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ION SOURCE DEVELOPMENT FOR THE
LOS ALAMOS HEAVY ION FUSION INJECTOR

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Abstract

A multi-beam injector is being designed and built at Los Alamos for the U.S. Heavy Ion Fusion Program [1]. As part of this program, development of an aluminum-spark, pulsed plasma source is being carried out. Faraday cup diagnostics are used to study current emission and to map the current profile. An aluminum oxide scintillator with photographic film is used in conjunction with a pepper-pot to obtain time integrated emittance values.

Introduction

The U.S. Heavy Ion Fusion Program Plan includes a High Temperature Experiment accelerator to test models for ion beam deposition in hot plasma and to answer accelerator design questions related to an HIF reactor system. An injector prototype for this machine is being designed and constructed at Los Alamos National Laboratory. The design criteria for this injector are as follows:

Number of Beams - 16
Particle Energy - 2 MeV
Current per Beam - 150-300 mA
Ion Mass - 20 to 39 AMU (Ne^+ - K^+)
Pulse Length - 6 µsec
Beam Emittance - 4×10^{-7} meter-radians normalized
Energy and Current Flatness - 0.1%

Various ion sources have been considered for this machine including zeolite, porous plugs, and pulse plasma sources. The pulsed plasma sources offer several engineering advantages over any hot source. They generate no heat load which could distort the ion optical structure and thus necessitate special cooling provisions at the high voltage end of the column. Consequently, they do not require a large motor generator to generate the power to heat the sources. Finally, there is the problem of neutral emission which would increase the background gas pressure in the accelerating column. Therefore, we have pursued the development of an aluminum spark source as a way around these problems.

Experimental System

A schematic of the source is shown in Fig. 1. A metal vapor spark is generated at one end of a drift space between annular electrodes. The spark is initiated by a Patco pulse generator operating at 50 kV peak pulse voltage, and it is sustained by the discharge of an LC PFN which is inductively isolated from the gap. The pulse is 35 µsec wide, and currents of ~500 amps at 3 kV charge are normally used. The plasma from the spark passes down the drift space to a double grid plasma switch (also shown in Fig. 1). The drift space walls serve to eliminate ions with high transverse energy; in other words, they provide geometric collimation to reduce beam emittance.

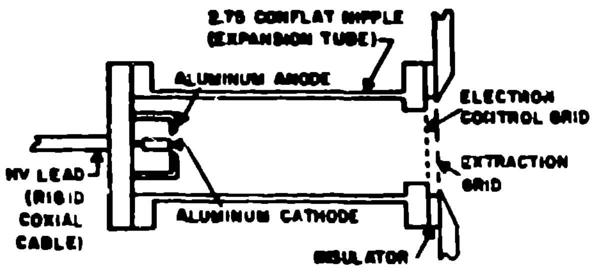

Fig. 1. Aluminum Spark Source and Double Grid Plasma Switch

The double grid switch is a device to prevent plasma drift into the extraction gap and to pre-establish a flat extraction sheath region. The first grid is at the source potential, allowing the plasma to drift through it freely, while the second grid is biased negatively with respect to the source potential. This second grid turns plasma electrons back while the ions continue through the grid to form a virtual anode. In actual operation, the second grid is in the aperture of the extractor focus electrode which is at ground potential while the source is biased at +200 V positive nominally. Once the extraction potential is applied, ions are extracted from the virtual anode.

Fig. 2 shows a computer calculation of the trajectories in the extractor itself. The extractor is a conventional electrostatic gun though it is not a Pierce geometry. A grid is incorporated at the exit aperture to counteract the normal exit aperture defocusing of the beam. The grid has a transmission coefficient of 90%. The calculation shown in Fig. 2 is terminated at the position of the pepper-pot described below. At this point, space charge expansion reduces the initial average current density by 8.6%. Thus, the average source current density is attenuated to 82.3% when both grid attenuation and space charge expansion effects are included.

