Electronics Research Laboratory
University of California
Berkeley, California
Internal Technical Memorandum M-89

A MECHANISM FOR INTERNAL CROWBARRING OF ROTATING PLASMAS

by

H. K. Forsen
A. W. Trivelpiece

The research herein was supported by the Joint Services Electronics Program (Air Force Office of Scientific Research, Army Research Office, Office of Naval Research) under Grant AF-AFOSR-139-64; the U. S. Department of Air Force under Contract AF-33(615)-1078; and the National Science Foundation under Grant GP 2239.

August 10, 1964

A MECHANISM FOR INTERNAL CROWBARRING OF ROTATING PLASMAS*

H. K. FORSEN AND A. W. TRIVELPIECE

The class of plasma experiments known as rotating[1, 2] or homopolar plasmas[3] involve crossed electric and magnetic field ionization in some configuration such as that depicted schematically in Fig. 1. Recent experiments[3] have led to encouraging results and modifications of this method of plasma creation are being incorporated into plasma guns or sources.[4-6] The one which is described here is shown in Fig. 2. If the ionization goes as expected,[7] electron avalanche breakdown occurs and the voltage on the driving capacitor will come to an equilibrium value corresponding to the ratio of plasma capacitor to driving capacitor.[2] However, it has been observed that there is mechanism to further drain the energy from the driving capacitor. In the past it has been identified with one or the other of the following mechanisms. One of these is slow in time and is a result of viscous drag forces of rotating particles in contact with the walls. The other is fast and is a result of particles reaching the high voltage insulator and shorting it out.

In addition to these forms of internal crowbarring, rotating plasma source experiments also suffer from another type of internal crowbar after initial electron avalanche and voltage division. This has been previously regarded as due to the fringing electric field at the tip of the central rod which has a component parallel to the magnetic field in that region. Particles that reach this region would be ionized by fast electrons and the internal crowbar would result. This explanation, however, is inconsistent with the results obtained in experiments using the arrangement of Fig. 2. Here, fast ion-gauge studies indicate that the axial gas flow from the fast acting valve, is at a rate of about 0.1 cm/μsec.

* The research herein was supported by the Joint Services Electronics Program (Air Force Office of Scientific Research, Army Research Office, Office of Naval Research) under Grant AF-AFOSR-139-64; the U. S. Department of Air Force under Contract AF-33(615)-1078; and the National Science Foundation under Grant GP 2239.

By increasing the length of the tip in various stages up to 25 cm no delay was observed in the internal crowbar of the experiment after initial avalanche. The time of this internal crowbar remained at 1 to 3 μsec after initial avalanche. Furthermore, this crowbar was found to increase the diamagnetic signal as measured by flux loops (Fig. 2) around the vacuum liner. Also if such a crowbar were to occur at the rod tip, evidence of local erosion or sputtering would be expected and none was observed in these experiments.

We propose here a mechanism which accounts for the observed internal crowbar and does not involve breakdown at the tip. This mechanism involves the emission of gas from the central conductor as a result of surface heating from electron bombardment. Although this mechanism presents an inherent difficulty in this type of rotating plasma experiment, we believe its deleterious effects on the plasma can be minimized.

The operation of this particular rotating plasma experiment involves the discharge of a capacitor system into the coils which provide an axial mirror field (rise time to maximum midplane value of 10 to 30 K gauss is 50 μsec). A predetermined amount of D_2 gas is admitted through a valve in the central conductor. The original quantity of gas breaks down and forms a rotating plasma whose diamagnetic current and second order drift velocity produces a magnetic field in the opposite direction to the original applied field. The total magnetic field in the vicinity of the central conductor is then approximately as shown in Fig. 3. It has been assumed that the flux lines which have diffused into the central conductor are frozen there during the 1-2 μsec avalanche time. The plasma diamagnetic energy density is about 0.1 joule/cm^3 which is sufficient to produce this type of flux configuration. Normally such magnetic field lines are equipotential surfaces because of the high mobility of electrons along these field lines. Here, however, such must not be the case because rotating plasma is observed and therefore an electric field must exist in the region of the plasma. This then implies that the electrons distribute themselves along the field lines according to the electric field. Therefore electrons from the rotating plasma can be accelerated into the central conductor with considerable energy and cause surface heating and adsorbed gas emission. This flux of high Z material is quickly ionized and accelerated by the $\vec{E} \times \vec{B}$ mechanism. The resulting ions will have a gyroradius larger than the electrode spacing (3.7 cm) and will strike the outer wall, thus not contributing to the ion-space charge which would tend to prevent electrons from reaching the central rod.

