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DEFLECTION OF A HIGH CURRENT RELATIVISTIC ELECTRON BEAM BY A WEAK MAGNETIC FIELD IN THE PRESENCE OF PLASMA

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E. Lauer, and R. Spoerlein

September 23, 1974

*Work performed jointly under the auspices of the U.S. Atomic Energy Commission, and the Department of the Navy under the contract number NAonr 13-74.

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Deflection of a High Current Relativistic Electron Beam

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Introduction

Some experiments have suggested that high current relativistic electron beams subjected to magnetic fields which are weak compared to the beams self-field have a different bending radius in plasma than in high vacuum. Experiments such as Astron have shown that relativistic electron beams have the expected radius of curvature when the bending field is large compared to the self-field.

A two part experiment is described here. In both cases the deflecting field is small compared to the beams self-field and the beam is immersed in plasma. The experiments differ in that in one case the beam is subjected to a deflecting field over the full length of the beams flight path and in the other case the beam traverses a short deflection field and then has free flight to the target.

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Description of Experimental Apparatus

The beam used in the experiment was a 160 A, 5 meV, 0.3 microsecond pulse width electron beam provided by the Astron accelerator. The current refered to is the average current during the pulse. The beam was bunched at 120 mHz to stabilize it against hose instability. The current peaks of the bunched beam were > 600 A.

The measurements were made in a 2.5 m dia gas tank shown in schematic form in Figure 1. The beam enters the gas tank through a 2.5×10^{-3} cm thick Kapton foil. The tank was typically pressurized to 2.66×10^{1} - 5.3×10^{1} Pa N_2. The beam rapidly ionizes the gas producing its own plasma. The beam was deflected either by the large degaussing coils that run the length of the tank or by the steering coil set shown in the throat of the gas tank. The degaussing coil is normally used to eliminate the vertical component of the earths magnetic field.

The measurement of the beams position in the tank can be made at two points namely 3.5 m and 6.9 m from the entrance foil. The measurement is made by passing a 3 mm diameter tungsten rod mounted on a motorized probe through the beam. The X-ray intensity is plotted as a function of position of the tungsten rod. This technique plots out the beams radial profile and locates the beam center with respect to the tank centerline. Hundreds of beam pulses are required to plot the radial profile of the beam. Therefore accelerator reproducibility and beam stability are of extreme importance.

The beam current is measured by resistive beam current shunts (e.g. RBS 30) in the tank wall or by Ragowsky coils. RBS 30 monitors the beam current just before the entrance foil. The other current monitors are labeled by their distance past the entrance foil to the gas tank.

Experimental Results

Case I: Deflection of the beam by a weak magnetic field over the full length of the beam flight path.

In this experiment the degaussing coils were energized to the level required to null the earth fields vertical component. The field was nulled to an average value of 1×10^{-6} T over the flight path. The coil currents were then increased by 20 A and the average field strength was increased to 3.8×10^{-5} T. Since the deflecting field is proportional to coil current, the field can be inferred for other values of coil current. Figure 2 shows a schematic of the experiment. It is apparent from the geometry that the beam deflection $S \approx \frac{\ell^2}{2\rho}$ where ℓ is the flight path in the deflecting field and ρ is the radius of curvature for 5 meV electrons in the applied field.

$$\rho = \frac{\gamma m_o C}{Be}$$

γ = 10.9 for these experiments

$\rho = 5 \times 10^4$ cm for $B = 3.7 \times 10^{-5}$ T

The X-ray position monitor at 6.9 m was used for these experiments, however, the field from the degaussing coil does not extend to the entrance foil therefore ℓ = 5.3 m. Figure 3 shows some examples of the data. The results of the experiment are tabulated below:

B Tesla	δ cm measured	δ cm calculated
1.85×10^{-5}	1.5	1.4
3.7×10^{-5}	3.0	2.8
5.7×10^{-5}	5.0	4.3

Case II: Beam deflected by a short deflection coil, then free flight to point of measurement.

Figure 4 shows the geometry of this experiment. The field of the coil was measured for two coil currents and a field value of 3.64 10^{-5} T/A average over a 90 cm length was established. The deflection measurement was made 3.8 m from the entrance foil. Using the notation of Figure 4

$$\ell = 90 \text{ cm}, \; \ell_2 = 210 \text{ cm}$$

$$\Delta y = (\ell_2 + \frac{\ell_1}{2}) \frac{\ell_1}{\rho} = 0.46 \text{ cm/A on coil}$$

