LBL--32593

DE93 010438

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July 1992

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Paper presented at the 1992 International Conference on High Energy Accelerators,
Hamburg, Germnay,
July 20 - 24, 1992

* This work is supported by SSCL and by the Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LBL-32593

Paper submitted to the XVth International Conference on High Energy Accelerators, Hamburg, Germany (July, 1992).

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Abstract

An RF driven H^- source has been developed at LBL for use in the Superconducting Super Collider (SSC). To date, an H^- current of ~40 mA can be obtained from a 5.6-cm-diam aperture with the source operated at a pressure of about 12 mTorr and 50 kW of RF power. In order to match the accelerated H^- beam into the SSC RFQ, a low-energy H^- injection system has been designed. This injector produces an outgoing H^- beam free of electron contamination, with small radius, large convergent angle and small projectional emittance.

1. INTRODUCTION

Multicusp plasma generators have been operated successfully as volume production H^- sources. The H^- ions formed by volume-production processes have low beam emittance and are therefore useful for the generation of high-brightness beams. In order to achieve high current densities, volume H^- sources require high discharge power. For this reason, the lifetime of the filament cathodes is normally short for steady-state or high repetition rate pulsed operations. The use of an RF induction discharge as an H^- source is attractive for high energy accelerator applications. There are no short life components in the source chamber. A clean plasma free of contamination from the cathode material can be maintained and the RF power supplies operate conveniently at ground potential.

At LBL, an RF driven source has been operated successfully for the extraction of H^- beams. In the past two years, we optimized the filter and the collar geometry to obtain higher H^- output and lower electron current in the extracted beam. An injector that would match the beam into the SSC RFQ has been designed. The injector consists of four electrodes and is operated in an accel-decel-accel scheme. This accelerator and transport system can deliver 30 mA of H^- current and it meets the RFQ acceptance requirement of 35 kV with beam radius = 0.2 cm, convergent angle = 139 mrad, and emittance (rms) = 0.018 π-cm-mrad.

2. DESCRIPTION OF RF-DRIVEN MULTICUSP SOURCE

A schematic diagram of the RF ion source is shown in Fig. 1. The source chamber is a copper cylinder (10 cm diameter by 10 cm long) surrounded by 20 columns of samarium-cobalt magnets that form a longitudinal line-cusp configuration. The magnets are enclosed by an anodized

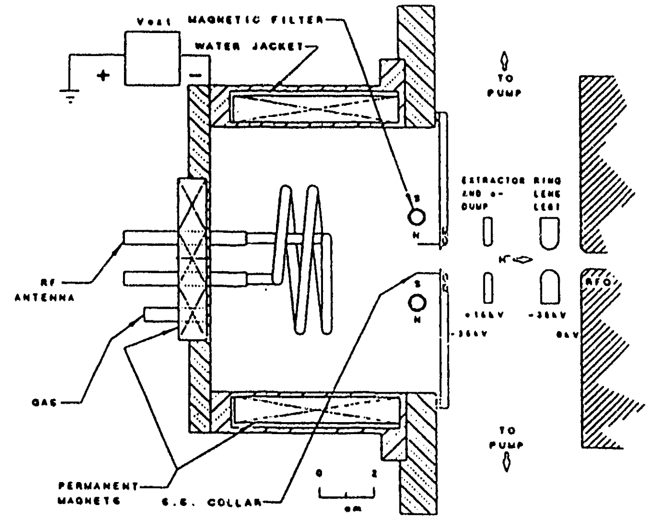

Fig. 1 A schematic diagram of the RF Multicusp Source.

aluminum cylinder with cooling water circulating between the magnets and the inner housing. The back flange has four rows of magnets cooled by drilled water passages in the copper.

In order to enhance the H^- yield, a pair of water-cooled permanent magnet filter rods is installed near the extraction region. The filter rods provide a narrow region of transverse magnetic field which divides the entire source chamber into a discharge and extraction region. The filter field is strong enough to prevent energetic electrons from reaching the extraction chamber. Excitation and ionization of the gas molecules take place in the discharge chamber. Positive and negative ions, together with cold electrons are present in the extraction region. They form a plasma with lower electron temperature, which makes it favorable for the formation of H^- ions by dissociative attachment and their survival to the accelerator.

