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Journal

Review of scientific instruments, 61(1)

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Publication Date

2017-12-13



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

To be presented at the International Conference on Ion Sources,
Berkeley, CA, July 10-14, 1989, and to be published in the
Review of Scientific Instruments

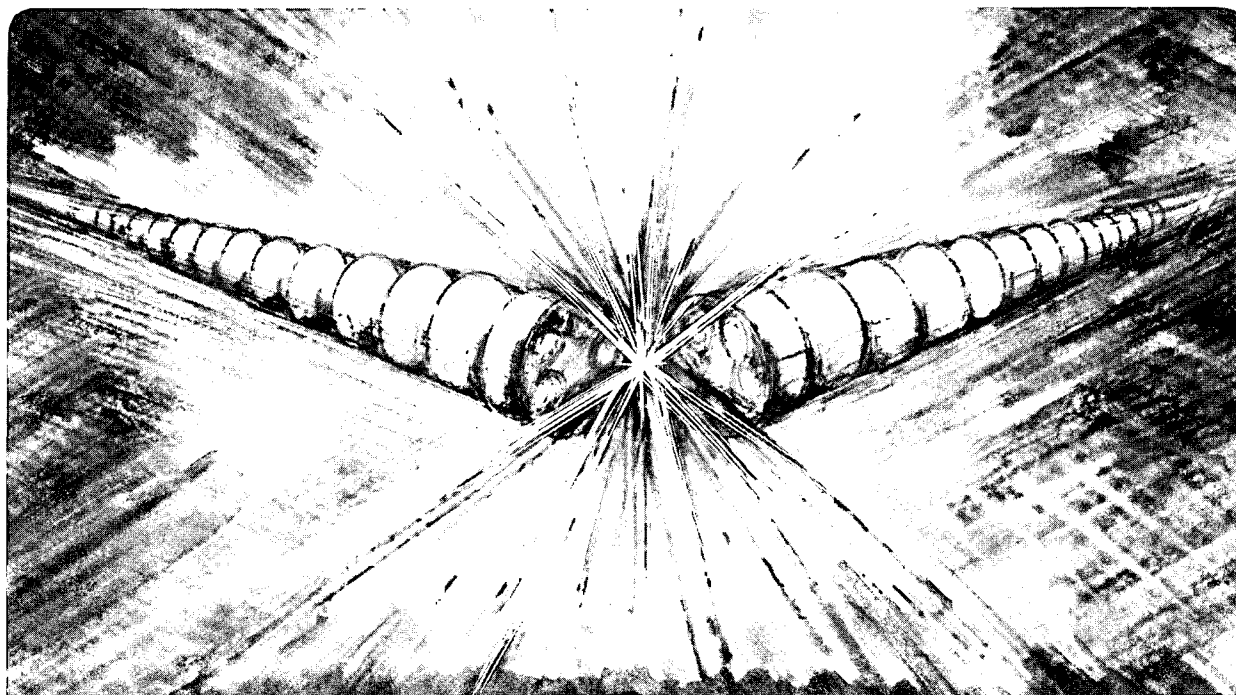
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June 1989

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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A High Charge State Multicusp Ion Source*

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Abstract

Attempts have been made to generate high charge state ion beams by employing a multicusp plasma source. Three experimental investigations have been performed at LBL and at GSI to study the charge state distributions and the emittance of the extracted beam. Results demonstrate that charge state as high as +7 can be obtained with argon or xenon plasmas. The brightness of a 11 mA xenon ion beam is found to be $26 \text{ A}/(\pi\text{-mm-mrad})^2$.

* Work is supported by a NATO Research Grant, by GSI Darmstadt, and by the Director, Office of Energy Research of the US Department of Energy under Contract No. DE-AC03-76SF00098.

Introduction

High charge state ion beams are commonly used in atomic and nuclear physics experiments. Multiply charged ions are normally produced in a ECR source or in a Penning discharge source. Recently, the use of a high charge state plasma as a neutralizer for stripping energetic H^+ or D^+ ions has been proposed.¹ Such high charge state neutralizers offer high optimum neutralization efficiency (~85%) as compared to a gas target (~50%), and considerably reduced target thickness. For this application, a large volume of uniform argon or xenon plasma with average charge state of four or higher is required.

