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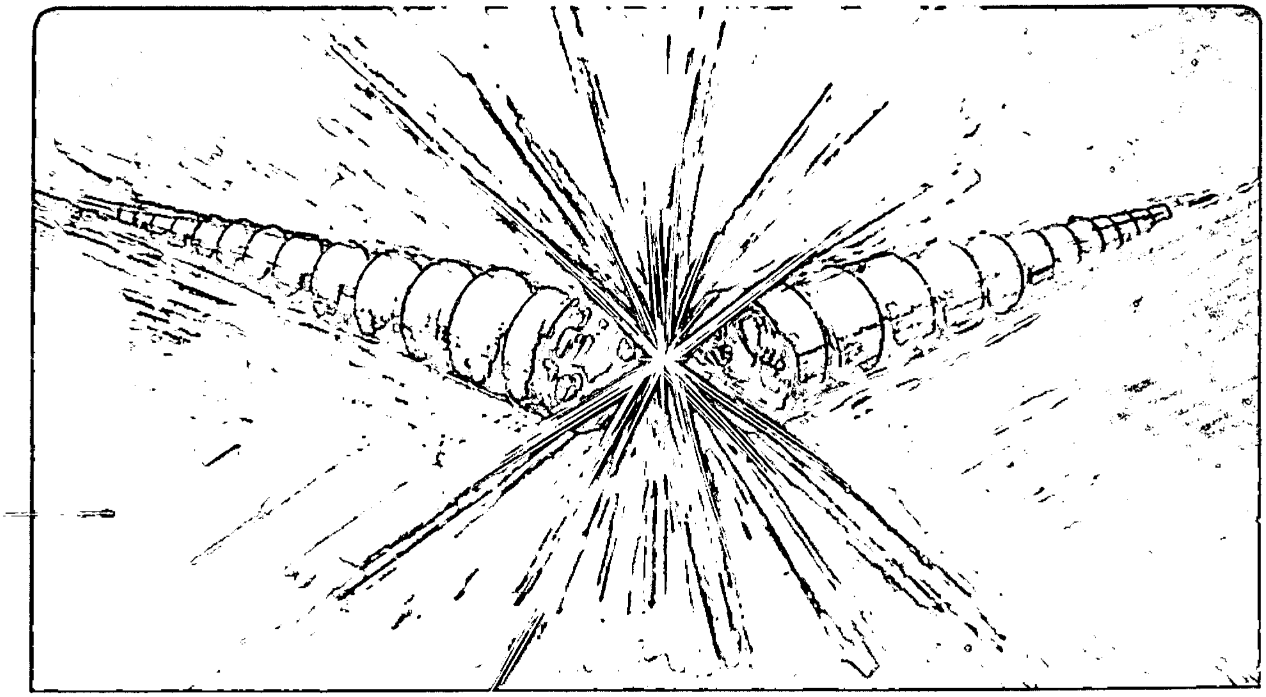

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Development of an Advanced "Volume" H$^-$ Source for Neutral Beam Application*

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Abstract

Based on recent experimental results made on the large and small multicusp volume H$^-$ sources, a new multicusp source has been designed to generate high brightness H$^-$ or D$^-$ beams for high duty factor or dc operations. Cesium will be introduced into the source plasma to enhance the H$^-$ output current. Arrangements for reducing the electrons as well as capturing them in the preaccelerator electrodes will be incorporated into the new source geometry.

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Introduction

Future neutral beam systems will require ion sources that can deliver high brightness H$^-$ or D$^-$ beams for high duty factor or dc operation. Recently, it was found that the addition of cesium to a hydrogen discharge can enhance the H$^-$ output current by more than a factor of five together with a substantial reduction in the electron-to-H$^-$ ratio in the extracted beam.[1] Based on these results and the observations made on a large volume H$^-$ source, we have designed a new multicusp source which should be able to operate in steady-state with H$^-$ beam current as high as 150 mA. Several new techniques will be employed to reduce the output electrons and to capture them in one of the pre-accelerator electrodes before they arrive at ground potential. This article discusses the design and some characteristics of this new H$^-$ source.

I. Ion Source Design

In the last several years, extensive studies on the available H$^-$ current density and beam emittance have been made on both the large (20 cm diam) and the small (7.5 cm diam) volume H$^-$ sources.[1-3] From these measurements, we concluded that a total H$^-$ current of 150 mA could be obtained from a cesiated volume source with an extraction aperture of 2 cm diameter. The source is expected to operate with a filling pressure of 10 mT and with an electron to H$^-$ current ratio of approximately five. In order to achieve these goals, a new multicusp ion source together with a pre-accelerator have been designed and are now under fabrication.

A. Source geometry

A schematic drawing of the ion source and the pre-accelerator is shown in Fig. 1. The source chamber is a thin-walled (4-mm-thick) copper cylinder (10 cm diam by 10 cm long) surrounded by 20 columns of samarium-cobalt magnets which form a longitudinal linecusp configuration for primary electron and plasma confinement. The magnets are enclosed by an outer anodized aluminum cylinder, with the cooling water circulating around the source between the magnets and the inner housing wall. The back flange has four rows of magnets cooled by drilled water passages. The source is designed for steady state operation with a power input of 36 kW.

