avoid overall bending of the particle trajectory and to minimize focusing effects, each magnet has 5 pole pairs of alternating polarity, such that the integral of the damping magnet field along the particle trajectory is zero (Figure 1). The lens strength D of such a 5 pole magnet is approximately $D = D^{*2} d$ in each plane, d being the distance between centers of poles, and D^* the lens strength of one of the three center poles. This overall focusing effect increases the betatron ν value in the synchrotron by .03 in each plane, a tolerable amount. Since the short poles have slightly different saturation behavior than the long ones, the polarity of all poles is reversed in the second damping magnet to provide exact overall balance of focusing properties.

During the multicycle filling the synchrotron magnetic field cycles between 160 and 3800 gauss. Ideally the field of the damping magnet would cycle in the same manner such that the field ratio $B_D/B_s = 1.9$ is kept constant. Originally, however, the design of an ac damping magnet was not considered feasible. For this reason the magnets are dc powered and the beam is moved into them whenever it has reached high energy. At low energies the beam is magnetically shielded from the damping magnets. Figure 2 shows on the same horizontal scale the B field and the product of $B \frac{\partial B}{\partial r}$. The maximum of $B \cdot \frac{\partial B}{\partial r}$ provides maximum damping for horizontal betatron oscillations and is chosen as the operating point. The correct amount of damping is now only provided as a time average over the cycle. To achieve this the damping magnet is excited to a level corresponding to 3.3 GeV peak energy.

The beam position is controlled by currents in backleg windings on certain synchrotron magnets which produce a "beam bump" at the damping magnet locations. To go from the ac multicycle filling mode to the dc storage mode the ac component of the synchrotron magnet excitation is turned off and decays exponentially with a time constant of .46 sec. At the same time the ac beam bump is turned off such that its pulses decay with twice that time constant. After a delay of a few tenths of a second a dc beam bump is turned on with a time constant of about 0.9 sec. The excitation of the damping magnet decays to the new dc level which corresponds to 1.5 GeV. During dc storage the beam is permanently in the damping magnet. By adjusting time constants and delays properly this transition can be performed without particle loss.

The influence of the different parameters on the lifetime of the stored beam has been investigated. As one example Figure 3 shows the decay time constant of the stored beam vs. the position of the beam in the damping magnet. Stable storage conditions are obtained within the region of positive damping for horizontal betatron oscillations as predicted by field measurements. The structure within this region is due to nonlinear effects in the magnetic field, which determine the size of the useful vertical aperture. In this picture the lifetime of 150 sec corresponds to a useful vertical aperture of 0.9 cm and the lowest dip with the lifetime of 105 sec corresponds to a vertical aperture of 0.75 cm. This explanation has been confirmed by measuring the lifetime while scraping the beam vertically for various horizontal positions of the beam in the damping magnets.

The horizontal acceptance of the damping magnets for betatron oscillations has been measured to be about 2 cm.

Vertical and horizontal acceptance both leave a comfortable margin of safety in the case of ac multicycle filling operation as well as for beam storage operation up to 3.5 GeV.

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REFERENCES

[1] Robinson, K. W. Phys. Rev., 111, p. 373 (1958).

[2] Robinson, K. W. and Voss, G.A., Internal Memorandum, CEAL-TM-155 (1965).