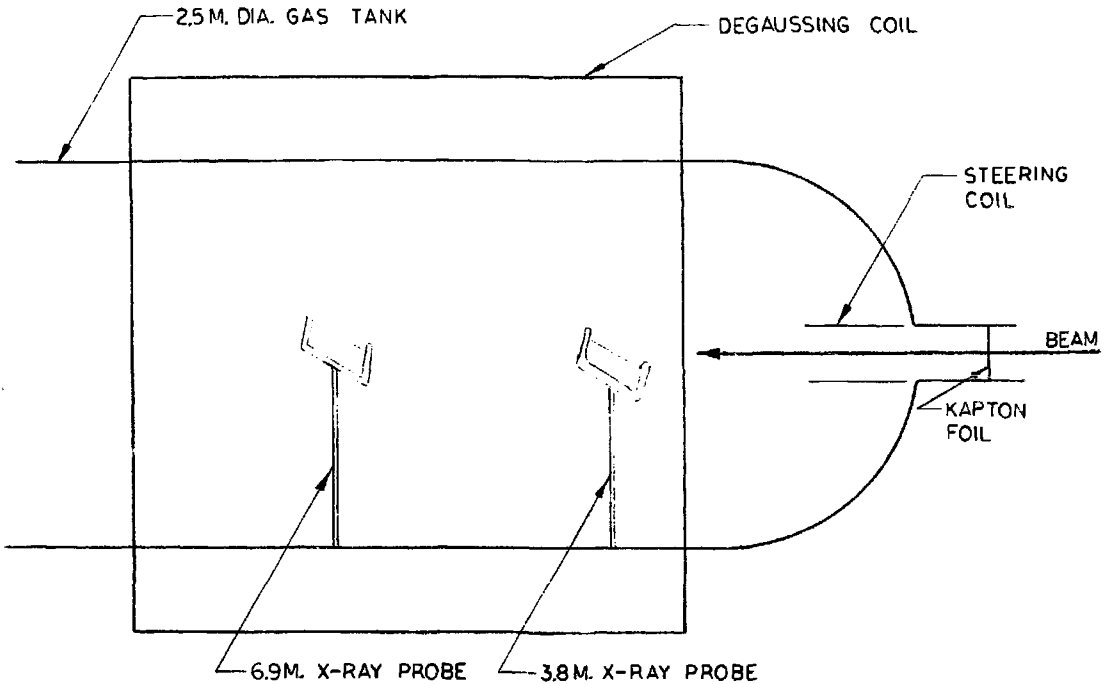
Figure 5 shows the actual data from the X-ray probe measurement. The results of the experiment are tabulated below:

Coil current A	B Tesla (Ave. over 90 cm)	Δy cm measured	Δy cm calculated
3	1.1×10^{-4}	1.3	1.4
6	2.2×10^{-4}	3.2	2.8
9	3.64×10^{-4}	5.0	4.1

Note in Figure 5 that the 0 A position had to be replotted after each deflection measurement because of accelerator drift.

Conclusion

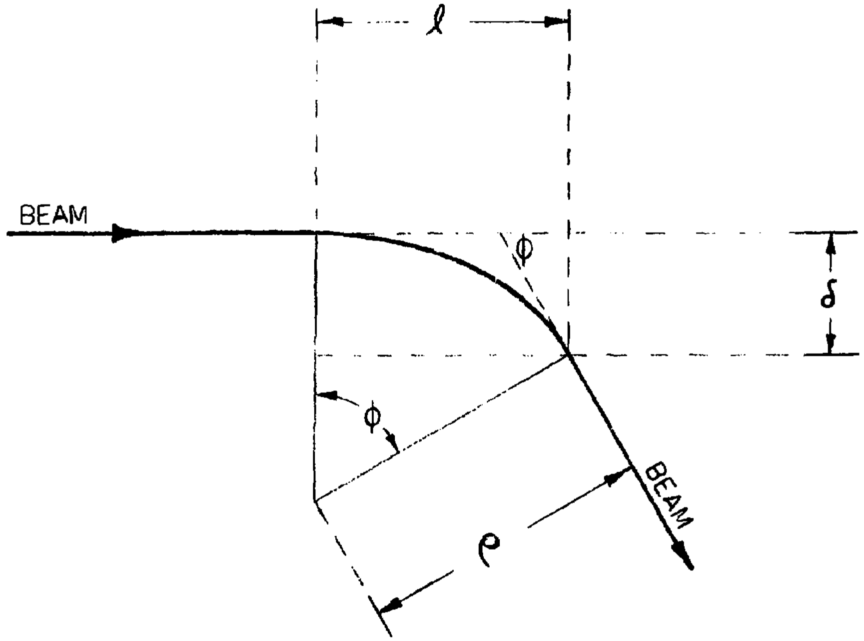
The beam was deflected by magnetic fields varying from 0.3 to 3.64 gauss. This is to be compared to the self-field of 16 gauss at the radius of 4 cm dia. 160 A beam. Differences of 10 to 20% were observed between predicted and measured values of beam deflection. This is within range of expected experimental errors. The largest errors are probably due to small changes in accelerator conditions over the time required to record data and the fact that the resolution of the measuring technique is marginal. However, the experiment demonstrates that no large differences between theory and experiment exist. Experiments where discrepencies exist may be influenced by beam interaction with metal walls.