Figure 2 shows a cross-sectional plot of the magnetic field distribution. Magnetic field calculations have been solved with a computer code[4] which uses the symmetry of the cylindrical line-cusp geometry. For infinitely long magnets with no steel or external currents present, the B-field can be written as:

$$B(x,y) = -\nabla\left[\frac{\mu_o}{4\pi}\iint\frac{M_x\cdot(x-x') + M_y\cdot(y-y')}{(x-x')^2+(y-y')^2}dx'\,dy'\right]$$

where M_x and M_y refer to the magnetization of the magnets. Using this equation, the magnetic field intensity and field lines can be evaluated. It can be seen that the discharge volume with magnetic field less than 30 G is approximately 6 cm diam. In order to achieve a quiescent discharge, the cathode must be placed inside this central "field-free" region.

A thin molybdenum liner covers the entire inner surface of the source chamber. Preliminary experimental results showed that the negative ion output current was about the same for liner temperature between 200 and 800°C. In the new source, cesium vapor will be introduced into the discharge through a transfer tube from an external oven. The temperatures of the oven and the transfer tube can be independently regulated by adjusting the current of the heating elements. The anticipated operating temperature of the cesium injector components is about 300° C.

The back flange of the source contains all the required feedthroughs and ports. These are the cesium injection, the gas inlet, and the pressure gauge ports as well as the cathode and four thermocouple feedthroughs.

B. Extraction Aperture Geometry

In the 7.5-cm-diam multicusp source, it has been observed that as the extraction aperture size increased, the noise level of the accelerated H^- beam became very large. The cause of this beam fluctuation is not understood. Presumably, it is related to the stability of the plasma sheath at the extraction surface.

Large beam oscillations should be avoided because they can generate emittance growth.[5] Experimental investigation showed that the use of an insert with many small apertures in the extraction hole greatly improved the quiescence of the H^- beam. This multi-aperture arrangement will be applied to the new ion source by means of removable inserts.

The scaling of H^- ion current as a function of extraction area is of great interest when considering ion sources for accelerator applications. To address this issue, three multi-aperture inserts with different extraction areas and aperture diameters have been tested in the 7.5-cm-diam source. One insert contained seven apertures (each of 0.7-mm-diam) inside a 2.26-mm-diam circle. The second contained seven apertures (each of 1.04-mm-diam) inside a 3.2-mm-diam circle, and the third contained 19 apertures (each of 0.9-mm-diam) within a circle of 5-mm-diam circle. All these three multi-aperture configurations provided approximately the same H^- current density ($J^- > 1$ A/cm^2) for the same discharge power and pressure in a cesium-hydrogen discharge. This observation seems to indicate that the extractable H^- current density does not depend on the over-all diameter of the extraction hole if cesium is added to the hydrogen plasma, provided that multi-small-apertures are being used.

Low energy electrons can reach the extraction region by crossing the magnetic field with positive ions. These electrons can be suppressed by applying a positive bias on the plasma electrode. There are also electrons trapped on the field lines between the filter rods. An effective way of reducing the trapped electrons was found by installing a collar electrode around the extraction aperture.

Collars with different lengths and diameter have been tested in the 7.5-cm-diam source for an extraction aperture of 5-mm-diam in pure hydrogen operation. It can be seen from Figs. 3 and 4 that collars with lengths of 3, 6 and 9 mm produce about the same H^- output as in the case of no collar. When the collar length exceeds 12 mm, the H^- output current drops. On the other hand, the extracted electron current decreases linearly with collar length. In order to optimize the H^- output and the e/H^- ratio, the source should be operated with the proper collar length which in this case is 9 mm long. In this collar configuration, the electron current is reduced by a factor of two compared with the case of no collar and with no degradation in H^- current.

The effect of using a collar in the 7.5-cm-diam source for a cesium-hydrogen discharge is illustrated in Fig. 5. Source operation with pure hydrogen produced a high e/H^- ratio that increased with discharge current. Addition of cesium to the discharge, however, reduced the ratio from 120 to 30 at high discharge power. If a 9-mm-long collar was used at the extraction aperture in addition to cesium, the ratio was further reduced to approximately 10. The H^- current in this geometry was still a factor of three larger than the case with no collar and cesium (Fig. 6). We plan to optimize the collar geometry in the new H^- source for cesium-hydrogen operation.

C. Optimization of Filter Geometry

The new multicusp source is equipped with two pairs of movable, water-cooled filter rods. The strength of the magnetic field can be changed by adjusting the filter rod separations. In a previous study with pure hydrogen discharges in the 7.5-cm-diam source, it was found that an optimum filter separation (~5.2 cm) exists for the H^- current. The extracted electron current, however, increases monotonically with the filter separation.

When the source was operated with an admixture of cesium and hydrogen, the dependence of the extracted electron current on the filter separation was similar to the case of a pure hydrogen plasma. However, no optimum filter separation has been observed for the H^- current. The larger the filter separation, the higher was the extractable H^- current.

A plot of the e/H^- ratio as a function of filter separation for a discharge power of 160 V, 300 A is shown in Fig. 7. Indeed, the e/H^- ratio is greatly reduced with the addition of cesium to the source discharge. As the filter separation is varied from 6 to 3 cm, the ratio is reduced further from 20 to 3 while the H^- current drops by approximately a factor of two. The same kind of filter optimization process will be conducted in the new H^- source.

II. Pre-accelerator Design

The design of the pre-accelerator for the new H^- source is based on an accel-decel-accel scheme. Figure 8 is a schematic diagram of the pre-accelerator calculation showing the H^- ion and electron trajectories. It can be seen that the extracted electrons are captured on the middle electrodes after they are deflected by magnets. Both 2-D and 3-D computer codes are used to calculate the particle trajectories. The new pre-accelerator corrects some of the defects of the previous pre-accelerator designed for the large (20-cm-diam) volume H^- source. It contains the following features: 1) small emittance growth from the source to the accelerator exit; 2) a trap for extracted electrons which is located far enough from the source so that the magnetic field of the movable electron-trap magnets will not perturb the motion of the H^- ions at the source exit; 3) low heat load on the surface of the trap; and 4) easy adjustment for variable energy and current.

