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REFLECTION OF ELECTRONS BY A MODEL MAGNETIC MIRROR MACHINE

Franklin C. Ford

May 28, 1954

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Livermore, California

532-1

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TABLE OF CONTENTS

 532-2

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ABSTRACT

A visualized electron beam has been reflected by a conventional magnetic mirror. Visualization of the beam path from the electron gun to and including the region of reflection was achieved by the "thread ray" technique of Wehnelt. The total current passing through a magnetic mirror has been measured as a function of the beam energy and angular momentum for H_2 over a range of pressures from 0.5 to 5 microns. (auth)

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INTRODUCTION

One of the fundamental problems in connection with proposed controlled thermonuclear devices is containment of a plasma. Among the several schemes devised for plasma containment by electromagnetic fields[1,2] is the magnetic mirror machine proposal of R. F. Post[3]. A magnetic mirror machine in operation at Livermore has been designed to contain the ions of a plasma and electron containment follows as a natural consequence of the space charge associated with such confinement. The same machine could conceivably "contain" electrons by magnetic mirror action by requiring the electron motion to satisfy certain fundamental mirror equations[3].

To test the principle of the magnetic mirror confinement for electrons, an experiment based on the visualization technique of Wehnelt[4] as described by Alfvén[5] was designed by John Foster. A conventional electron gun was to be used as the source of a variable-energy electron beam capable of being deflected upon entrance axially into a magnetic field of cylindrical geometry. By introducing various ratios of $v_\perp$ to $v_{||}$ (best thought of as varying the angular momentum of the beam particles with respect to the field axis), it appeared possible to satisfy the conditions for reflection at the mirror. In addition, by operating in a restricted pressure range of 1/2 to 5 microns, it appeared possible to have gas-focusing keep the beam fairly well defined over its entire path while its motion was still determined principally by the magnetic field. The presence of gas atoms along the beam path would enable one to observe the process directly by reference to a "thread ray" of light originating at the beam. The electron gun was sealed in a glass cylinder on the axis of the magnetic field. The cathode emission was found to be poor and it was necessary to replace the electron gun. A new gun with oxide cathode and large focusing apertures was designed and installed by Charles B. Wharton. For 5.0 ma of cathode emission, a beam current large enough for visual observation of the beam path was then obtained. A magnetic yoke served as the deflecting mechanism to obtain angular momentum. A third and final experimental arrangement was decided upon, and a new gun was built and mounted off-axis in the magnetic field. It was from this final model that data were obtained.

APPARATUS AND EXPERIMENTAL ARRANGEMENT

Figure 1 is a schematic representation of the apparatus employed, and Figure 2 is a diagram of the electronic circuit. The vacuum equipment consisted of a C.V.M. 3153 forepump, a 10 l/s D.P. (AV 10), an L.N. trap, and a 1949 type ion gauge. A 4-in. diameter by 24-in. long pyrex pipe, sealed with rubber "0" rings, served as the vacuum chamber. (See Figure 3.) The magnetic windings consisted of No. 12 lacquer-coated wire with 2 turns/inch on the first coil and 8 turns/inch double layer on the second coil (mirror coil). The two coils were connected to separate current supplies so that the field ratios of the coils could be varied as desired. The end flange opposite the gun served as a collector for the current which passed through the mirrors. The inside of the pyrex pipe was coated with a grid work of Aquadag connected to the gun end of the system for the purpose of avoiding surface charge effects that might arise from the electron beam reaching the walls of the vacuum vessel.

PROCEDURE, RESULTS AND DISCUSSION

Typical procedure for the operation of the electron model first operated on August 1, 1953 follows:

The cathode heater was operated at 10 volts which yielded a cathode emission current of 3.0 ma. By adjustment of the focusing mechanism of the gun, a visible, straight pencil-ray beam was obtained, for pressures in

