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"THE PLASMA EATER:" A DEVICE TO MEASURE THE RATE OF FLOW OF A PLASMA

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OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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ABSTRACT

The "plasma eater" is a device which measures the rate of flow of a neutralized plasma. The device absorbs or "eats" the plasma entering it, and yields a current equal to the number of electrons entering the device per second. An experimental model of the device has been successfully used with a mode I arc[1], a reflex discharge, to measure steady state plasma flow rate, ion density, and plasma decay time.

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I. INTRODUCTION

Measuring the properties of a dense plasma supported by a magnetic field is difficult. Therefore, new diagnostic methods have been developed at Oak Ridge National Laboratory. This report discusses one such method, the "plasma eater." Although this method is very simple and easy to use, it appears to yield reliable information on plasma flow rate, ion density, and plasma decay time.

II. THEORETICAL DISCUSSION

The "plasma eater" is composed of closely spaced metal plates, as shown in Fig. 1. Alternate plates are connected to a source of voltage. The device resembles a radio tuning condenser connected across a battery. Plasma is directed between the plates. If conditions are correct, the ions and the electrons can be pulled to alternate plates across a restraining magnetic field. For ions and electrons entering the gap with negligible velocity, the spacing of the plates, R(cm) should be smaller than the value

$$R \leq 2 \frac{E\, m_e\, C^2}{e\, H^2}$$

Here E is the electric field between plates (esu), m_e is the electron mass (grams), C is the speed of light (cm/sec.), e is the electron charge (esu) and H is the magnetic field (gauss). The first experimental model operated at a lower electric field than that predicted by the formula.

III. TESTS ON THE FIRST EXPERIMENTAL MODEL

A "plasma eater" was constructed out of 16 plates of sheet tantalum. The plates were 0.005-in. thick and were separated by mica strips 0.017-in. thick. The depth, ℓ, of the device was 1/2-in.

Tests of the "plasma eater" were made in a mode I arc[1], as shown in Fig. 2. The sustaining gas was argon at a pressure of 6.5×10^{-4} torr. The cathode voltage was 85 volts and the arc current was 1.05 amps. A magnetic field of 3000 gauss restricted the arc diameter to the defining hole diameter, 1/4-in. The arc length (cathode to anticathode) was 10.25-in. With the "plasma eater" in place, the arc length was 8.75-in.

Test 1. Visual check to see if "plasma eater" absorbs plasma.

If the "plasma eater" had no voltage across its plates, but was left electrically floating, plasma would stream through the device. The plasma emerging toward the anticathode was observed as a bright glow. This could be extinguished by placing about 200 volts across the plates of the "plasma eater." Switching the voltage across the "plasma eater" on and off had no perceptible effect on the main plasma column on the cathode side of the "plasma eater."

[1] R. V. Neidigh, The ORNL Thermonuclear Program, ORNL-2457, p. 55, 164-5, January 15, 1952.

R. V. Neidigh, The Effect of a Pressure Gradient on a Magnetically Collimated Arc, ORNL-2288, May 27, 1957.

<u>Test 2.</u> Characteristic curve for the "plasma eater."

The voltage vs. current characteristic curve of the "plasma eater" is shown in Fig. 3. The curve is rather symmetric, and indicates that the current of the device approached a saturation value. A current saturation is to be expected, if the "plasma eater" is eating all the plasma entering it.

<u>Test 3.</u> Measuring the steady state plasma flow rate.

The saturation current, observed in Test 2 above, should be equal to the number of electrons reaching the device per second. This assumption was verified by a test made with a "plasma sweeper;" a device discussed in detail elsewhere[2]. A brief description of the "plasma sweeper" is given in the appendix. The average steady state current yielded by the "plasma eater" was 62 milliamperes. The rate of steady state loss of plasma ions from the end of the column as measured with the "plasma sweeper" was 71 milliamperes. Both measurements were made with the same apparatus and under the same conditions. The agreement is good, and suggests that the "plasma eater" does yield the steady state plasma flow rate.

<u>Test 4.</u> Measuring the ion density and the plasma decay time.