The pre-accelerator contains seven electrically independent electrodes. Special care was taken in the design of these electrodes to minimize the collection of cesium on surfaces subjected to high electrical gradients so as to assure adequate voltage holding. Cesium accumulation is to be controlled by maintaining selected electrodes at elevated temperatures either by direct resistive heating or indirectly through radiation from adjacent surfaces.

A second design consideration was maximizing the cross-section of the pumping passages between electrodes so as to minimize stripping of the H^- beam by background gas. If the source chamber pressure is 10 mTorr, Monte-Carlo code computation shows that approximately 45% of the H^- beam will be stripped before it emerges from the pre-accelerator. Thus, it is essential to operate the source at a pressure as low as possible. Addition of cesium to the hydrogen discharge indeed can reduce the optimum source pressure substantially. The new H^- source together with the pre-accelerator will be tested in 1990. Results of the experiment will be reported in the near future.

Acknowledgments

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Figure Captions

Fig. 1 Schematic diagram of the H^- ion source and the pre-accelerator.

Fig. 2 A computer plot of the magnetic field produced by the multicusp magnets surrounding the source chamber. The upper half plot shows the field lines (10, 30, 100, 300 G-cm), and the lower half plot shows the field intensity contours (10, 30, 100, 300, 1 kG).

Fig. 3 H^- output current as a function of discharge current for different collar lengths. Diameter of the collar is maintained at 11.6 mm.

Fig. 4 Extracted electron current as a function of discharge current for different collar lengths. Diameter of the collar is maintained at 11.6 mm.

Fig. 5 A plot of the e/H^- ratio as a function of discharge current for three different discharge conditions.

Fig. 6 A plot of the H^- output current as a function of discharge current for three different discharge conditions.

Fig. 7 A plot of the e/H^- ratio vs filter rod separation when cesium is added to the source.

Fig. 8 Schematic diagram of the pre-accelerator showing the H^- and electron trajectories.

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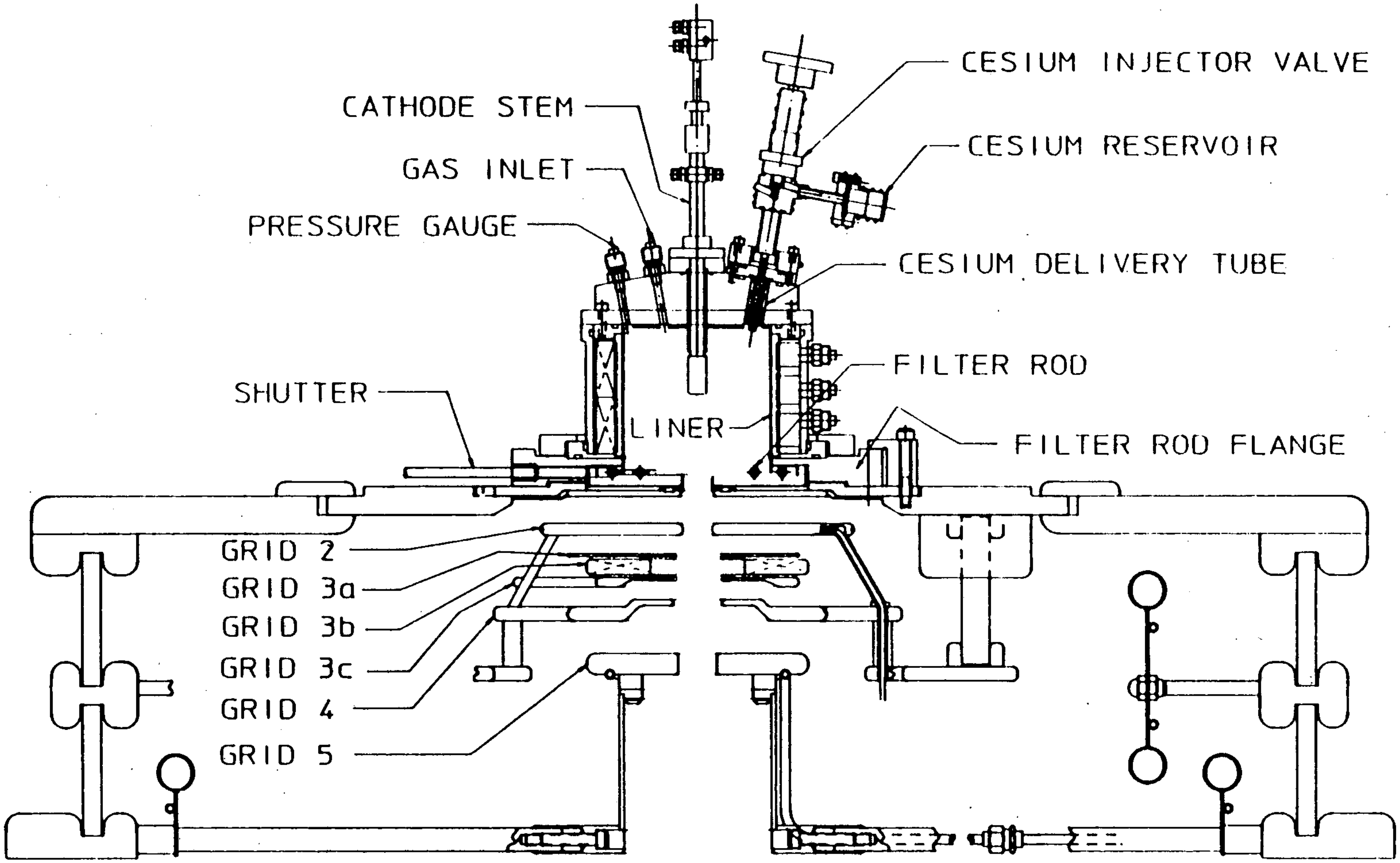