The observations we have made which are consistent with this model are as follows. Sputtering or surface erosion is observed in the vicinity of the fast valve and extends to either side of the gas port for about 3 cm. It becomes very pronounced in a narrow strip about 1 cm wide at a distance of 3 cm from the center of the mirror field. The observed time of crowbar after the initial avalanche is 1-3 μsec, and this is consistent with the radial velocity of an energetic high Z ion whose gyroradius is larger than the electrode spacing. These high Z ions contribute substantially to the theta (θ) current of the plasma and result in an increased diamagnetic signal. This signal is observed to continue to increase as long as the crowbar current is increasing, i.e., until the capacitor is discharged.

Measurements with magnetic probes which are inserted into the upper two ports of Fig. 2 and oriented to measure only B_θ exhibit the following properties. If the tip crowbar is purposely triggered by allowing D_2 gas to fill the device before the H. V. is fired, both probes peak and decay together. Their time history is identical to the current as would be expected. However, when a rotating plasma is created and the internal crowbar occurs, the lower probe stays essentially at zero while the upper probe gives a signal similar to the current trace. This indicates that the axial current of the rod passes through the plasma between the two probes to the return conductor as the model would indicate.

There appear to be several methods of reducing and/or eliminating this effect. First of all, the experiment could be fired during the rising magnetic field and hence the region where lines are frozen into the central rod would be moved farther axially from the mirror center. Secondly, a high conductivity sleeve could be placed over the central anode, thus accomplishing the same results as the first by increasing L/R. Thirdly, and perhaps best, is to reverse the polarity making the ions strike the rod and reduce the heating by the square root of the mass ratio. Fourthly, the heating and diamagnetic distortion of the flux surfaces both can be reduced by reducing the initial amount of gas from the source, however, this may introduce other difficulties.

REFERENCES

1. O. Andersen, W. R. Baker. A. Bratenahl, H. P. Furth, and W. B. Kunkel, "Hydromagnetic capacitor," J. Appl. Phys., Vol. 30, p. 188; 1954.
2. D. A. Baker, J. E. Hammel, and F. L. Ribe, "Rotating plasma experiments. I. Hydromagnetic properties," Phys. Fluids, Vol. 4, p. 1534; 1961.
3. K. Halbach, W. R. Baker, and R. W. Layman, "Production of a hot rotating plasma," Phys. Fluids, Vol. 5, p. 1482; 1962.
4. W. R. Baker and K. Halbach, Phys. Fluids, to be published.
5. J. Phillips and H. Carr, LASL, private communication.
6. J. Steinhouse and N. Oleson, University of California Radiation Laboratory, private communication.
7. G. A. Pearson and W. B. Kunkel, Phys. Rev., Vol. 130, p. 864; 1963.

