PERFORMANCE OF THE SSC RF-DRIVEN VOLUME SOURCE

K. Saadatmand, N. C. Okay

Superconducting Super Collider Laboratory*
2550 Beckleymeade Avenue, suite 260, MS1043
Dallas, Tx 75237-3946

Abstract

The Superconducting Super Collider (SSC) Ion Source is required to provide 30 mA of H^- beam at 35 kV with normalized rms emittance of less than 0.2 π-mm-mrad. Furthermore, the ion source has to be highly reliable, easy to maintain, and must provide a quick turn around time in case of failure. The RF-driven volume source[1] developed at Lawrence Berkeley Laboratory (LBL) has been adopted as the developmental ion source for SSC. An extensive experimental program is under way to investigate the performance and reliability of the SSC RF-driven volume ion source. Available experimental results pertinent to the performance of the SSC RF-driven volume ion source will be discussed.

Introduction

Multicusp plasma sources provide volume production of low energy (<2 eV) H^- ions which lead into low emittance, high brightness beams. However, the volume source requires a large discharge power in order to yield a high beam current density. Since the SSC ion source must operate reliably for many months continuously, the use of filament cathode type volume sources is not realistic. Thus, an RF driven volume H^- source, based on RF induction discharge, was developed for SSC by LBL[1] and delivered to SSCL in December 1991. Furthermore, the RF-excited volume source has the promise of being simple to maintain and operate. It also may have an additional advantage in terms of system reliability since it can be operated without filaments or cesium injection.

SSC Volume Source

A schematic of the SSC RF volume ion source is shown in Figure 1. The source chamber is made out of a 10 cm long by 10 cm diameter copper cylinder with a back plate at one end and a plasma electrode at the other end. The plasma is confined by the longitudinal line-cusp field produced by twenty columns of samarium-cobalt magnets that surround the source chamber. These magnets are enclosed by the source outer shell (an anodized aluminum cylinder). Magnets are cooled by water circulating between the source chamber and the outer shield. To close the confining magnetic cusp field, the back flange of the source also contains four rows of water cooled magnets. A pair of water cooled permanent magnetic field rods which are placed near the plasma electrode creates a narrow region of transverse magnetic field which divides the source chamber into discharge and extraction regions. The gas molecules are

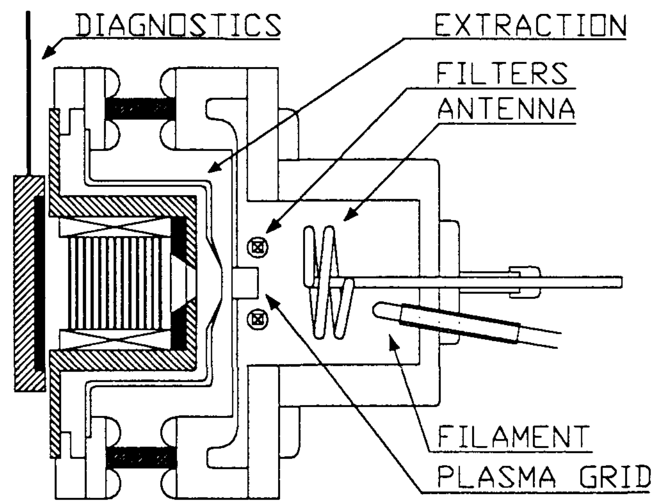

Fig. 1 RF Volume Source

excited and ionized in the discharge region. To generate the plasma a small hairpin tungsten filament is used as a starter which adds enough electrons to the hydrogen gas that RF power (at 2MHz) can be inductively coupled to the mixture via a two turn ceramic coated copper antenna. As soon as the plasma is formed, the RF power is matched efficiently to the plasma for the duration of the pulse. The antenna is connected through an isolation transformer to a matching network which matches the impedance of the RF amplifier to the impedance of the plasma. The filter rod's magnetic field prevents the energetic electrons from entering the extraction region while the cold electrons along with the positive, negative and vibrationally excited ions will drift across the field. Thus, a plasma with a lower electron temperature is formed in the extraction region which allows the formation of H^- ions by dissociative attachment.

Figure 2 shows our volume source test stand. The source is mounted on a diagnostic chamber. In addition to the diagnostic systems, slit-collector and Faraday cup, all the pumping is done through the diagnostic chamber. Two 500 liter/sec turbo pumps are used to keep the test stand under vacuum (base pressure of 5*e-7 torr). The source is operated in the pressure range of 10 to 20 mtorr and RF power of 15 to 50 kW. Beam is extracted at 35 kV and we have been able to extract up to 40 mA of H^-. As one would expect, the extracted beam current depends on the RF power level and the extracted electron current to H^- current ratio could be as high as 50:1 at high powers. However, after allowing time (2-3 hrs) for the source to condition, we have achieved the ratio as low as 20:1 when

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extracting 30 mA of H$^-$ at 35 kV. The high electron current that is extracted along with the H$^-$ beam is separated out of the beamline by spectrometer magnets placed downstream of the extractor electrode. These magnets are placed inside a soft iron envelope which prevents the spectrometer magnetic field penetrating the extraction gap and the volume source.