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Figure 1

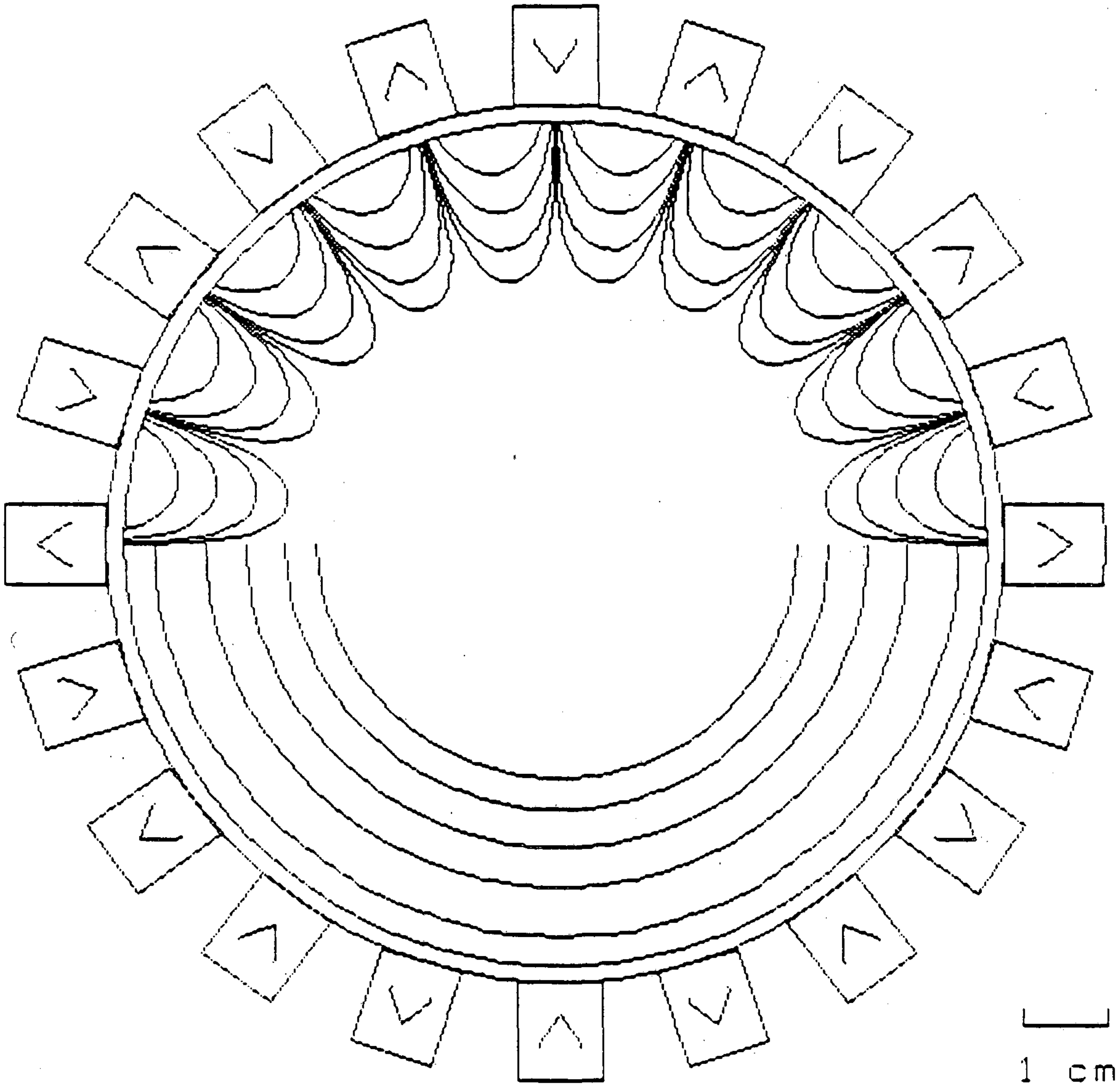

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Figure 2