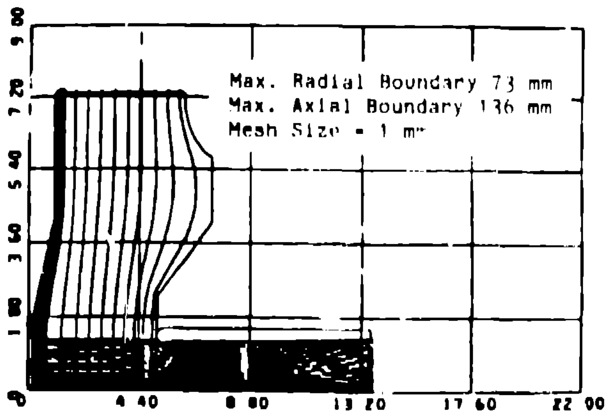

Fig. 2 Computer calculation of trajectories in ion source test stand.

The beam exiting the gun is diagnosed by Faraday probes to obtain current density as a function of extractor voltage and as a function of beam radius. The two types of probe are shown in Fig. 3. The probe (a) uses a gridless aperture and a cylindrical electron trap to prevent electrons from entering the probe and to prevent secondaries from leaving the detector plate. The second probe (b) uses a long cup to trap plasma generated at the aperture for the duration of the ion pulse.

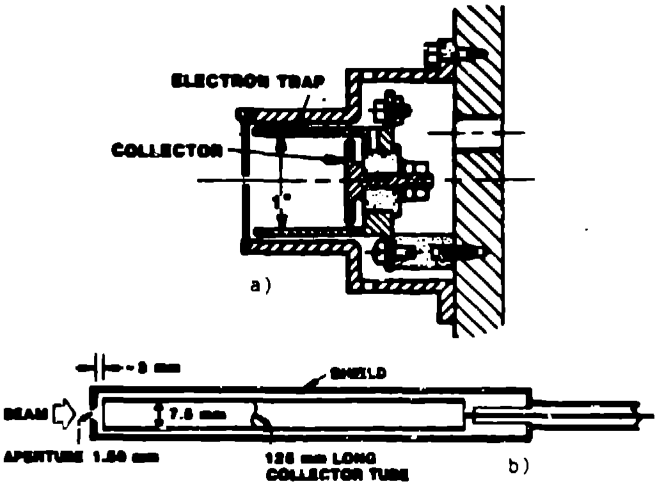

Fig. 3 Two Types of Faraday Probe

The beam was recorded using an aluminum scintillator and Tri-X film. The aluminum coating was 1000 A thick and plated on 1-mil mylar sheet. The film was pressed against the mylar in a light-tight container. For time integrated emittance measurements, a pepper-pot plate with a one-inch diameter array of 4-mil diameter holes was placed in front of the scintillator. The scintillation material is actually the oxide layer on the aluminum and its response time is ~300 nsec [2].

Results

In order to measure the extractable current as a function of extractor voltage the probe shown in Fig. 3a) was used. This is a gridless probe based on the work done by one of the authors (E. A. Meyer) on electron traps for electrostatic extractors and for accelerator columns. The idea was to prevent electrons from either entering or leaving the detector by creating a negative potential wall between the entrance aperture and the detector plate. The detector is shielded electromagnetically inside an aluminum case which is at the extractor potential. The ions leave the extractor at high potential rather than at ground for convenience in testing a wide variety of plasma sources. The signal from the probe is relayed to an oscilloscope via a fiber optic link for high voltage isolation.

Two different length drift tubes were used for the source plasma. The distances from the spark to the first grid of the double grid switch were 175 mm and 124 mm. Only one double grid separation was used, 15.9 mm, and the normal bias on the double grid was 200 V.

The results for the shorter length drift tube are shown in Fig. 4. The solid line is the result of a computer calculation of the beam envelope at the location of the probe aperture and it represents the average current density expected at that location corrected for the effects of grid attenuation and space charge expansion. Actually the beam is slightly focused at this location due to an 11 mrad convergence of the beam envelope at the exit grid. Individual data points are plotted on Fig. 4 and there is considerable scatter. This scatter in the data increased when tests were made with the longer drift tube. Originally, it was planned to map the current profile of the beam with this probe. However, the data scatter did not permit this.

