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PENETRATION OF A PLASMA BEAM IN A MAGNETIC BARRIER

by

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1.0 Introduction

This report describes work undertaken at Case Western Reserve University under contract AF19(628)69-C-0104 covering the period from July 1, 1969 to January 31, 1971. The aim of this work was to investigate a number of problems associated with the dynamics of the penetration of a plasma beam in a magnetic barrier. In order to study this beam-magnetic field interaction a series of associated problems of varying importance had to be investigated. Accordingly the research program was divided into three parts which dealt with the generation of the plasma beam, the design of ancillary equipment: coils to produce a magnetic field of special configuration, a very large vacuum installation and finally the study of the interaction proper.

The investigations reported here and which are both theoretical and experimental have been grouped under three headings. The publications pertaining to these investigations and cited at the end of each section contains a complete description of the experiments, calculations and results corresponding to this section. Whenever appropriate special diagnostic techniques developed for the project have been described.

2.0 Summary Description of Projects

2.1 Generation of Plasma Beam

After a number of trials towards producing a dense, low-temperature but highly energetic plasma beam, we finally decided to produce the beam by means of a modified version of a conical plasma gun described by Cheng. (Ref. 1) The gun is composed of a cylindrical inner conductor of radius $\sim$0.5 cm and a conical outer conductor of mean radius $\sim$4 cm. The essential difference between our gun and Cheng's is the addition of a conducting back plate. This configuration causes the initial breakdown of the gun to occur as an inverse pinch which has been shown to result in a considerable improvement in the overall consistency of the operation of the gun.

We found two distinct modes in which this gun could be operated. In the first mode, the gun was filled prior to discharging the condensers. In this static mode the gun produced a distinct focus, leading to high temperatures as in a conventional focus. The neutrons produced and measured by means of a neutron activation counter similar to that developed by Lanter and Bannerman (Ref. 2) were of the order of 10^7. The energy in the main condenser bank for the discharge was quite small of the order of 2 kjoules. The background pressure was of the order of a fraction of a millimeter.

In the second mode, the gun was operated with the gas being introduced on a pulsed basis. The resulting appearance for the plasma when ejected from the gun was in the form of a beam. The density was of the order of

$10^{14}/cm^3$. Image converter camera observations of the beam indicated that the beam was pencil-like, about 15 cm long and moving with a velocity of about 10^7 cm/sec. Although a focus did form during the early part of the current sheet collapse, no neutrons are produced (for the same 2 kjoule energy) and the plasma appears to be quite cold and of the order of a few volts. The addition of the metallic back plate appreciably increases the reproducibility of the beam characteristics.

Systematic investigations of the properties of the current sheet in the gun, prior to its collapse at the focus indicated that an anomalous resistance is necessary to account for the heating of the electrons in the sheet. It also turned out that the reproducibility of the beam produced is very sensitive to the initial temperature of the plasma prior to its collapse.

An interesting theoretical investigation on the dynamics of a spindle-like plasma focus with increased stability and trapping time was completed. (Ref. 3).

The actual dynamics of the jet formation can be explained on the basis of the J x B forces on the electrons and the subsequent acceleration of the ions through the Coulomb forces between the ejected electrons and ions. The details of this mechanism are further complicated by trapped magnetic fields in the ejected plasma caused by the arc restriking. (Ref. 4)

References

1. Cheng, D. Y., Bulletin Am. Phys. Soc. 13, 1560 (1968).

2. Lanter and Bannerman, Los Alamos Report. LA-3498-NS.

3. F. J. Mayer, Bull. Am. Phys. Soc. 15, 1462, (1970).

4. F. J. Mayer and O. K. Mawardi, "Some Post-Collapse Observations of a Low-energy Plasma Focis Device" (To appear in Phys. of Fluids).

2.2 Ancillary Equipment Used

Several novel installations were specially constructed to perform the beam plasma interactions. Although, they did not require any new concept for their operation they did need specialized instrumentation of interest.

2.2.1 Vacuum System

A fairly large vacuum system was needed in order to meet the essential criterion of the size of the apparatus being much greater than the mean free path of the electrons. Accordingly a cylindrical cold-rolled steal chamber four feet in diameter and six feet long was constructed. Indium wire seals were used on ports and with a 50 CFM mechanical pump for roughing and a 6 inch cold-trapped oil diffusion pump it was possible to reach a base pressure of 6×10^{-7} Torr. This relative inexpensive installation turned out to be easy to operate and to maintain.

2.2.2 Magnetic Field Configuration

The success of the experiment required the generation of a magnetic field with a fairly sharp gradient. It was necessary in particular to have the characteristic steepness for the magnetic field $(B_{max} - B_{min})/\Delta$ such that Δ be smaller than a Larmor radius of the ions.

The field was produced by a large pair of rectangular coils which form the main field and two pairs of compensating coils which shape its leading edges. The relative number of turns and size of these two pair of coils was optimized so that the field rose to 90% of its value over a distance of 10 cm. By exciting the field coils by means of a pulsed source maximum fields of about 4 kgauss were produced. The coils are separated by roughly 25 cm.

A summary report on the system is now under preparation.

2.3 Beam-Magnetic Field Interaction

The dynamics of the beam interaction in the case of a cold dense plasma can be calculated first simply on the basis of an idealized cold perfectly conductory model. (Ref. 5) The diamagnetic property of the plasma will be responsible for the plasma tunneling its way in the magnetic field. A more refined theory requiring the consideration of the plasma compressibility will lead to the formation of shocks at the transition. (Ref. 6)

Preliminary measurements were started to obtain the behavior of the beam at the interface. Theoretical investigations to investigate the possible destruction of the magnetic field at the shock interface and thus account for the heating expected. (Ref. 7) The analysis bears some similarity to the dynamics of combustion waves, here the ohmic losses play the role of the exothermic chemical sources of energy.

A report on the experimental findings of the behavior of the beam at the interface is now being prepared.

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7. O. K. Mawardi, Bull. Am. Phys. Soc. 15, 1473, (1970).

2.4 Personnel

The following individuals participated in the research reported above.

G. Lee, O. K. Mawardi, F. J. Mayer, C. Speck, M. Wolf.