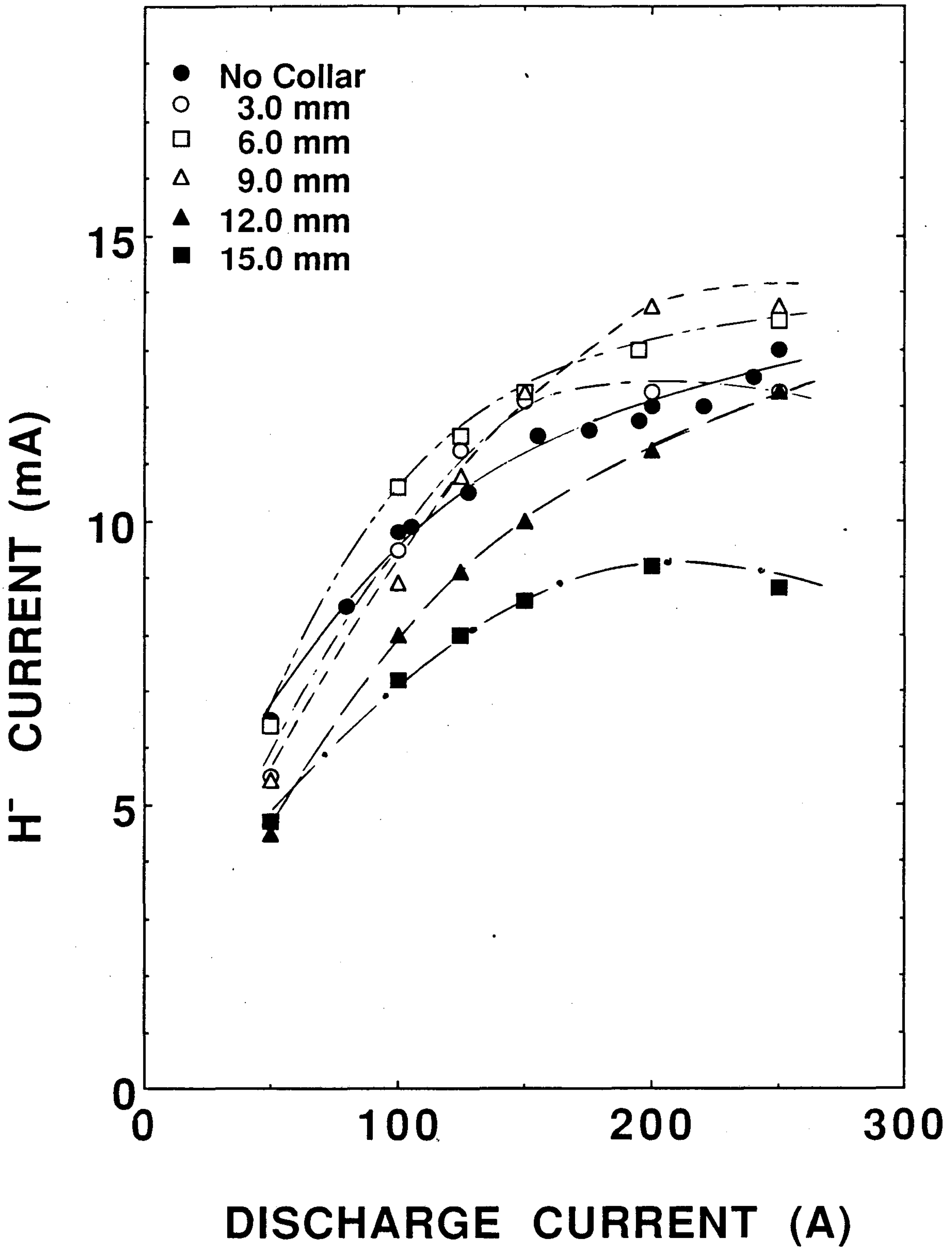

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Figure 3

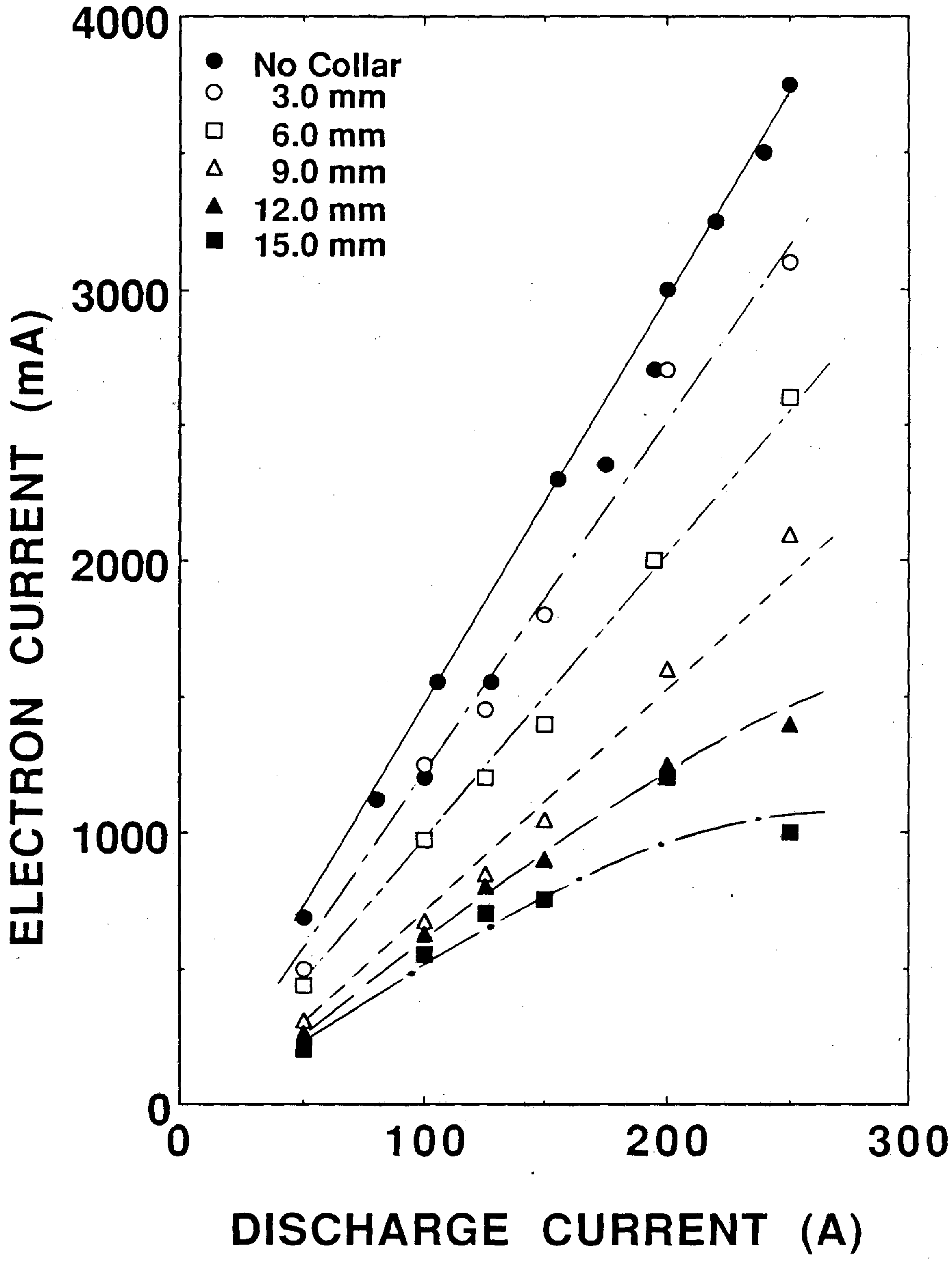