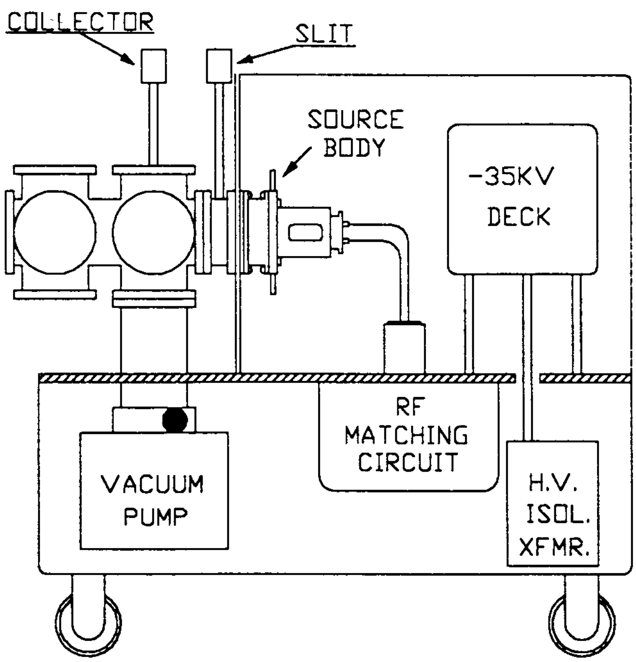

Fig. 2 RF Volume Source Test Stand

Emittance Measurements

To characterize the SSC RF volume source we have measured the transverse emittance of the extracted H$^-$ beam in the vertical plane using a slit & collector system. It is desirable to place the slit as close as possible to the extractor electrode because of drastic effects of space charge at low energies. However, because of the long electron separating spectrometer we placed the slit 13.46 cm down stream of the extractor electrode. The separation between the slit and collector was 21.83 cm which resulted in very good measurement resolution. Figure 3 shows a typical vertical emittance contour plot for a 30 mA beam at 35 keV. There are two distinct beams present. The main beam is the H$^-$ beam (which constitutes over 80% of the beam current) and the secondary beam is H^0 produced by gas stripping downstream of the extraction gap. The two beams are separated in the spectrometer by the electron separating magnetic field. The angular separation between the two beams is 66 mrad (3.8 degrees) which is the amount that the spectrometer magnet bends the H$^-$ beam. Figure 4 shows the vertical emittance contour plot of the H$^-$ beam alone. The rms normalized emittance (extrapolated to 100% of the beam assuming a gaussian beam[2]) is calculated to be 0.11 π mm-mrad, about half the required emittance value for the SSC ion source, while the emittance of the H^0 beam is 0.2 π mm-mrad.

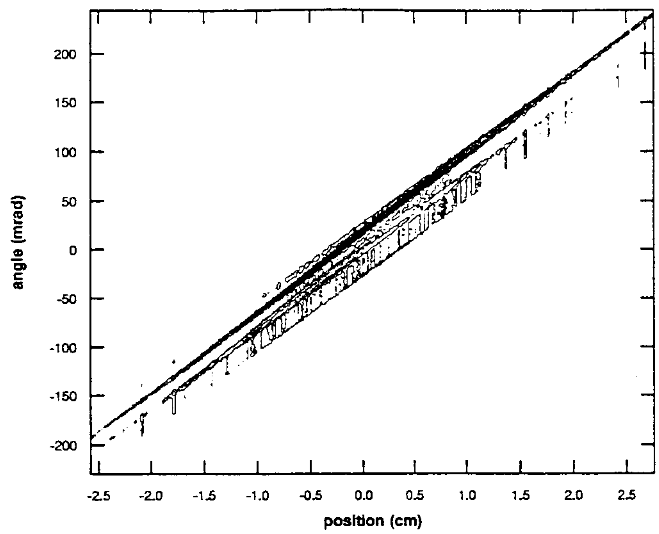

Fig. 3 Vertical Phase-Space emittance plot

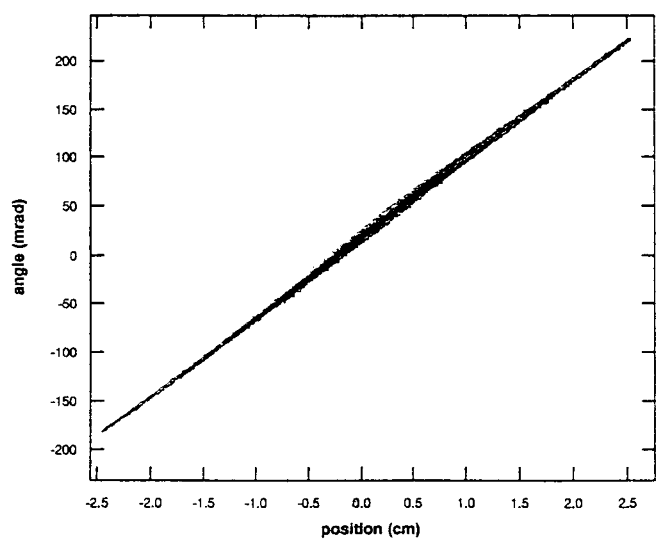

Fig. 4 Vertical H$^-$ Phase-Space emittance plot

We have also measured the beam emittance in the horizontal plane. Figure 5 shows the horizontal emittance contour plot. The rms normalized emittance is calculated to be 0.15 π mm-mrad. This is much larger than the emittance in the vertical plane. However, this apparent larger emittance is probably due to the fact that the H$^-$ and H^0 beams are not separated in the horizontal plane and the measured emittance is the effective emittance of the two overlapping beams.