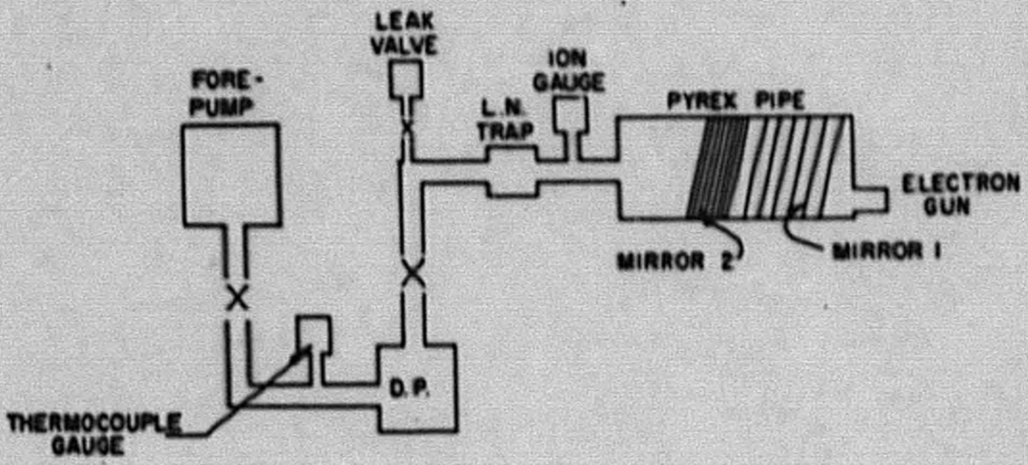

Fig. 1 --- Block Diagram of Apparatus for Mirror Machine

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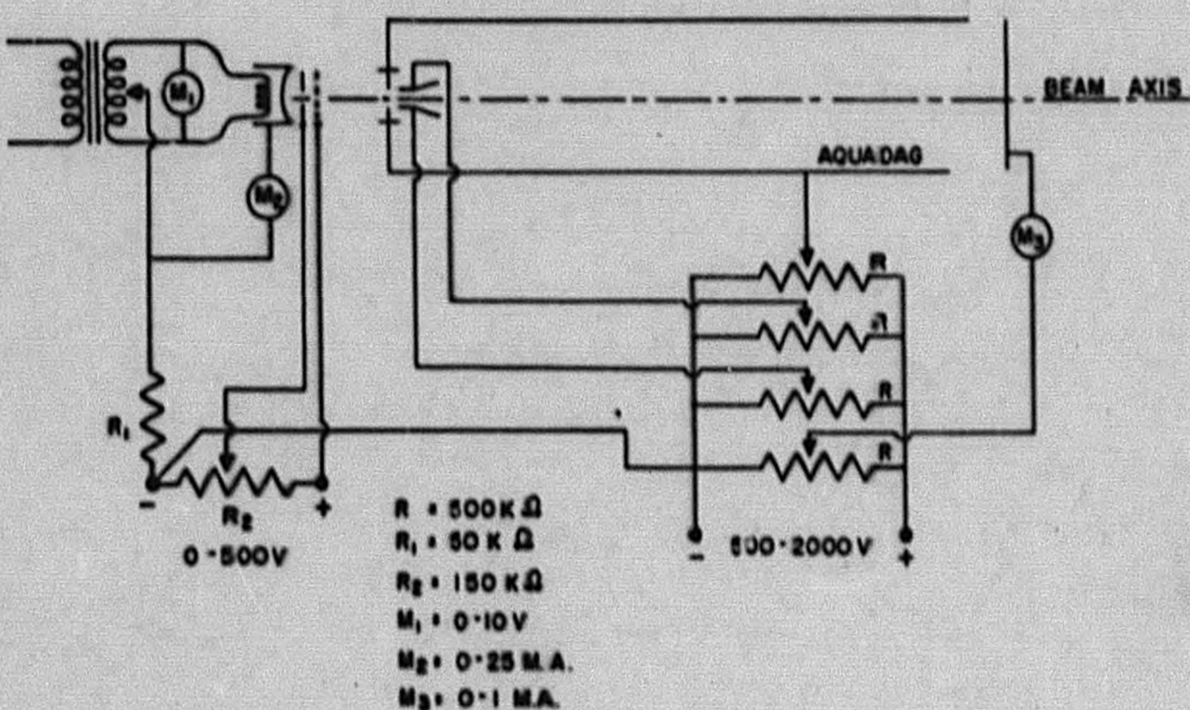