It has been demonstrated that permanent magnets can be used to improve the density and uniformity of dc discharge plasmas.² Such multicusp systems can confine primary electrons very efficiently³ and therefore the electrical and gas efficiencies of these devices are high. Since the magnetic fields are localized near the chamber wall, large volumes of uniform and high density plasmas can be obtained at low pressure and thus favorable for the formation of high charge state ions. Multicusp sources are being developed at Lawrence Berkeley Laboratory (LBL) and at GSI Darmstadt for the production of high brightness multiply-charged ion beams. This paper summarized the collaborative study performed between these two laboratories on this type of ion source.

The experiment can be divided into three stages. A small multicusp source was initially tested at LBL for high charge state ion production. A similar ion source was then fabricated at GSI and the extracted beam

emittance was measured. Finally, a larger multicusp source was designed and tested at LBL. This source was operated in a pulsed mode with different types of cathode. Both the extractable current density and the charge state distribution of a xenon plasma were measured for a discharge voltage of 400 V and a discharge current of 100 A.

I. Small Multicusp Source Experiment at LBL

A "closed" multicusp plasma generator (15-cm-diam by 20-cm-long) has been fabricated from a copper cylinder which is surrounded externally by eight columns of samarium-cobalt magnets to form a longitudinal linecusp configuration for primary electron and plasma confinement. Three rows of the same size magnets were mounted on the end flange to complete the line cusps. Water channels were drilled in the chamber wall so as to provide adequate cooling for the magnets during discharge operations. A photograph of the ion source assembly is shown in Fig. 1.

The open end of the source chamber is enclosed by a two-electrode acceleration system. The first or plasma electrode contains a single 1-mm-diam aperture. Eight samarium-cobalt magnets are installed radially on the downstream side of the plasma electrode and arranged so as to provide continuous line-cusps to the side-wall magnet columns. In this arrangement, the plasma is enclosed by the cusp magnetic fields on all sides. Only a small magnetic field free region of approximately 2 cm diameter exists near the extraction aperture.

During the experiment, a steady-state argon plasma is produced by primary electrons emitted from four 0.5-mm-diam tungsten filaments

(mounted on the end flange). The entire source chamber serves as the anode for the discharge. In normal operation, the argon pressure inside the source was maintained at $\sim 5 \times 10^{-4}$ Torr. A small positive ion beam was extracted from the source and this beamlet was analyzed by a small magnetic deflection spectrometer located just outside the extractor. Figure 2 shows a plot of the charge state distribution for a steady-state argon discharge. It can be seen that the source is capable of producing argon ions with charge state as high as +7. The highest discharge power employed in this measurement was 250 V, 25 A.

II. Testing of the MUCIS Source at GSI

A new multicusp ion source (MUCIS) was designed and built at GSI with all the basic features of the LBL multicusp source described in Sec. I. The source (20-cm-diam by 20-cm-long) is surrounded by 10 columns of permanent magnets. There are four parallel magnets on the back flange which provide continuity of the cusp fields on the side wall. In addition, ten magnets are installed on the extraction side of the plasma electrode. A schematic diagram of MUCIS is illustrated in Fig. 3. This GSI source is made entirely from stainless-steel and has cooling channels below every magnet. Two cathode feed-throughs are inserted in between two adjacent magnets in the back flange, each one bearing two tungsten filaments.

The GSI source operates very reliably with discharge voltages as high as 250 V. Ion beams were extracted by a 13-hole (total area = 1 cm^2) accel/decel system (essentially a copy of the GSI CHORDIS⁴ design). For emittance measurements, a 10-mm-diam single aperture system was

used. In view of an application at the GSI accelerator, the discharge was pulsed with 10% duty factor, at 50 Hz repetition rate.

In comparison to the existing GSI reflex-multicusp CHORDIS source, MUCIS needs about five times less gas pressure, presumably due to improved plasma confinement. The charge state spectra for xenon are comparable for both sources if CHORDIS is operated at 390 V and MUCIS at 250 V discharge voltage. When the source is operated with a discharge power of 250 V, 37 A and at 1.5×10^{-3} Torr xenon pressure, the charge state distribution for xenon ions (+1 through +6) is: 36.4 / 36.4 / 19.1 / 5.8 / 2.0 / 0.3% (electrical peak heights).