SCHEMATIC OF EXPERIMENTAL APPARATUS

FIGURE 1

FIGURE 2



ℓ = LENGTH OF DEFLECTING MAGNETIC FIELD.

ρ = ELECTRON RADIUS OF CURVATURE IN MAGNETIC FIELD.

ϕ = ANGLE OF DEFLECTION.

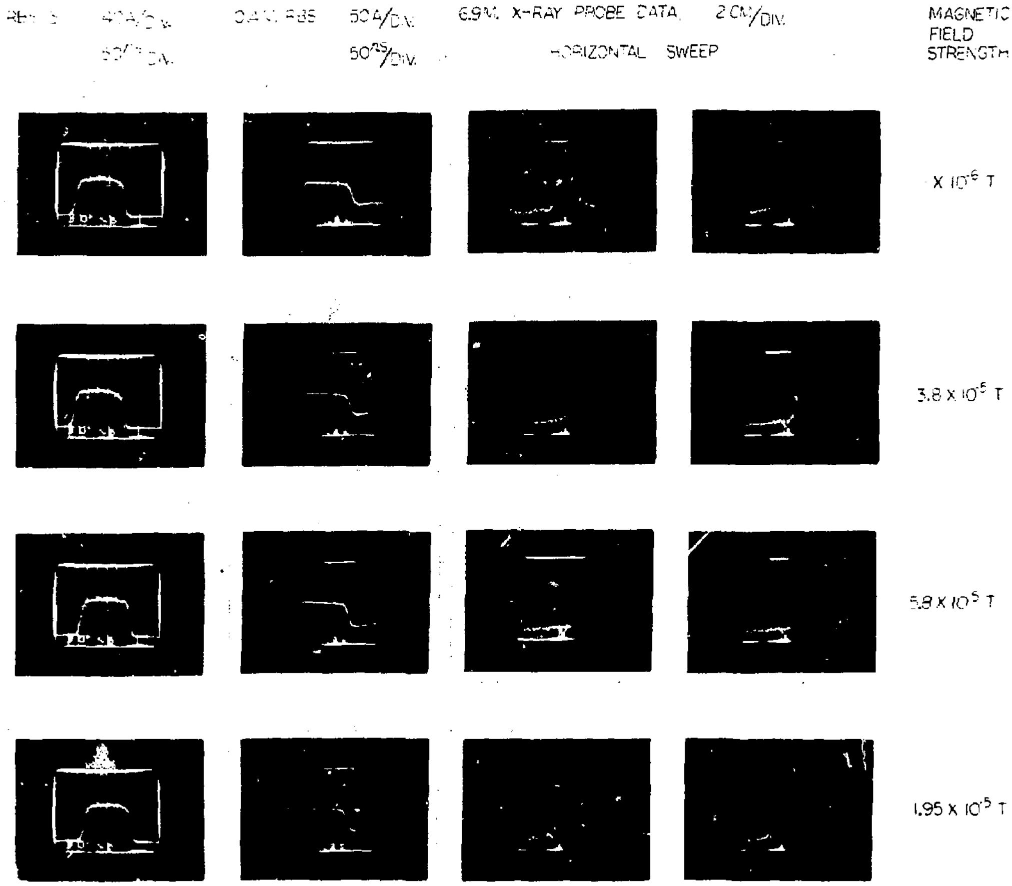
δ = DISPLACEMENT AT END OF DEFLECTING FIELD.

$$\delta \ll \ell \ll \rho$$

$$(\rho-\delta)^2+\ell^2=\rho^2 \qquad \therefore \delta \simeq \frac{\ell^2}{2\rho}$$

$$\phi \simeq \frac{\ell}{\rho}$$

FIGURE 3



DEFLECTION OF BEAM WITH DEGAUSSING COILS

GAS PRESSURE

120 MHz

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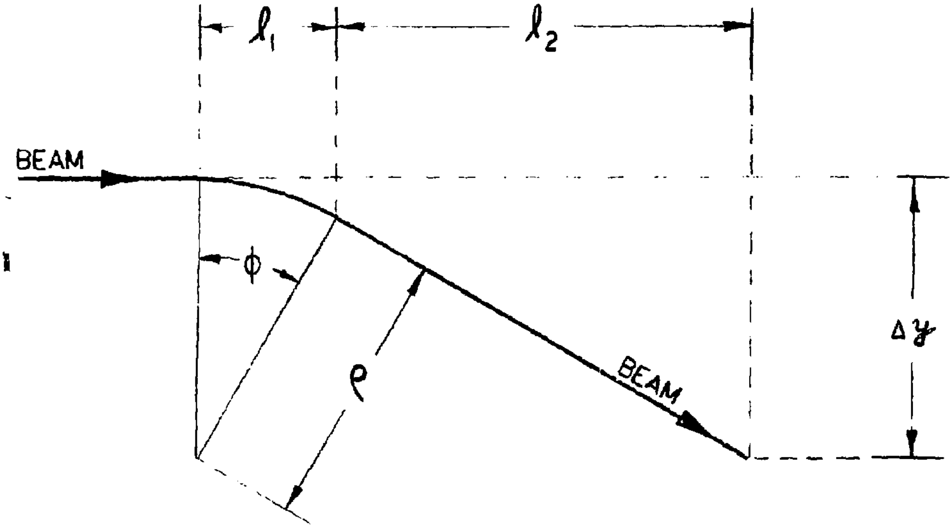
FIGURE 4