Fig. 2---Electronic Circuit Diagram

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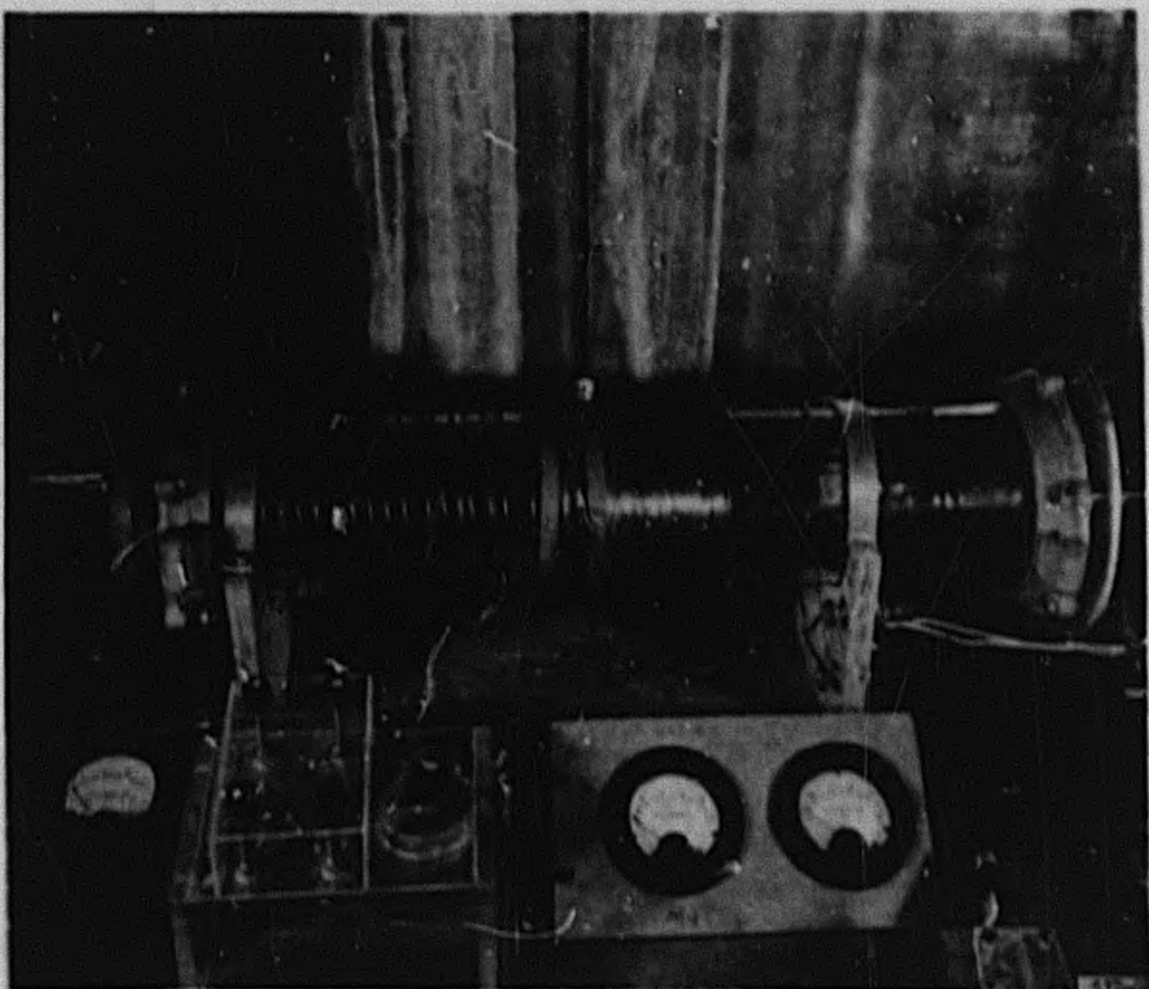

Fig. 3 - Photograph of Vacuum Chamber and Mirror Sections

the range of 0.5 to 5 microns Hg for hydrogen. The gas pressure was controlled and kept steady by means of a leak valve. The collected current at a point 24 inches away from the cathode was 100 μa for a collection voltage of 12.5 volts. This magnitude of current resulted in a beam which was well defined for 18 inches of the 24-inch length of pipe. The light beam, which resulted from the ionizing collisions of electrons with residual gas molecules (and subsequent deionization) clearly indicated the electron beam path through the gas in the pyrex pipe. Once a stable beam had been obtained, coil No. 1 was turned on by establishing a 10-ampere current in the coil. This current established a field of about 8 gauss. Deflecting plates were then used to obtain a helical beam path having a diameter of 2-1/2 to 3-1/2 inches and a pitch of 4 to 5 inches along the field axis. (See Figure 4.) Such adjustment rarely resulted in a drop in the collected current of more than 10 percent. Coil No. 2 was then turned on to establish the mirror action. For very low ratios (order of 2 or 3 to 1) of the fields in coils 1 and 2, total reflection of the gas-focused beam was obtained (for the type of helix described). Increasing beam energy (and not readjusting the deflection) required higher mirror ratios as predicted by theory. For axial beams (no deflections) no mirror setting could reflect the beam. The largest ratio used was 16 to 1, as estimated from the currents to the coils.

The helical pencil-ray beam was observed to change its pitch and diameter as the mirror coil was slowly turned on until the beam was reflected at the proper mirror ratio as indicated by zero collected current.

For purposes of photographing the beam, the cathode emission was increased to 15 ma for a period of one minute.

Electron beam energies were between 100 and 300 volts for the tests. The average mirror ratio for $v_{\perp}/v_{\parallel}$ of the order one was about 2:1. It would thus appear possible to reflect charged particles with a small mirror ratio when the ratio $v_{\perp}/v_{\parallel}$ can be made equal to or greater than one. The electron model is a convincing demonstration of the magnetic mirror principle.

ACKNOWLEDGMENTS

The author gratefully acknowledges the help and cooperation of Charles B. Wharton, who performed most of the intricate electron gun construction feats and was responsible for the electronics associated with beam control.

532-9

Fig. 4 - Photograph of Visualized Electron Beam

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