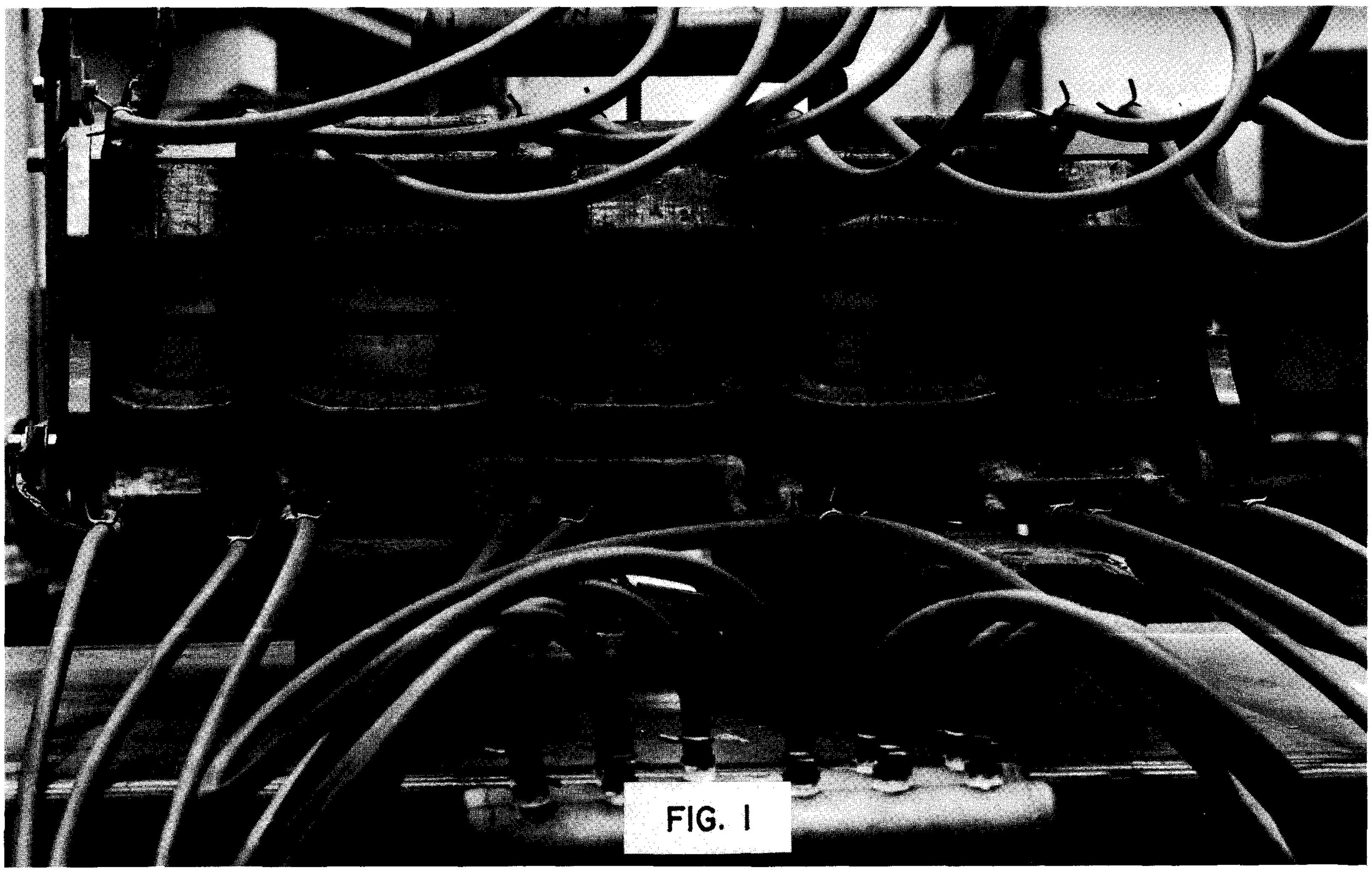

FIG. 1

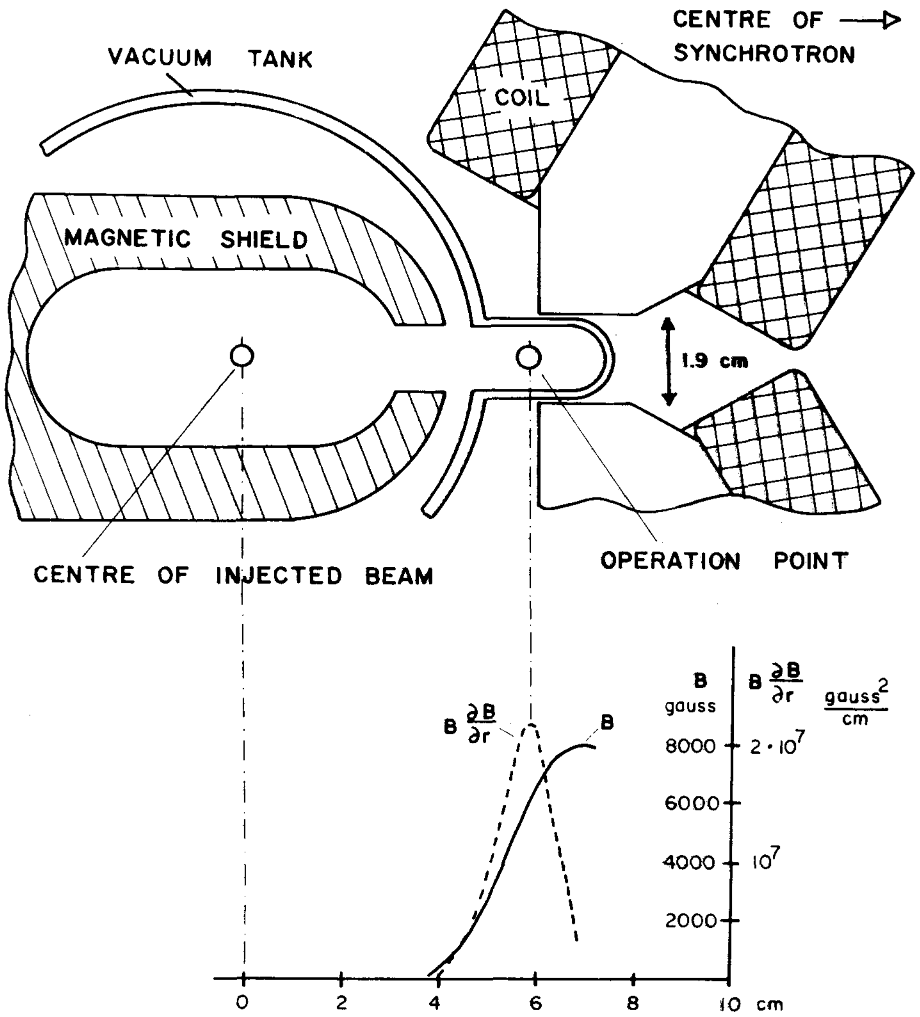

FIG. 2