The "plasma eater" was used to measure both the ion density and the plasma decay time in mode I arc, and the results agreed well with measurements made with a "plasma sweeper." Measurements were made by turning

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[2] Thermonuclear Division Semiannual Report for Period Ending October, 1961, in press.

off the source of plasma, then collecting the plasma. Dividing the total amount of charge by the volume of the column yields the average ion density. Measurements with the "plasma eater" and the "plasma sweeper" were made with the same apparatus and under the same conditions.

To measure ion density and plasma decay time with the "plasma eater," the device was placed in a mode I arc as shown in Fig. 2. The cathode of the arc was shorted to ground with a fast closing switch, and the current flow through the "plasma eater" was observed with an oscilloscope. Presumably half the plasma in the column reaches the "plasma eater", the other half being lost on the cathode. Precautions were made so that no sweeping electric field would be present along the plasma column. Both the "plasma eater" with its associated electronics, and the anticathode electrode, were electrically floating. To measure ion density and plasma decay time with a "plasma sweeper", both sets of "plasma eater" plates were connected to the anticathode, and measurements were made as described in the appendix.

The charge density in the plasma column can be computed from the area under the decay curves for the "plasma eater", and for the "plasma sweeper". Some decay curves are shown in Fig. 4. Assuming that the "plasma eater" absorbs <u>half</u> the plasma in the column, and assuming that the column has a volume of 7 cm^3, the ion density is 1.1×10^{12} ions/cm^3. Assuming that the "plasma sweeper" absorbs <u>half</u> the ions in the plasma column, the ion density is 1.1×10^{12} ions/cm^3. Thus the "plasma eater" and the "plasma sweeper" give the same ion density.

The decay times for the "plasma eater" and the "plasma sweeper" are also shown in Fig. 4. The decay for the "plasma eater" is 30% longer than that for the "plasma sweeper." Perhaps, the sweeping field of the "plasma sweeper" penetrates the plasma to some extent. However, in view of the newness of the two devices, agreement on plasma decay times to within 30% can be considered quite good.

IV. SUMMARY

The "plasma eater" is a device which measures the rate of flow of a neutralized plasma. When tested on a mode I arc, it appeared to absorb or "eat" all the plasma entering it, and to yield a current equal to the number of electrons entering it per second. The device gave values for the plasma steady state flow rate, ion density, and plasma decay time, which agreed with the values found by a "plasma sweeper."

V. APPENDIX - "PLASMA SWEEPER"

Measurements are made with a "plasma sweeper" by turning off the source of plasma, then sweeping out the plasma along line of magnetic flux and collecting it. The schematic of a "plasma sweeper" is shown in Fig. 5 for a mode I reflex arc. Instead of electrically insulating the anticathode electrode, it is connected to ground through a resistor and a battery. However, the voltage of the battery is so chosen that the anticathode electrode draws no net current; effectively, it is still floating. In practice, the correct battery voltage is a few volts greater than the cathode potential.

Measurements are made by shorting the cathode to ground by a fast closing switch. In our measurements a relay with mercury wetted contacts was used. Since the anticathode bias remains, a sheath forms which reflects the electrons. There is a flow of plasma ions across the sheath to the anticathode. The current to the anticathode as a function of time is recorded as a voltage drop across the resistance, R_2, in the anticathode circuit. Subsequent investigations suggest that the ions migrate both ways along the plasma column[3]. Thus the total positive charge contained in a uniform plasma column is obtained by integrating and doubling the area under the current vs. time decay curve. Dividing the total positive charge by the volume of the plasma column yields an average value for the ion charge per unit volume.

Possibly, the "plasma sweeper" may yield both the steady state rate of plasma flow out of the ends of the column, and the ion temperature. Subsequent investigations[3] suggest that the rate of ion flow is not affected by the sweeping field. Apparently, the sweeping field appears only across short sheaths at the ends of the plasma column. The peak current observed with the "plasma sweeper" probably yields the steady state loss of plasma out of the column ends. The shape of the current vs. time decay curve, under certain assumptions[2], gives the ion temperature.

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[2] Thermonuclear Division Semiannual Report for Period Ending October, 1961, in press.

[3] Not yet published.