Figure 4 shows an emittance plot for an accelerated xenon beam. The absolute (un-normalized) emittance of an 11 mA xenon beam produced by the 10-mm-diam single aperture extraction system at 25 kV is 32.5π -mm-mrad. The correspondent (normalized) beam brightness is $26 \text{ A}/(\pi\text{-mm-mrad})^2$ which is equal to the best brightness values found with CHORDIS and is also a factor of ten higher than that of the "Nielson Source".⁵ The brightness definition used here is: $B_n = I/(\epsilon_n)^2$ where I is the accelerated current and ϵ_n is the normalized emittance.

III. Testing of a Larger Multicusp Source at LBL

In general, the larger the multicusp plasma generator, the lower the gas pressure that one can operate. For a high charge state ion source, low operating pressure can reduce the recombination rate of the multiply-charged ions. With the experience we obtained from the initial testings at

LBL and GSI, a larger (25-cm-diam by 25-cm-long) multicusp source was fabricated at LBL (Fig. 5). Construction of this new source is similar to the smaller multicusp source described in Sec. I.

The large multicusp source has adequate cooling for long pulse or steady-state operation. Instead of tungsten filaments, a coaxial lanthanum hexaboride LaB_6 cathode⁶ (Fig. 6) was employed. This directly-heated LaB_6 cathode requires much less heating power and it operates at a much lower temperature than regular tungsten filaments. As a result, the contamination of the xenon plasma by metallic ions coming from the tungsten filaments is reduced.

With this new prototype source together with an electronic switch, xenon ion beams have been extracted from a 1-mm-diam aperture in short pulsed mode (~ 2 ms) operations. The charge state distribution of the accelerated beam was then analyzed by a magnetic deflection mass spectrometer. Xenon ions with charge states as high as +7 and total ion current densities higher than 63 mA/cm^2 were obtained with a discharge of 400 V, 100 A. This result together with the emittance measurements performed at GSI clearly demonstrate that the "closed" multicusp source geometry is capable of generating high brightness ion beams with modest charge state. However, additional experimental work is needed in order to extend the charge state to values higher than +7. If this is successful, the multicusp source will become very useful for accelerator, ion implantation and neutral beam applications.

Acknowledgments

We would like to thank M. D. Williams, C. Hauck, D. Moussa, and J. DeVries for technical assistance. This work is supported by a NATO Research Grant, by GSI Darmstadt, and by the Director, Office of Energy Research of the US Department of Energy under Contract No. DE-AC03-76SF00098.

Figure Captions

- Fig. 1 A picture showing the LBL multicusp source assembly.
- Fig. 2 Charge state distribution of an extracted argon ion beam.
- Fig. 3 A schematic showing the GSI multicusp source (MUCIS). The source chamber **A** is the anode, **C** is the filament cathode, and **EX** is the accel/decel extraction system.
- Fig. 4 The emittance plot for a 25 keV xenon ion beam (total beam current is 11 mA and charge state of the ions is mostly +1) obtained from a 10-mm-diam single aperture of MUCIS. The normalized emittance for this case is 0.0207π -mm-mrad.
- Fig. 5 A picture showing the large LBL multiply-charged ion source.
- Fig. 6 A directly-heated, coaxial lanthanum hexaboride LaB_6 cathode.

