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AXIAL INJECTION INTO A MULTIPOLE GUIDE FIELD

by

R. G. Tuckfield, Jr. and F. R. Scott

June 25, 1964

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AXIAL INJECTION INTO A MULTIPOLE GUIDE FIELD⁺

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ABSTRACT

A linear hexapole magnetic field was employed as a guide field for the accelerated plasma produced by an inductive gun. Photography, diamagnetic probe measurements and calorimeter data indicate that, near the axis, the energy attenuation along the 100 cm guide field was significantly reduced. A good separation between plasma and field was also maintained. With application of the guide field a significant reduction in the percentage of impurities was observed.

One of the major problems of plasma containment is purity. Several recent experiments which rely upon injection of a plasma produced by guns have shown containment limitations due to charge exchange arising in part from impurities and neutrals.^{1,2} These impurities usually originate in the region of the gun and contain a velocity spectrum similar to the plasma itself making separation difficult. One solution is gun design but this appears difficult. Guiding and filtering by means of a static axial guide field also has been attempted.^{3,4} The present note describes the results obtained from injecting a plasma axially into a linear hexapole field. This field has the attractive features of zero axial field and cusp stability. Hopefully the plasma would be guided without serious plasma-field mixing.

The guide field was constructed of 6 straight $3/4$ " bare copper rods mounted on a circle of 7.5 cm radius. Current thru adjacent rods was in opposite directions. The current to the rods was supplied by means of an 80:1 step down transformer whose primary was connected to a 12 kV 120 μ f condenser bank. This permitted a peak current of 40,000 amps at only 40 volts. No vacuum insulation of the rods was required. The cross over and feed points of the current to the rods were brought out to a diameter of 30 cm. This was found necessary to decrease the effects of cross currents near the ends of the rods. A schematic diagram of the experimental set-up is shown in Figure 1.

The gun used to accelerate the helium plasma was an inductive accelerator.⁵ It was attached to a large 4 foot square x 18 inch high vacuum box in which the six rods comprising the hexapole field were placed

Fig. 1--Experimental set-up for hexapole guide field experiment

and aligned with the injection axis of the gun. The base vacuum was $\sim 1 \times 10^{-6}$ torr at each firing of the gun. A fast electromagnetic valve let in $\sim .05$ atm cc of helium gas 80 μ sec before firing the main condenser bank.

The plasma flow was examined by simple photography, time resolved photography, magnetic probes, an energy-momentum particle analyzer⁶ and calorimeters.

Total light photographs of the plasma bombarding a large frosted glass disc placed perpendicular to the rods indicated its profile at various points along the guide field. These photographs showed that with no rod current there was no detectable light at the plate for distances greater than 25 cm from the gun. As the current was increased more and more light appeared. At the higher field strengths a consistent light pattern which corresponded to the field line was observed outside a radius of 2 to 3 cm. Within this radius an intense uniform core was observed.

The overall picture was not six sided. Instead there was a definite increase in emission light under every other rod. For normal operating conditions the direction of the current in the top rod flowed toward the gun (upstream), and there was a definite decrease of light under this rod as there was in each of the other two rods carrying current upstream. Under the three rods carrying current downstream there was a much less decrease in light intensity. This phenomenon was most pronounced at the lower field strengths and inverted when the currents were reversed. This polarization effect can be explained by simple orbit particle motion assuming that the ions have most of the axial momentum.

A series of 1 μ sec exposure, time resolved photographs were taken. They showed that the emission light at the glass plate, 70 cm from the gun, occurred abruptly at 5 μ sec and lasted 10 μ sec. Most of the light was produced in 5 μ sec.

The diamagnetic effects of the plasma were determined by magnetic probes at distances of 30 cm and 90 cm and are shown in Figure 2. For the low field (~ 265 g between rods) at 30 cm the probe showed large diamagnetic effects, extending out to a radius of 10 cm near a separatrix. At 90 cm for this field strength the probe indicated a very low β beyond 4 cm. At the higher field strength (800 g) the upstream probe showed strong diamagnetic effects within 6 cm with a fairly sharp decrease from 6 to 8 cm radius. There was only a slight decrease in this profile at 90 cm for this field strength.

A 1 cm diameter calorimeter was placed perpendicular to the injection axis. The output was a measure of the total energy of the plasma over this 1 cm diameter. This data is presented in Figure 3. With no current to the rods, the exponential decay of energy with distance from the gun follows quite well that which is expected from free expansion of a gas with both directed and perpendicular energy. As the field was increased the slope decreased. At the highest field there was only a 50% loss in total plasma energy received by the calorimeter on the axis of injection. Measurements were taken at various radii but beyond $r = 3$ cm the signals were so small that the lack of reproducibility from discharge to discharge masked any gross effect.

The energy-momentum analyzer analysis was used to determine ion energy and mass at the downstream end of the guide field. The energy distribution

Fig. 2--Magnetic probe measurements of $\frac{\Delta B}{B}$ as a function of radius at 30 cm and 90 cm from the gun and with guide fields of 265 G and 800 G

Fig. 3.--Plasma energy as measured by a 1 cm diameter calorimeter on the injection axis at 30 cm and 90 cm from the gun with various guide fields

and impurity content of the plasma without guide field was determined previously.⁷ With application of the hexapole guide field a significant reduction in the number of impurity ions was observed, leaving only the helium ions. The impurity content was reduced to $\sim 5\%$ with guide field from 15% without field.

These results indicate that low z plasmas produced by guns may be purified and guided by linear multipole fields. In the presence of the guide field the calorimeter data showed that along the axis of injection the energy attenuation was significantly reduced and the magnetic probe signals showed a good separation between field and plasma even at 90 cm. Work is in progress to examine the effects of using a curved guide field to further reduce the neutral impurity.

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