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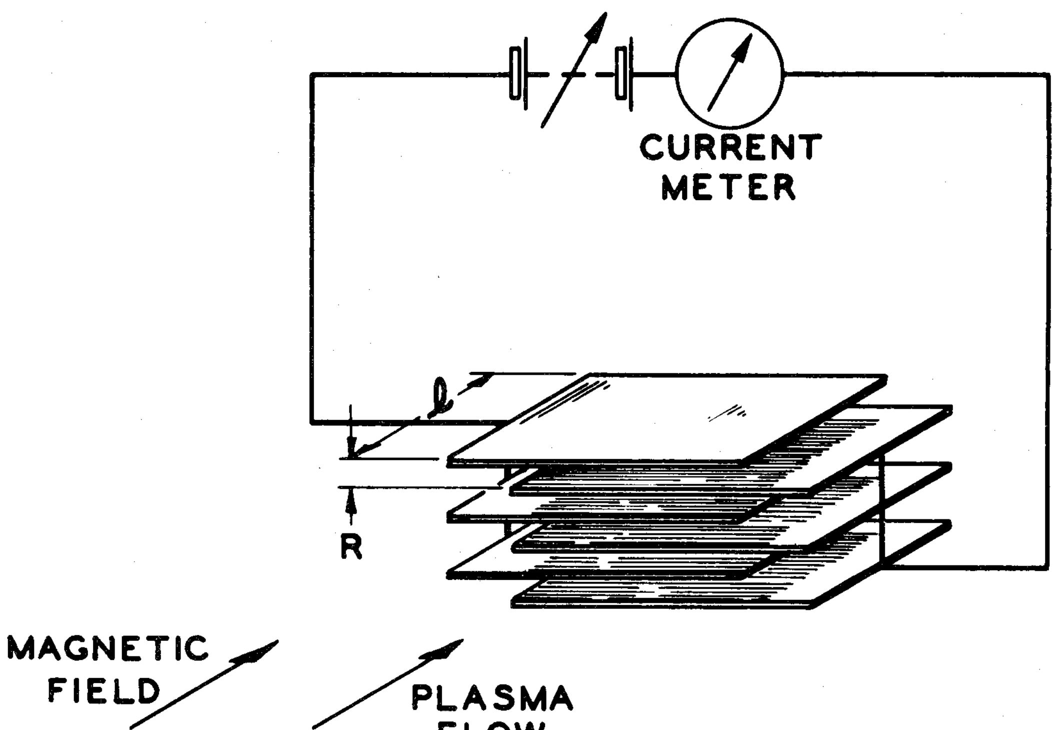

Fig. 1. Schematic of Plasma Eater.

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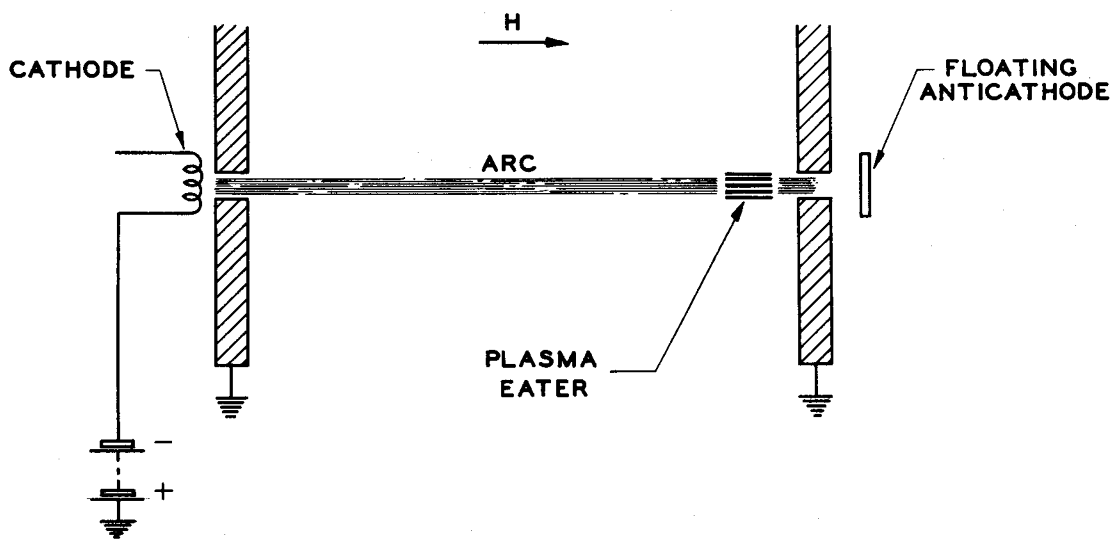

Fig. 2. Plasma Eater Tested in Mode I Arc.