The plasma is generated through inductive coupling of the plasma via a two-turn copper antenna. The RF antenna is fabricated from 4.7-mm-diam copper tubing and is coated with a thin layer of hard porcelain material. The thin coating is slightly flexible and resistant to cracking. It has maintained a clean plasma in cw operation for periods of a week or more; the antenna life expectancy has not yet been determined.

The antenna is connected to a matching network and isolation transformer (Fig. 2), matching the 50 ohm impedance of the amplifier with the impedance of the plasma. The RF signal is generated by a digital synthesizer. The signal (~2 MHz) is sent to a preamplifier, and then to the rf amplifier. Peak performance allows a maximum pulsed RF input power of 50 kW. This power travels through a 50 ohm coaxial cable to the isolation and matching network. The RF power can be controlled by changing the amplitude and frequency of the synthesizer signal. Maximum efficiency is achieved when the output voltage and current from the RF amplifier are in phase and operating at a 50 ohm impedance. For pulse operation, a small hairpin tungsten filament is normally used as a starter for the RF induction discharge.

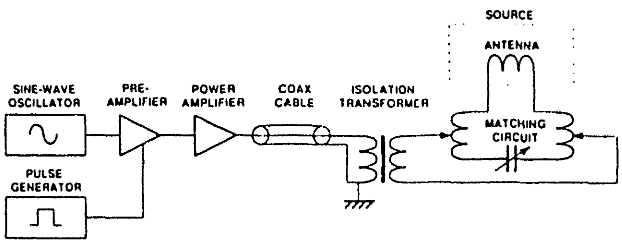

Fig. 2 RF circuit diagram.

3. EXPERIMENTAL RESULTS

Operation of the RF driven multicusp H^- ion source has been previously reported [1,2]. During the last two years, we optimized the filter and the collar geometry to obtain higher H^- output and lower electron current in the extracted beam. Figure 3 is a plot of the extracted H^- current as a function of RF input power. An H^- current of ~40 mA can be obtained from a 5.6-mm-diam aperture with the source operating at a pressure of about 12 mTorr and 50 kW of RF power. The ratio of electron to H^- ions in the extracted beam varies from 8 to 12 as the RF power is changed from 20 to 50 kW. Based on these experimental results, along with the previous emittance measurement [3], we have designed a simple four-electrode electrostatic injector system for the SSC RFQ.

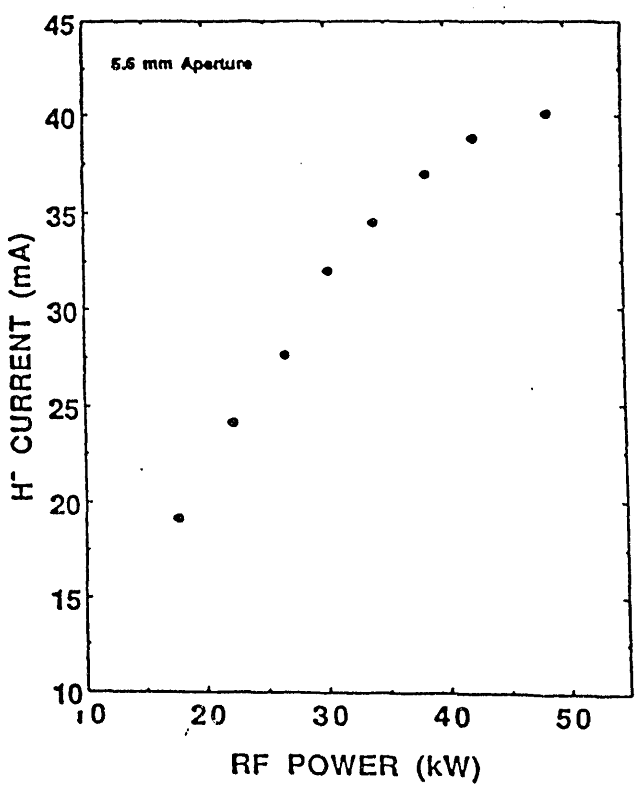

Fig. 3 Extracted H^- current vs. RF Power

4. LOW-ENERGY H^- INJECTOR DESIGN

The injector consists of four electrodes and is operated in an accel-decel-accel scheme. The first two electrodes employ an acceleration voltage of 50 kV to extract the H^- ions and the unwanted electrons. The latter are swept away by a pair of permanent magnets embedded in the first electrode. The H^- beam is then decelerated by the third electrode (normally biased at the same voltage as the first one). The beam expands as it slows down. It is then reaccelerated and compressed by the fourth electrode, which is also the entrance to the RFQ.