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Figure 4

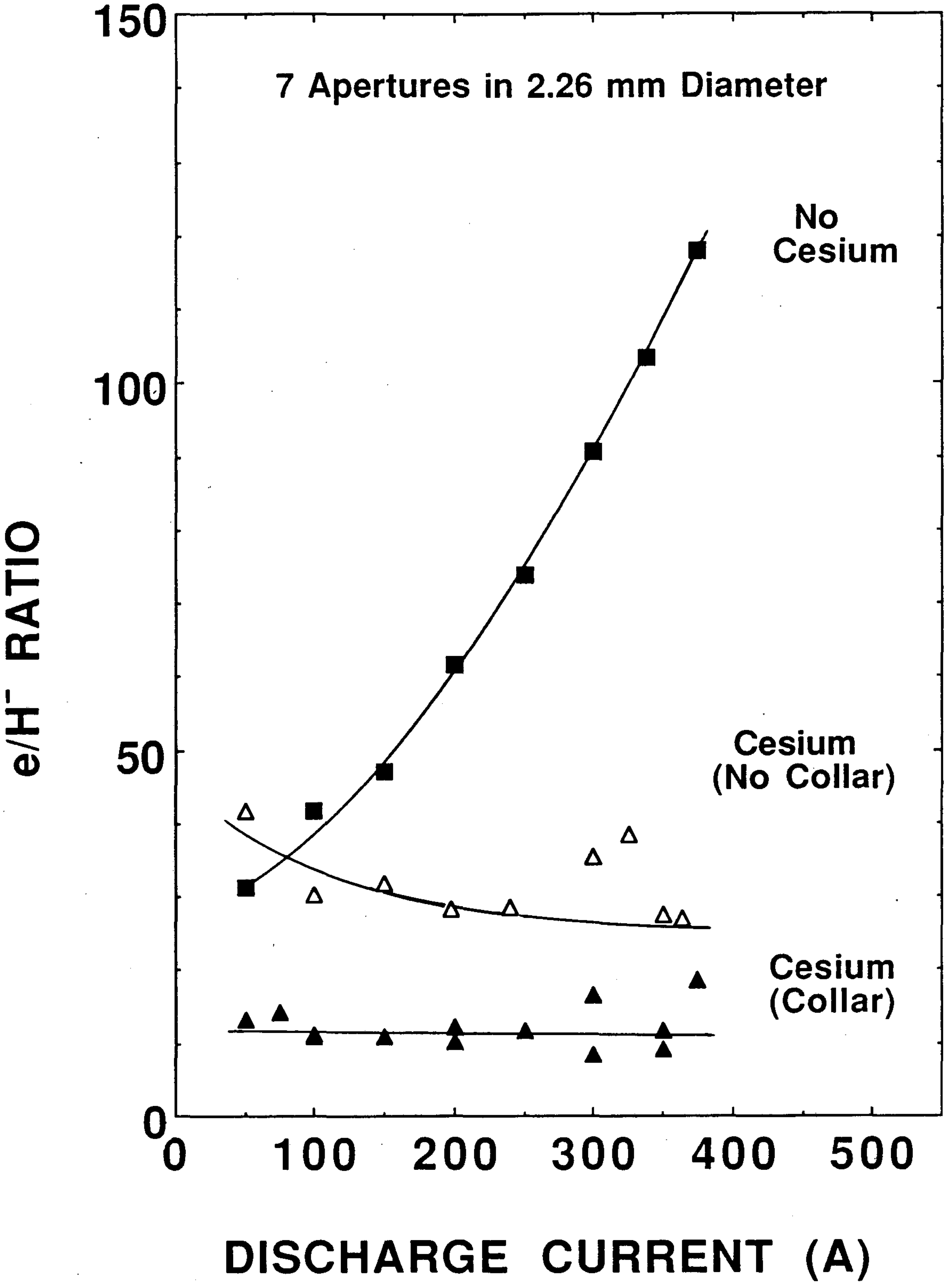

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Figure 5

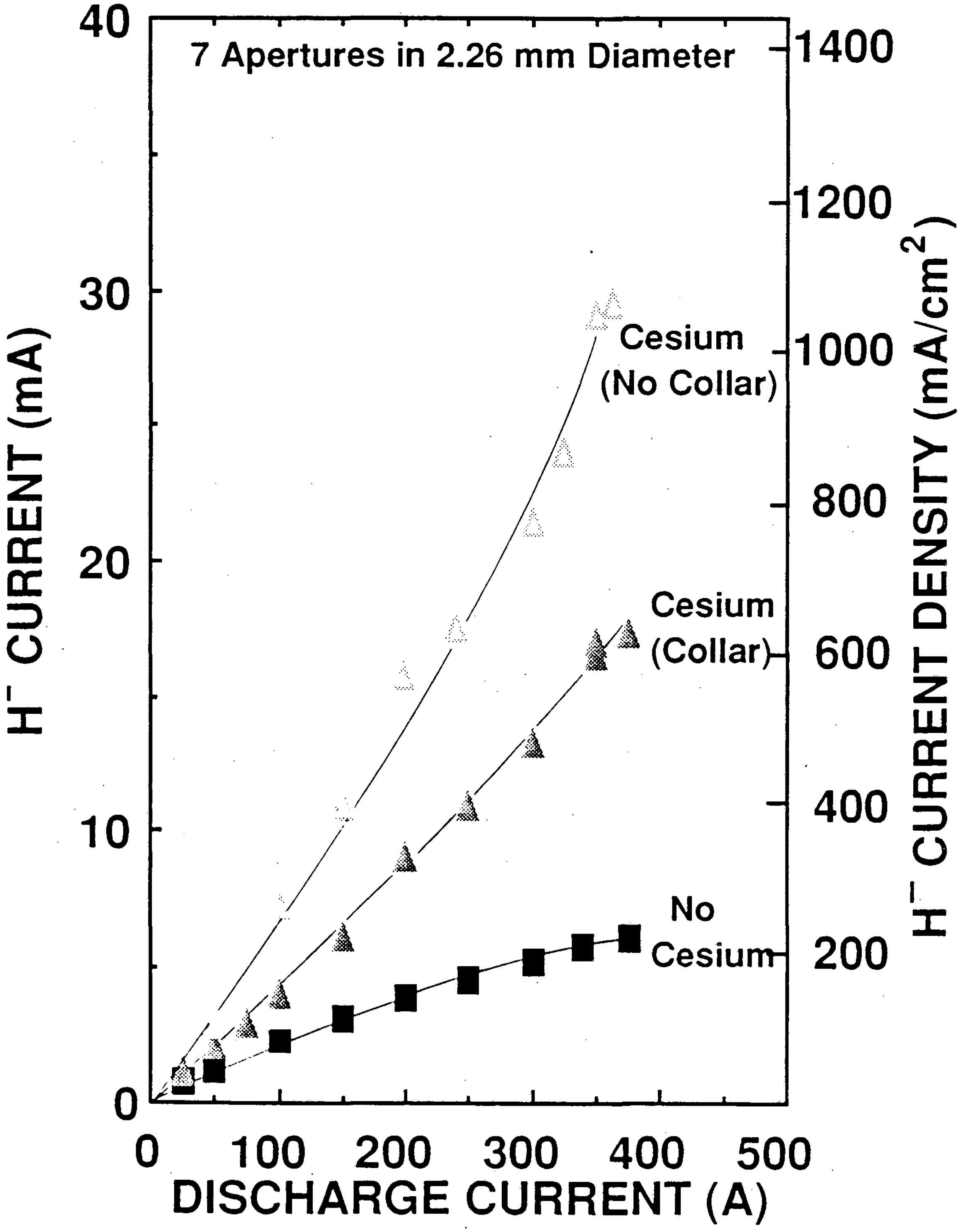