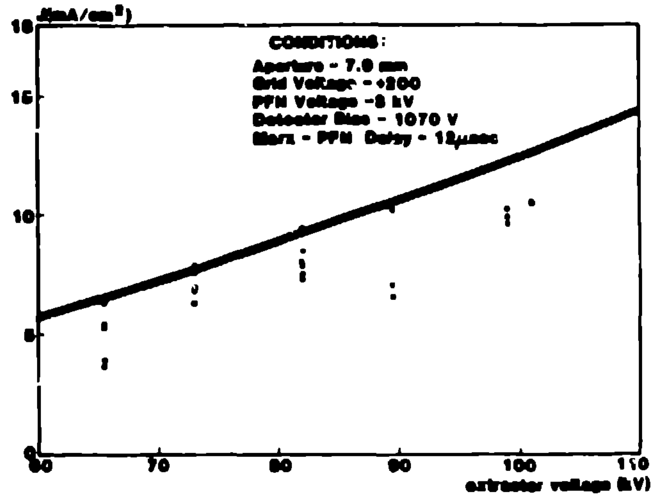

Fig. 4 Extracted Current From Gridless Probe

The design goal for use of this source in our application is to obtain 10 mA/cm^2 of space charge-limited current. The data points tend to fall below the calculated curve in this vicinity. We think this is due to inadequate plasma density at the extraction surface to support this current level and that the more erratic data with the longer drift tube confirm this explanation since even lower plasma densities would be expected with the longer tube. At the low voltage end the points are obtained later in the extraction pulse and source depletion is probably occurring. However, in a moderate voltage range at current densities between 8 and 9 mA/cm^2, the current is reasonably close to the calculated amplitude and slope.

To reduce the scatter in data, in case it were not a real source effect, a new probe was built (Fig. 3b). This longer cup was designed to trap plasma from the aperture inside the cup and provide a drift time for this plasma that was large compared to the ion pulse. It was hoped that keeping any beam produced plasma inside the cup would reduce the current noise by keeping plasma from shorting the cup bias. A bias curve for the cup indicated an optimum operating point of +90V.

Fig. 5 shows beam current maps taken at 8.5 cm from the exit grid for two different conditions. The probe aperture is 1.59 mm in diameter. The horizontal lines labeled 100 kV and 80 kV represent the expected average current density at the aperture location including space charge expansion and grid attenuation. The beam clearly has a hot spot in the middle 1-1.5 cm in diameter which is qualitatively consistent with beam images recorded with the scintillator and with microdensitometer readings of the pepper-pot photos. The error bars reflect great shot-to-shot variability which is also consistent with the pepper-pot photos. It seems likely that the data scatter is a real source effect since the second cup also showed scatter. Furthermore, it has been observed that when the source is first reassembled very reproducible data is obtained for a short time.

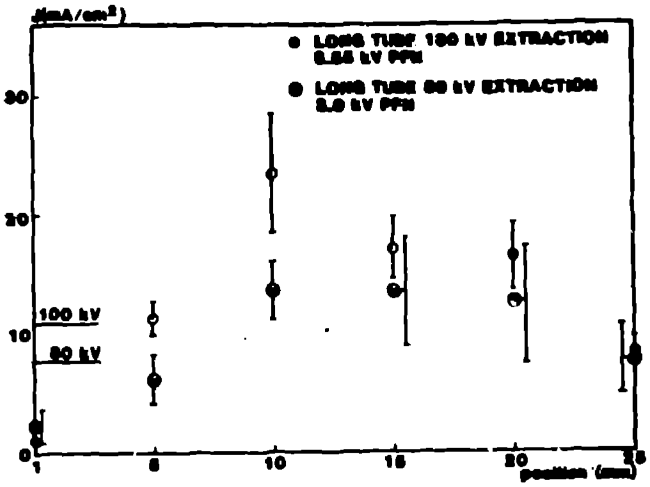

Fig. 5 Extracted Beam Scans

Fig. 6 shows a photo of an actual pepper pot shot. The plate holes are 4-mil diameter separated by 1/16 inch to form a one inch wide pattern. The separation between the plate and the scintillator was 10.6 mm. We attribute much of the irregularity in some parts of the photo to time dependent motion of the beam during the rise and fall of the pulse.