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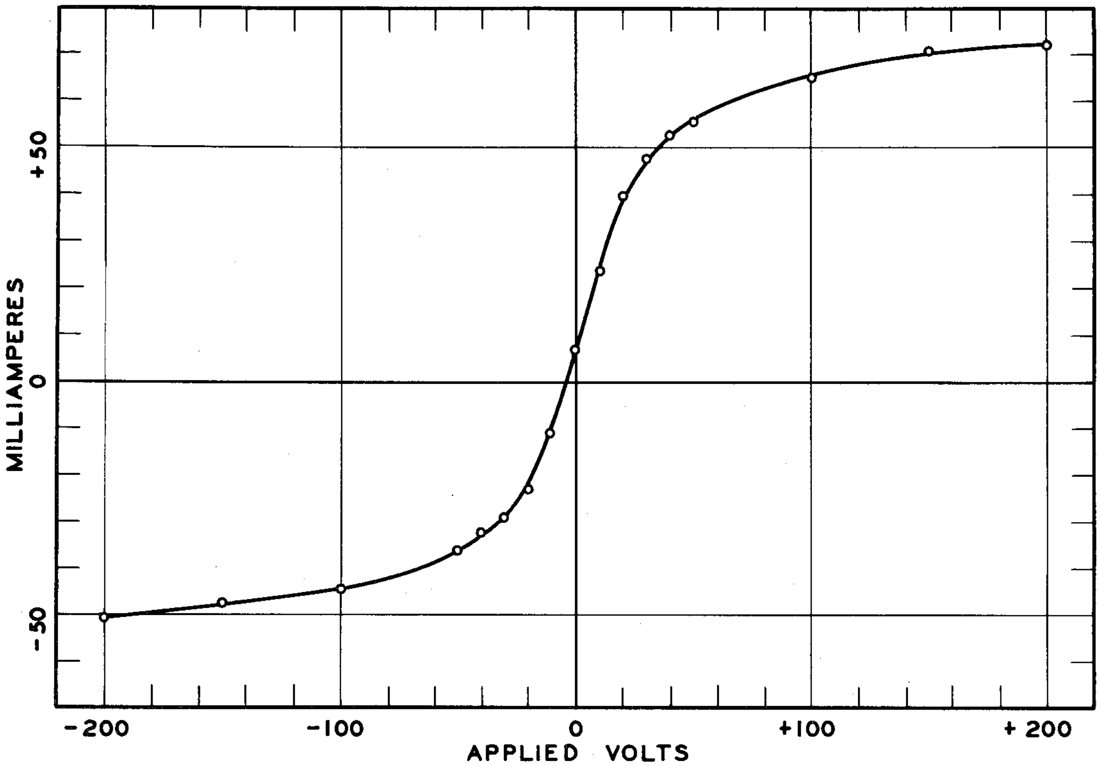

Fig. 3. Characteristic Curve of Plasma Eater.