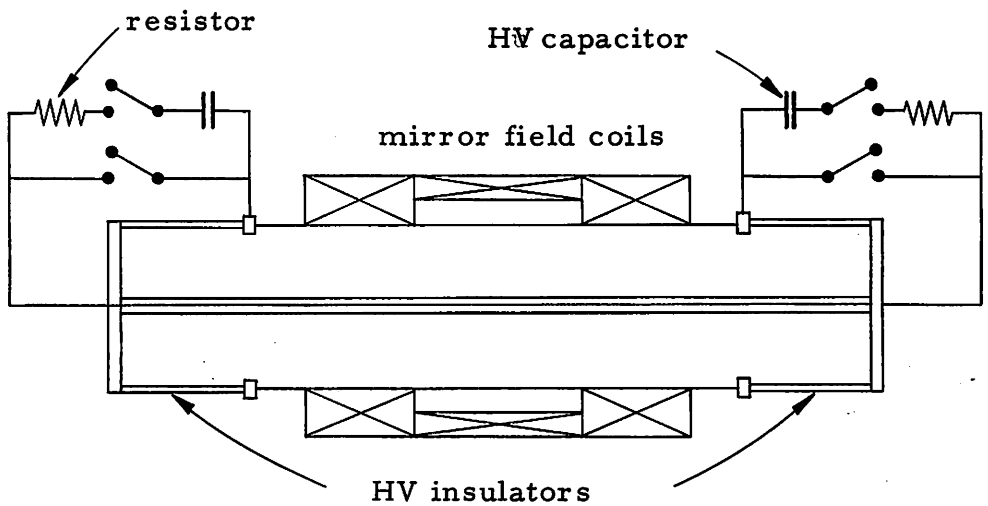
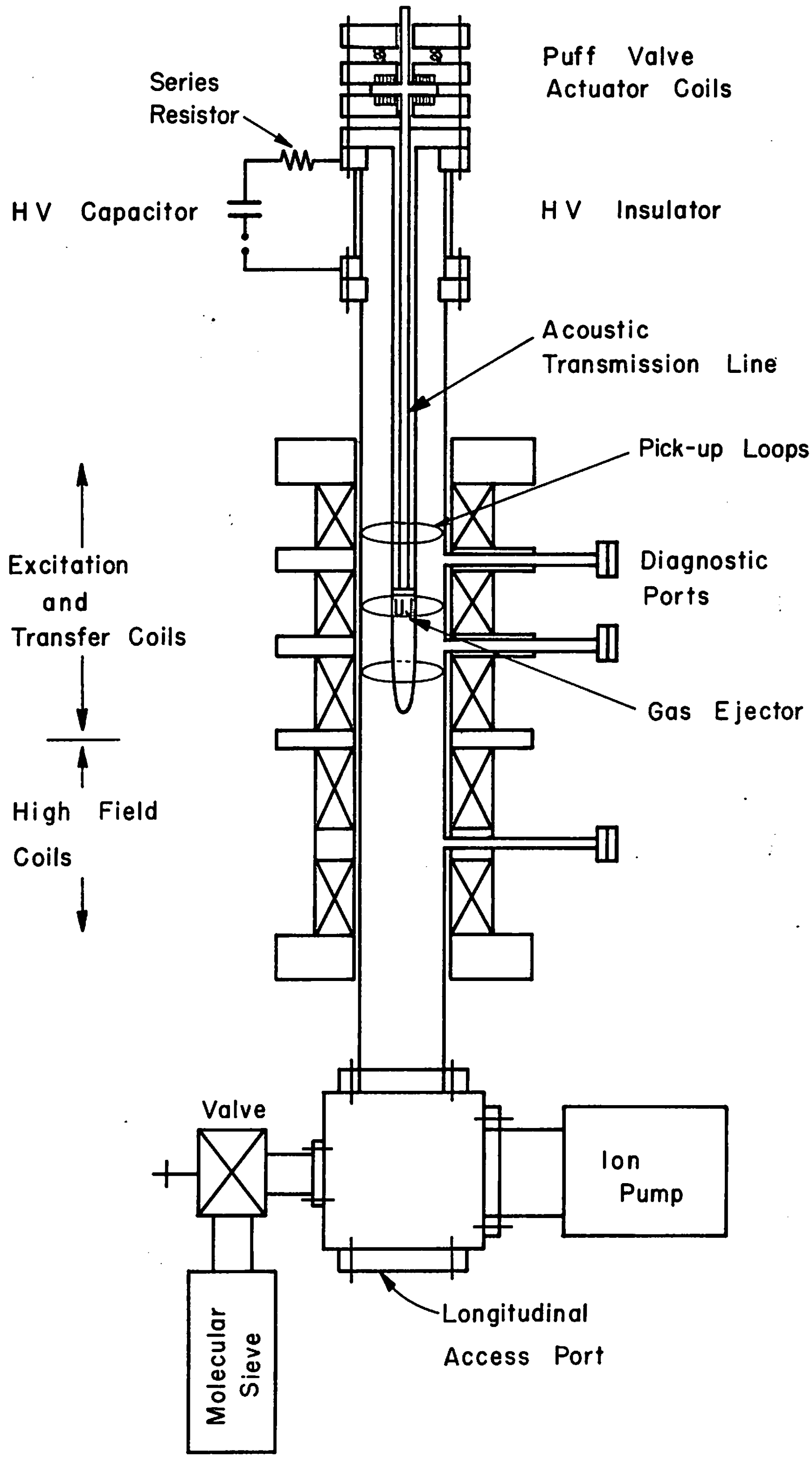


Fig. 1.