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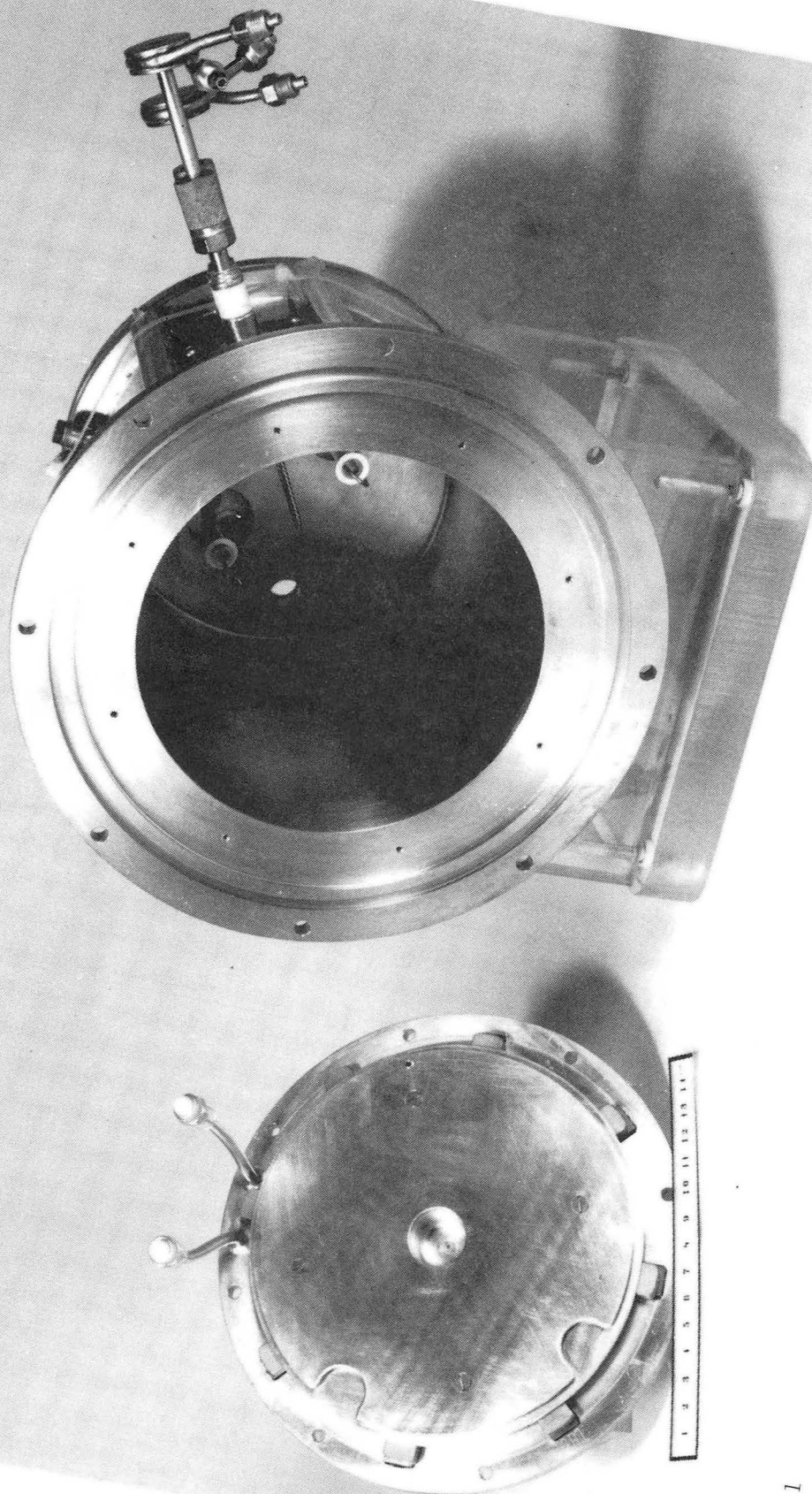