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Figure 6

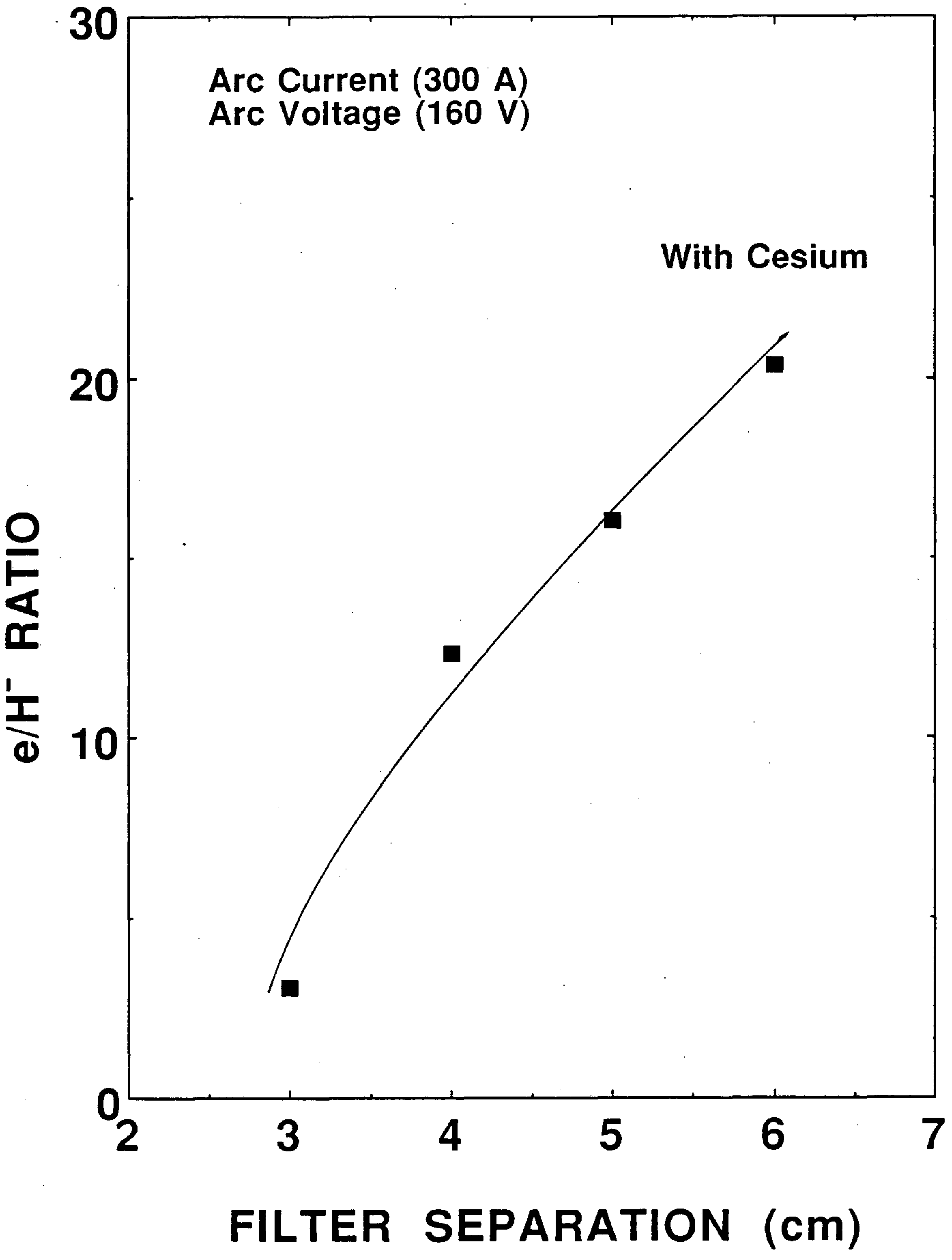

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Figure 7