Series
Resistor
Puff Valve
Actuator Coils
HV Capacitor
HV Insulator
Acoustic
Transmission Line
Pick-up Loops
Excitation
and
Transfer Coils
Diagnostic
Ports
Gas Ejector
High Field
Coils
Valve
Ion
Pump
Molecular
Sieve
Longitudinal
Access Port

Fig. 2.

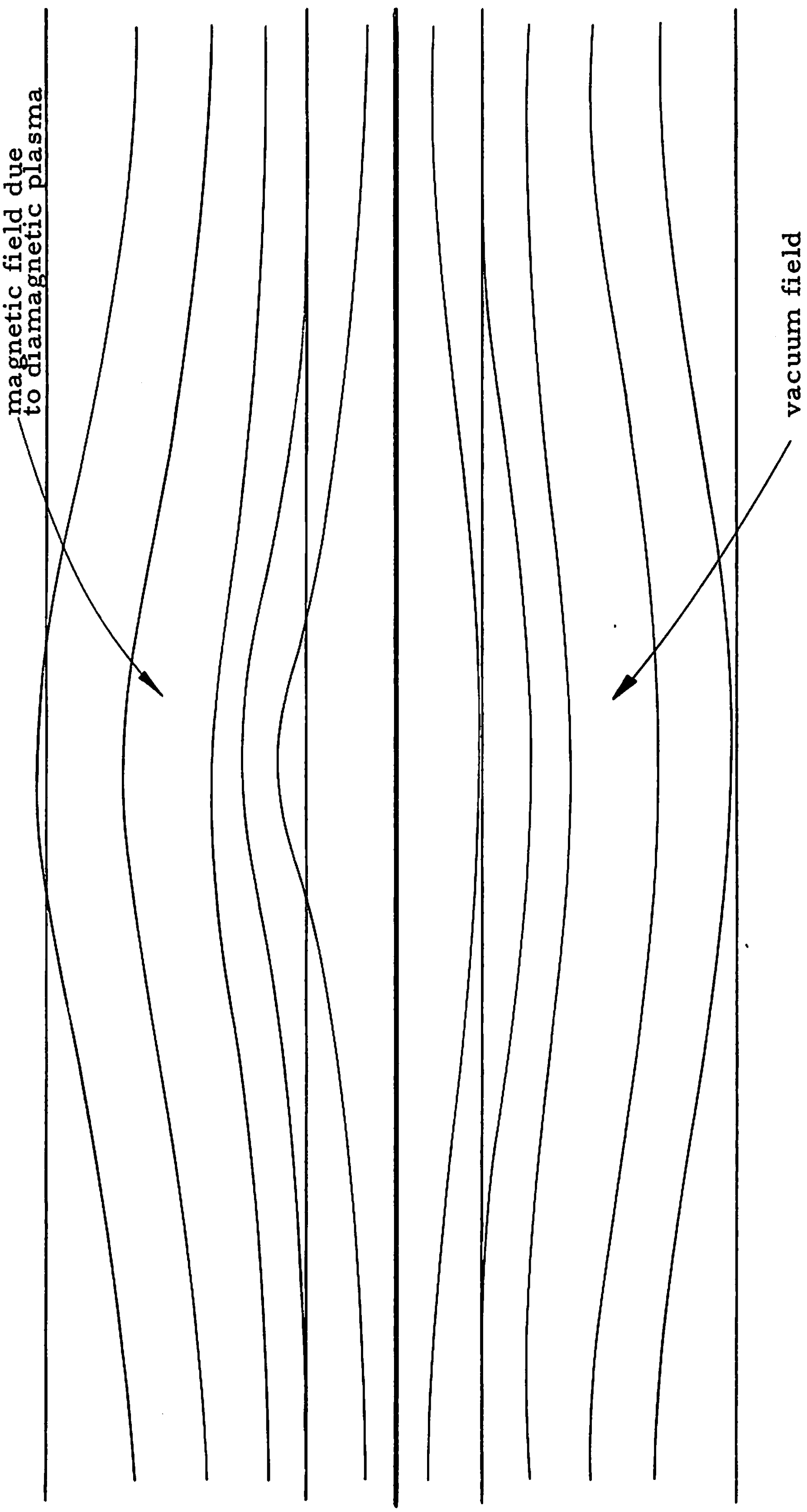


Fig. 3.