l_1 = LENGTH OF DEFLECTING COIL.

l_2 = DISTANCE TO POINT OF MEASUREMENT.

ρ = ELECTRON RADIUS OF CURVATURE IN MAGNETIC FIELD.

ϕ = ANGLE OF DEFLECTION

Δy = DEFELECTION

$$\rho \gg l_1 \qquad \therefore \qquad \phi = \frac{l_1}{\rho}$$

$$\Delta y \simeq \left(l_2 + \frac{l_1}{2}\right)\phi = \left(l_2 + \frac{l_1}{2}\right)\frac{l_1}{\rho}$$

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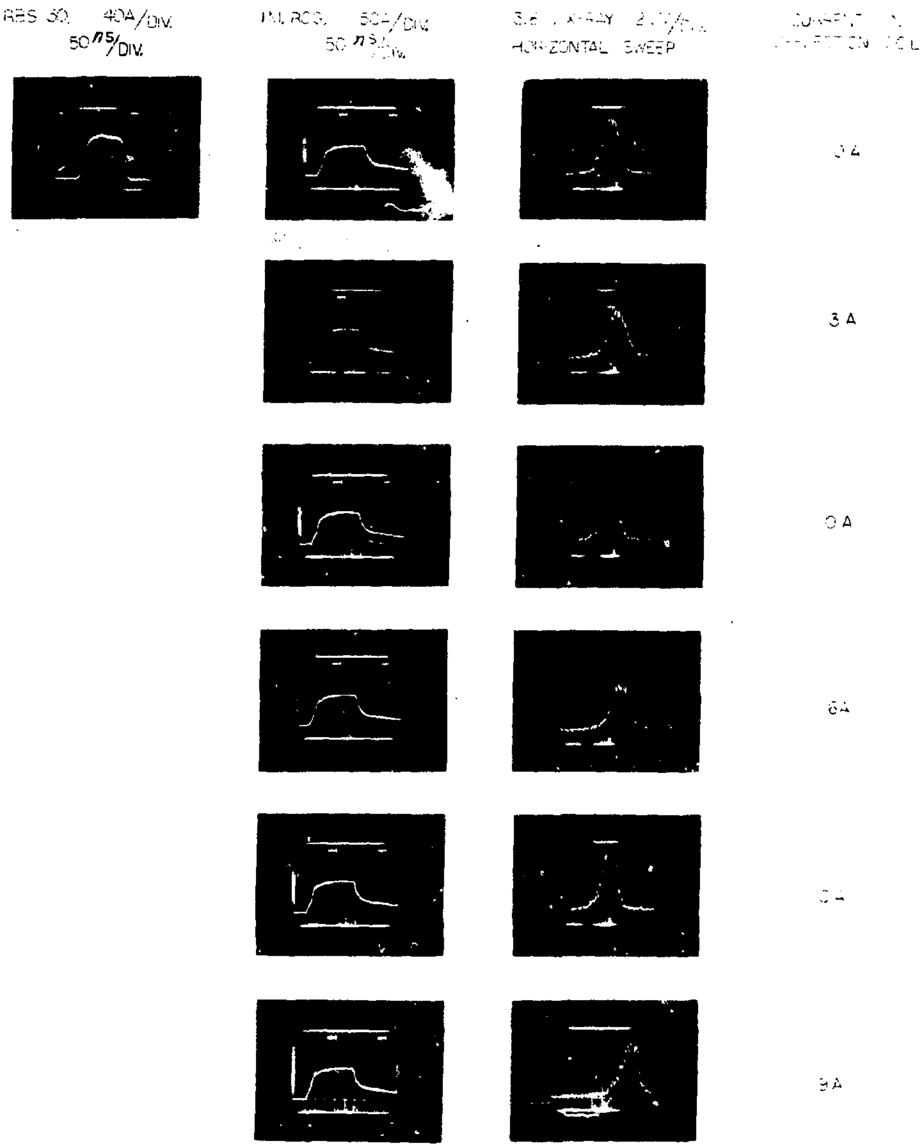

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