CROSS SECTION THROUGH THE DAMPING MAGNET

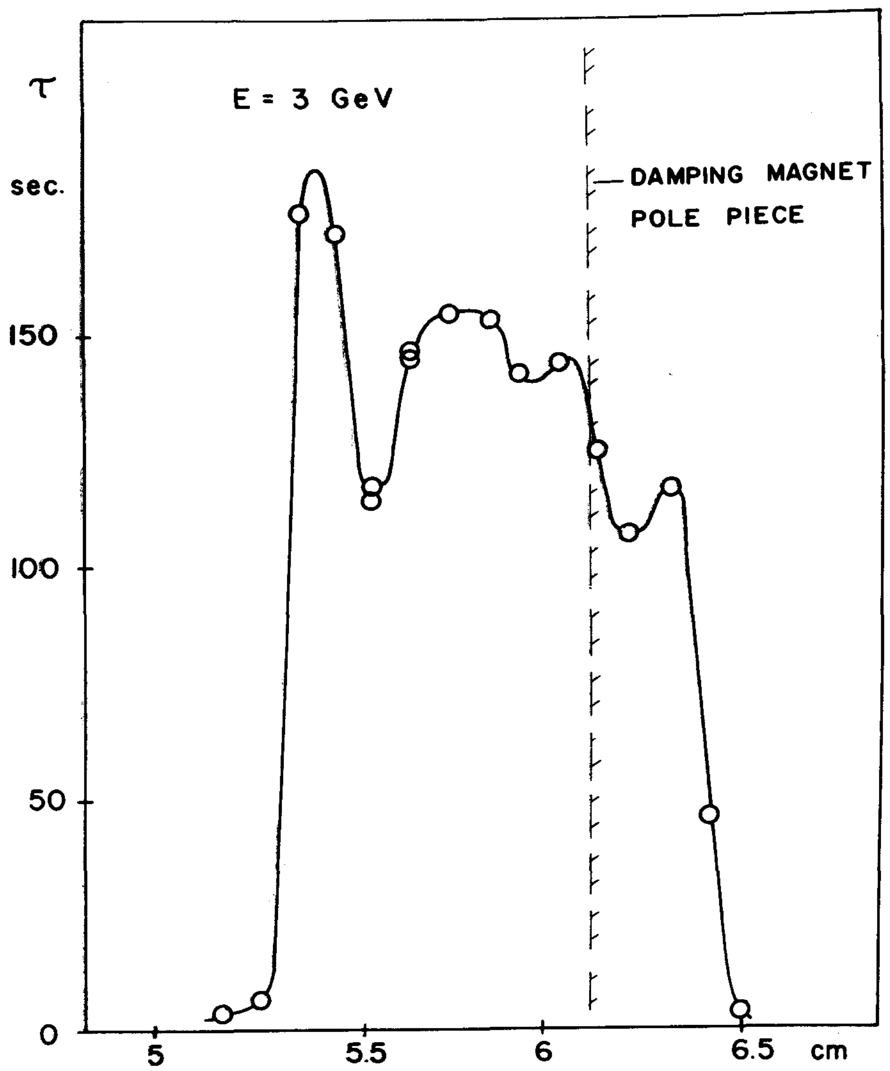

FIG. 3. BEAM LIFE TIME VERSUS BEAM POSITION