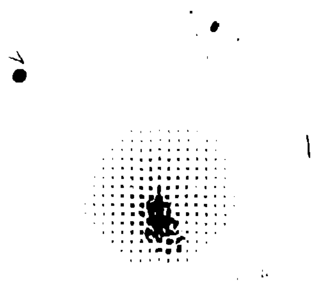

Fig. 6 Pepper-pot photo

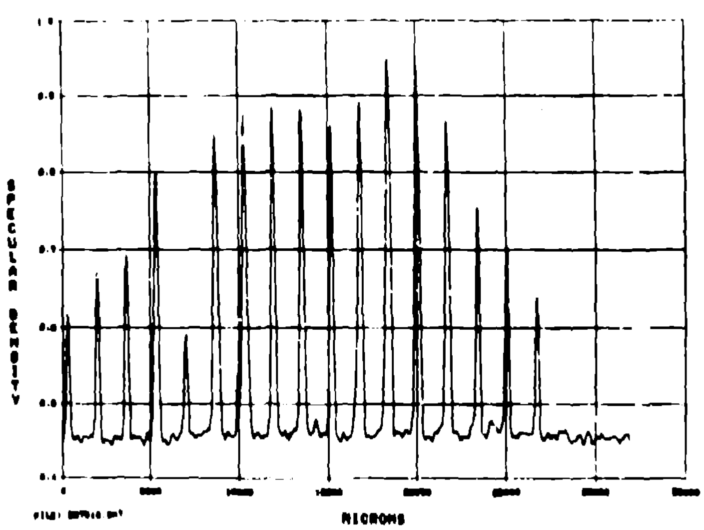

Fig. 7 Microdensitometer Plot Corresponding to Picture in Fig. 6

Fig. 8 shows a divergence vs. position plot for three shots of roughly the same peak voltage. The photos were read with a microdensitometer using 60μ resolution. The ellipse drawn on the plot corresponds to a normalized emittance of 5.8 x 10^{-7} meter-radians. Similar areas were obtained for higher voltages. The measured emmitance is within 50% of the required emittance. Therefore, we are encouraged to continue development of this type of source.

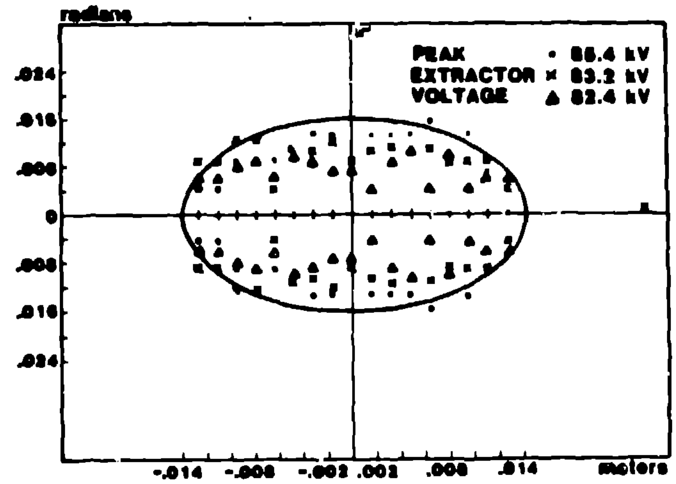

Fig. 8 Emittance Plot for Long Tube

Acknowledgements

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(2) Private Communication - S. Rosenbloom.

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