Figure 1

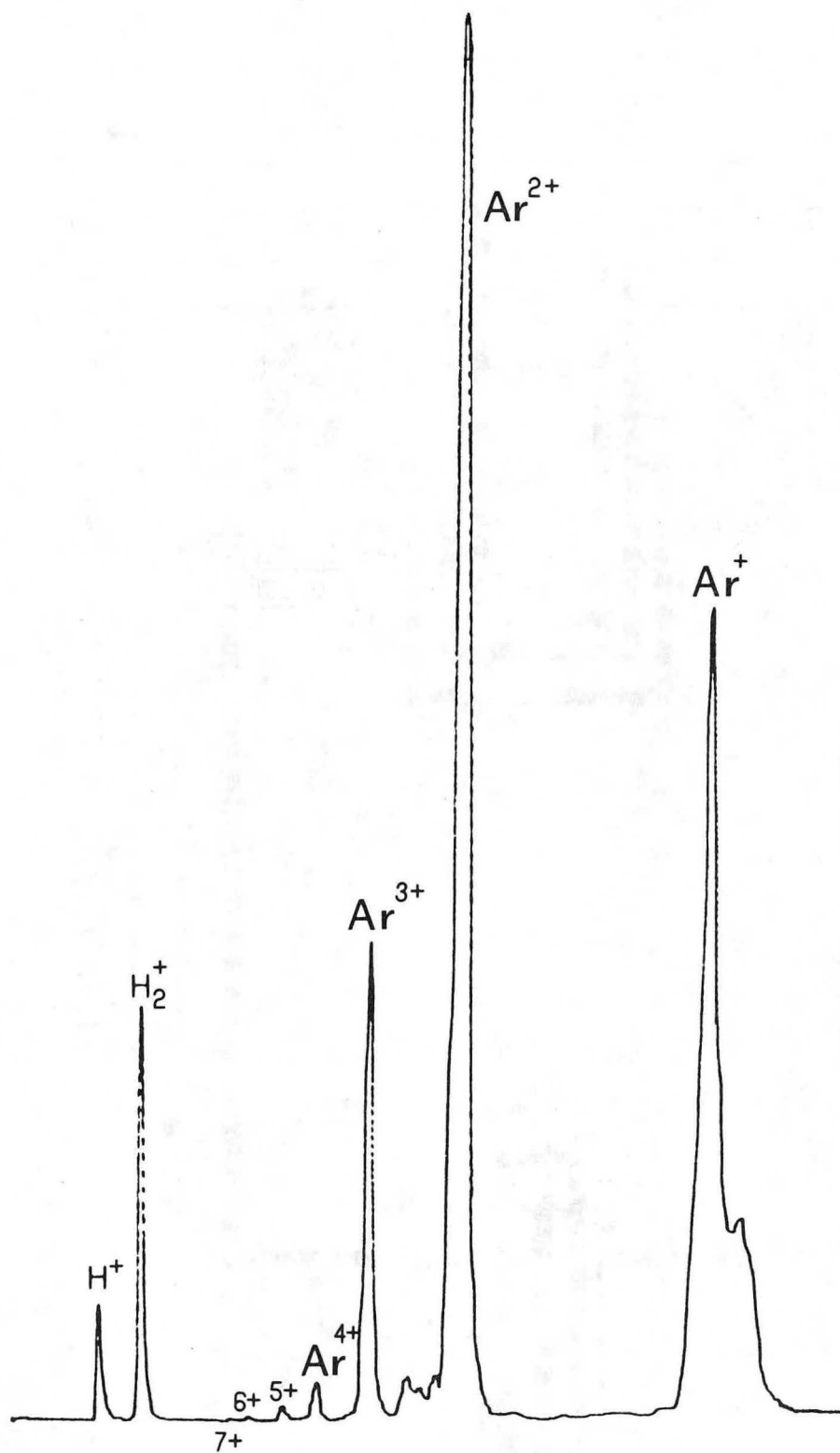