An axisymmetric 2-D ion beam optics code is used to compute the charged particle trajectories and projectional emittance [4]. Beam attenuation due to gas stripping as well as the space charge effect due to the extracted electrons are included in the computation model. The shape and location of the electrodes are displayed in Fig. 4. The voltages of the four electrodes are 0, 50, 0 and 35 kV respectively. Alternatively, they can be labeled as -35, 15, -35 and 0 kV. The x-x' phase plot in Fig. 4 shows 90% of the emittance as the beam enters the last electrode.

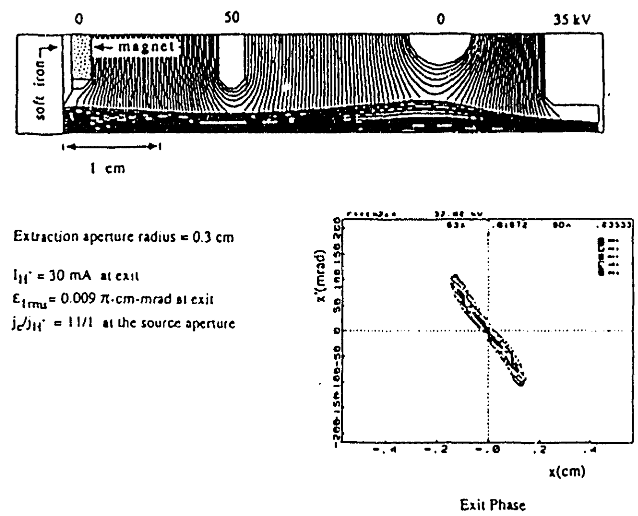

Fig. 4 Schematic diagram of extraction electrodes

Direct extraction of H^- ions from a volume source is always accompanied by a large amount of unwanted electrons. By installing a pair of permanent magnets inside the first electrode, these electrons can be deflected and subsequently captured by the second electrode (Fig. 5). The soft iron housing which forms part of the first electrode reduces the magnetic field to a minimum at the extraction plane. In this accel-decel arrangement, there exists an electric field reversal before and after the second electrode. Any secondary emission of electrons produced by the impact of the extracted source electrons on the upstream face of the second electrode would be confined to the first gap and would not migrate downstream.

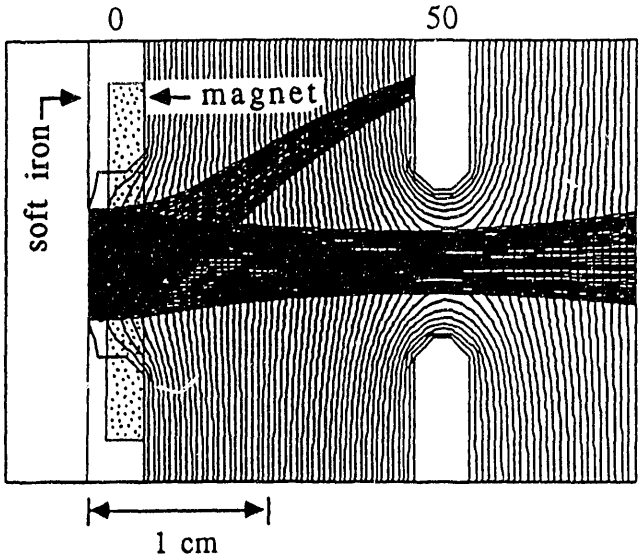

Fig. 5 Electrode diagram with permanent magnet filter

The potential of the third electrode is normally equal to that of the first one. However, if a larger convergent angle of the beam into the RFQ is desired, it should be biased at a few kV negative. Thus one can adjust the beam angle continuously to provide the proper entrance angle for a particular RFQ requirement. The electrode configuration in the present design is simple and open, and therefore allows fast gas pumping. The overall arrangement of the compact injector is shown in Fig. 1. The exit emittance is about a factor of two smaller than the SSC RFQ injector requirement. This is achieved by good ion beam optics and the low H^- ion temperature obtained from a volume production source.

In this study, we have ignored the contribution of the emittance growth due to the perturbation of the ion trajectories by the magnetic field, as well as its steering effect on the beam as a whole. However, we don't expect these effects to be dominant factors. We intend to investigate them in 3-D calculations in the future.

ACKNOWLEDGMENTS

This work is supported by SSCL and by the Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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