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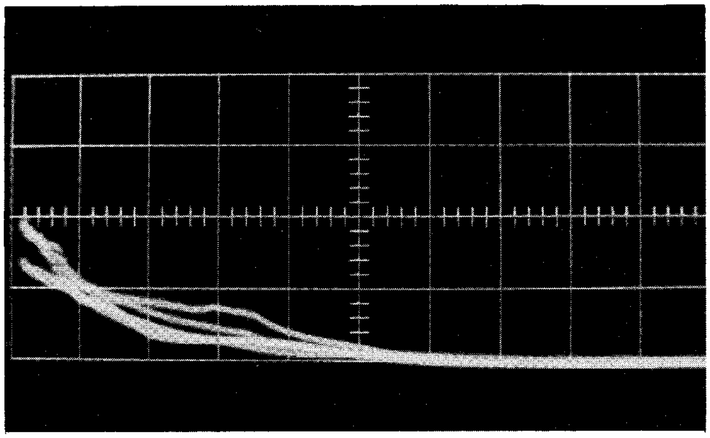
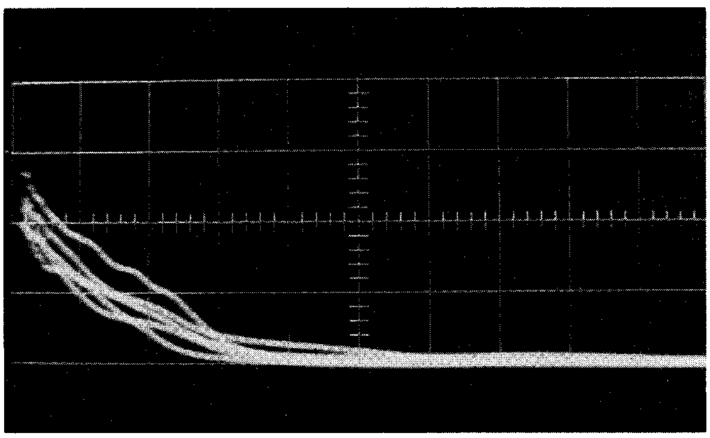


PLASMA EATER



PLASMA SWEEPER

Fig. 4. Observed Decay of Plasma Current. Five traces were recorded on each picture. Horizontal scale – 10 microseconds per large division. Vertical scale – 2 volts per large division. A 96 ohm load resistor was used.

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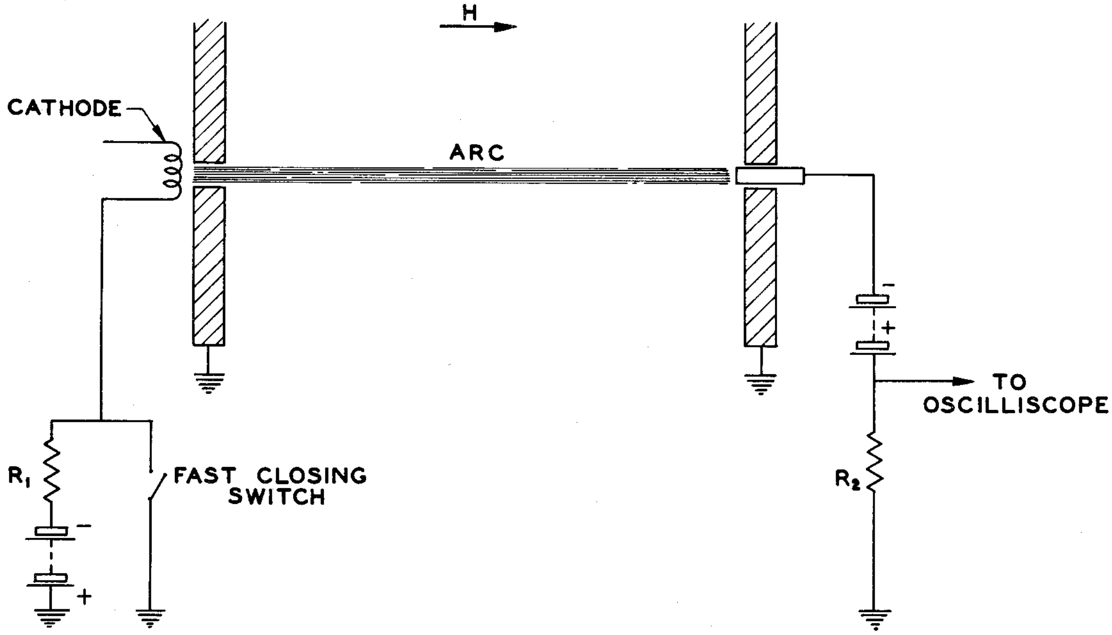

Fig. 5. Plasma Sweeper Arrangement on a Mode I Arc.

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