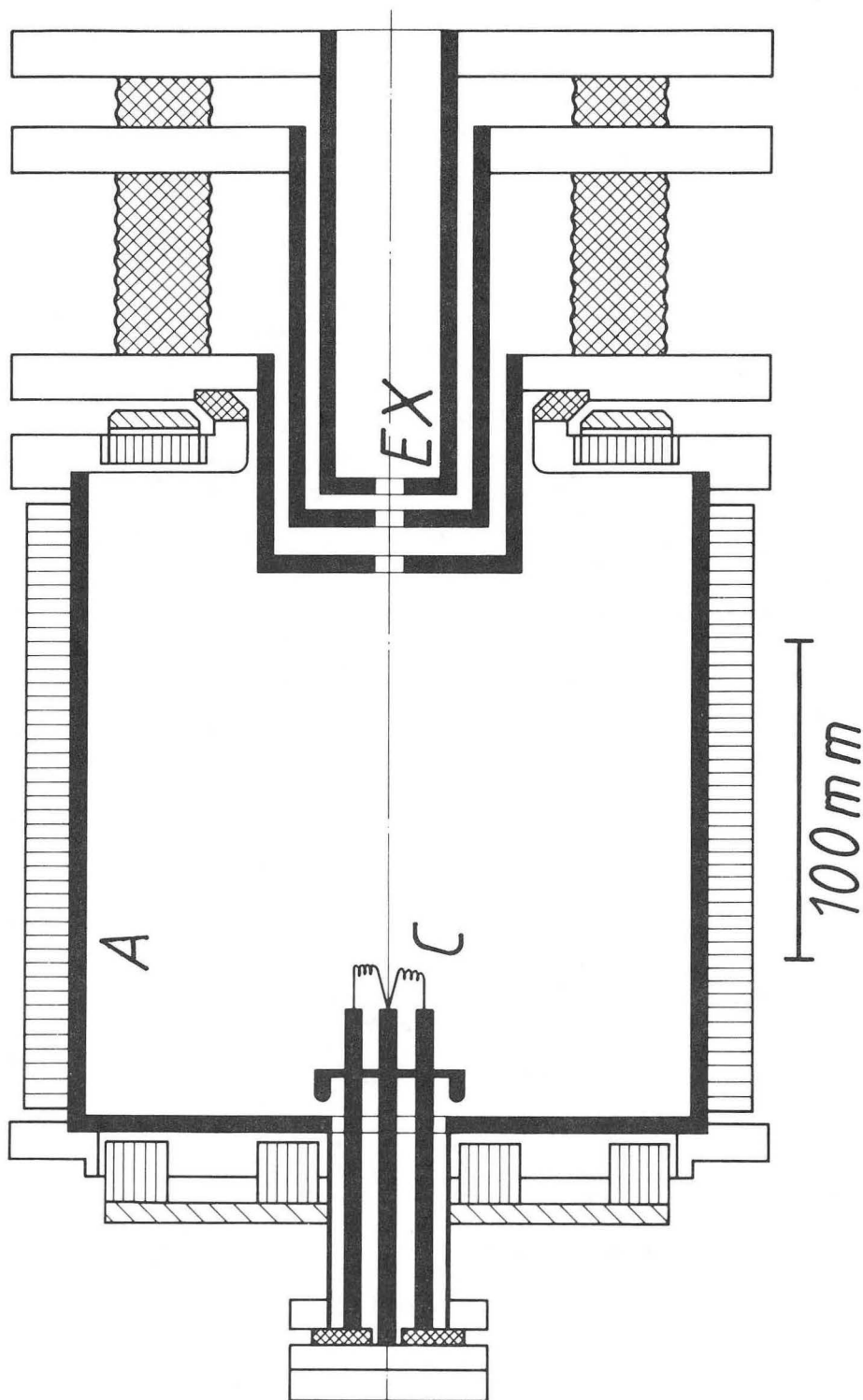