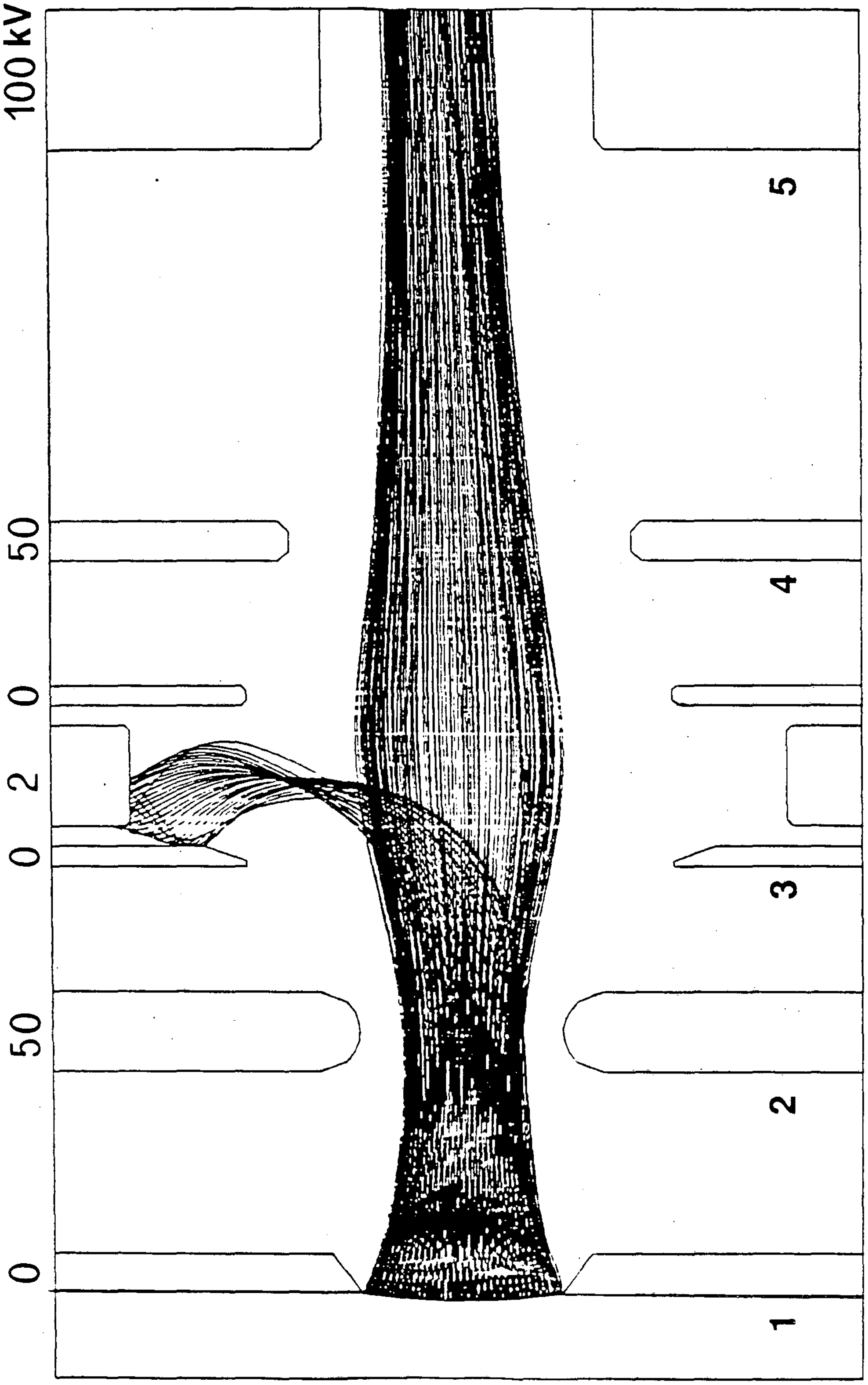

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Figure 8

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