Discussion

The measured normalized rms emittance of a H$^-$ beam is related to the plasma ion temperature by[3]:

$$\varepsilon_{n\ rms}=\frac{a}{2}\sqrt{\frac{KT_i}{M_Hc^2}}$$

M_Hc^2: Hydrogen mass in eV (939 MeV)
$\varepsilon_{n\ rms}$: normalized rms emittance in π m-rad
KT_i : Hydrogen ion temperature in eV
a : emitter radius in meters.

This equation leads to an H^- ion temperature of 5 eV for the measure normalized rms emittance of 0.11 π mm-mrad which is much larger than the expected ion temperature of 2 eV in a RF driven volume source. With ion temperature of 2 eV one would expect normalized rms emittance of .07 π mm-mrad. A closer look at the contour plots reveals that the beam is highly diverging, encompassing 400 mrad, and very large, 5.4 cm in diameter. Figure 6 shows the H^- emittance contour plot with the end wings (which contains only 4% of H^- beam) cut off. The emittance is 0.09 π mm-mrad, angular spread of the beam is 280 mrad and it is only 3.5 cm wide. Furthermore, the beam emittance is measured 13.46 cm downstream of the extractor electrode and for a portion of this distance there is one Ampere of electrons accompanying the H^- beam. The space charge forces in this area could cause an emittance growth. However, adding neutralizing argon to the spectrometer region did not affect the emittance noticeably.

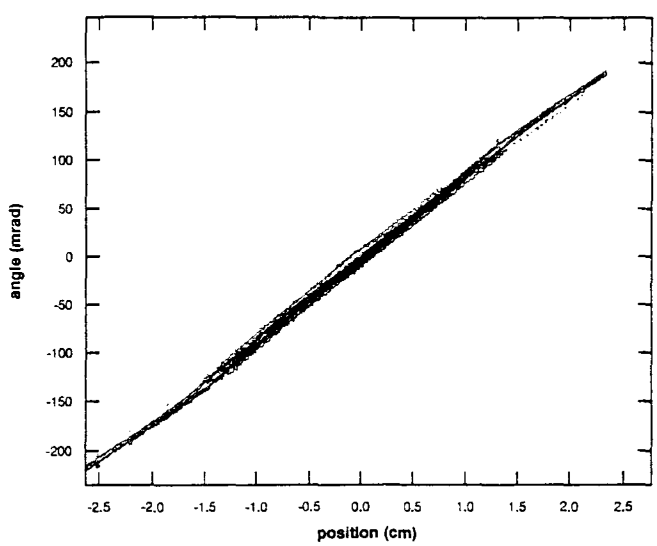

Fig. 5 Horizontal Phase-Space emittance plot

In a separate experiment the extraction voltage was reduced, the emittance increased slightly while the angular spread of the beam was reduced. This result seems to suggest that the 35 keV beam comes to a waist near the extractor (under dense plasma) and then diverges sharply. The next step is to increase the extraction gap distance in order to achieve a parallel beam (medium dense plasma) output.

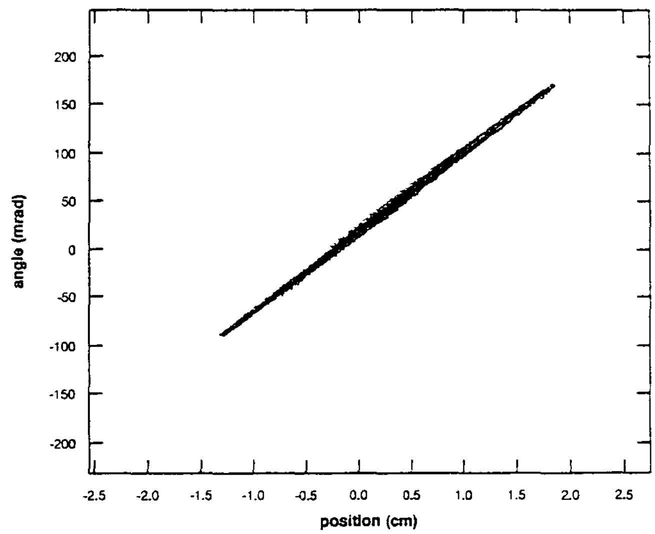

Fig. 6 Vertical H^- Phase-Space emittance plot with the wings cut off

Conclusion

We have achieved the SSC beam requirements with the RF driven volume source. The next task is to develop/select a LEBT that provides the required beam into the SSC RFQ. At the same time more work needs to be done in order to refine and understand the RF volume source output beam characteristics.

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References

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