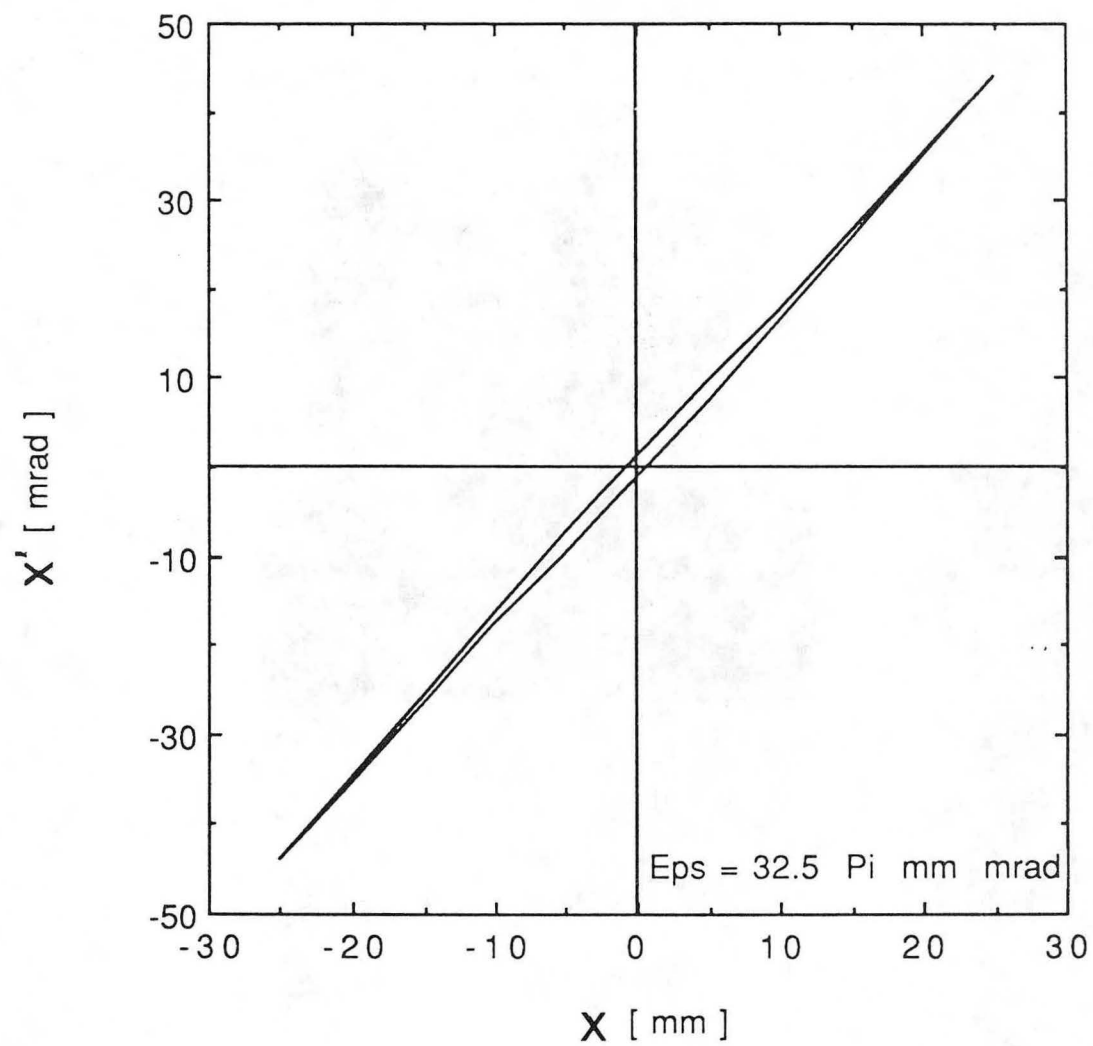
Figure 2

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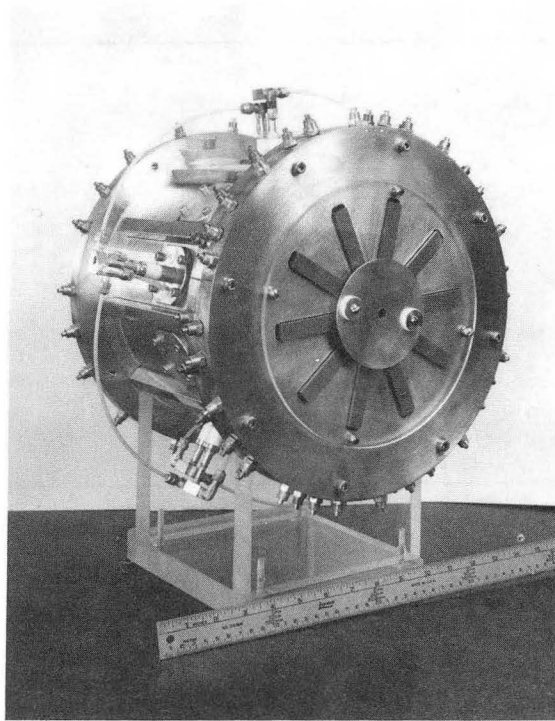
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Figure 3



XBL 896-2277A

Figure 4



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Figure 5

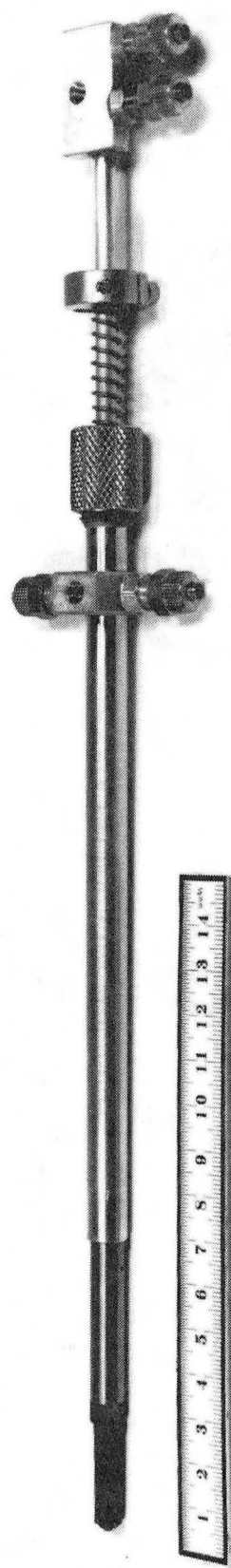


Figure 6

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