Positive Hydrogen Ion Beam Production by an RF-driven Multicusp Source

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Abstract

A 10-cm-diam rf-driven multicusp ion source has been tested for positive (H\textsuperscript{+}) ion production in cw mode for future use in the 870 keV Cockcroft-Walton preinjector at Paul Scherrer Institute. The source is optimized for the best atomic hydrogen ion species and extractable current. It is found that the porcelain coating on the antenna is very durable and stays intact after days of continuous operation. It is expected that the antenna will have a very long lifetime for an rf input power of ~6 kW.

I. INTRODUCTION

An rf-driven source has recently been developed at Lawrence Berkeley Laboratory to efficiently produce H\textsuperscript{+} ion beams for use in the injector unit of the Superconducting Super Collider. Under optimum conditions, an H\textsuperscript{+} beam current as high as 40 mA has been obtained from a 5.6 mm diameter aperture [1]. The same source has also been tested for other ion beam production and the results are reported in Ref. [2].

The cyclotron at Paul Scherrer Institute (PSI) requires a long lifetime positive hydrogen ion source that can generate high current and high proton percentage. The present PSI source utilizes tungsten filaments for the plasma discharge. The lifetime of the cathode is limited to about one month of low arc power and about ten days of higher arc power source operation. Results of the rf-driven source testing in pulsed mode indicate that it can satisfy both the current and ion species requirement for the PSI Cockcroft-Walton injector [2]. The objective of this experiment is to investigate the extractable current, hydrogen ion species distribution and the durability of the antenna when the rf-driven source is operating in cw mode.

The durability of the antenna is an important factor when considering the long-term performance of ion sources. Antenna lifetime has been demonstrated for high power (>50 kW) pulsed operation at LBL, Grumman Corporation, and SSCL, but has not been tested for cw operation in a plasma environment until now. The results are encouraging. The porcelain-coated copper antenna has been observed to have a high durability after continuous plasma exposure. It is expected that the antenna will have a very long lifetime when the source is operated with an rf input power of ~6 kW.

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II. EXPERIMENTAL SETUP

A schematic diagram of the rf ion source is shown in Fig. 1. The source chamber was a copper cylinder (10 cm diameter by 10 cm long) surrounded by 20 columns of samarium-cobalt magnets that formed a longitudinal line-cusp configuration. The magnets were enclosed by an anodized aluminum cylinder with cooling water circulating between the magnets and the inner housing. The back flange had four rows of magnets cooled by water passages drilled in the copper.

![Schematic diagram of the rf-driven multicusp source.](image)

The open end of the source chamber was closed by a two-electrode extraction system. Positive or negative ion beams were normally extracted from the source through a 2 mm diameter aperture. A permanent magnet mass analyzer was used with a Faraday cup to measure the electron, positive or negative ion currents in the accelerated beam. When multiple ion species were present, an electromagnetic mass analyzer was used to determine the species distribution.

The rf antenna was fabricated from 4.7 mm diameter copper tubing and was coated with a thin layer of hard porcelain material. The thin coating was slightly flexible and resistant to cracking. The rf system consisted of a series circuit of capacitive and inductive components with a plasma acting as the resistive load (Fig. 2). Rf power was delivered to the system by means of an isolation transformer with a step-down ratio of 10:1. To assure maximum power dissipation in the plasma and minimal power reflection, the matching circuit's impedance was adjusted to minimize the phase difference between the current and voltage. This
tuning was done at an rf operation frequency of approximately 1.8 MHz.

Fig. 2 Schematic diagram of the complete rf power system.

In the initial operation of the system, a moderate rf power of 4.8 kW could be coupled to the plasma in cw mode with only a small amount of power being reflected from the matching circuit. However, as the source operation continued, a shift in the rf coupling gradually developed. The current and voltage phase difference began to increase, thereby delivering less power to the plasma. The remainder of the power was then dissipated as heat in the matching circuit's components. The phase difference eventually became so pronounced that the system's circuit breakers tripped due to excessive reflected power.

When the impedance of the matching circuit was remeasured, a significant change in phase had occurred. In addition, the isolation transformer had become exceedingly hot. To try remedy the situation, the circuit was retuned while hot and a plasma reignited. It soon became apparent though, that the hot circuit was less efficient and that the circuit components could be damaged. A cw rf discharge became difficult to maintain for any duration of over twenty minutes.

The majority of heat dissipation occurred within the isolation transformer. Approximately 70 watts of the input power was being dissipated in the primary and secondary windings of the transformer. This heat may appear small in comparison with a 5 kW input power but the cumulative effect on the electrical components becomes significant when there is no cooling to carry this heat away. The increasing temperature changed the transformer's ferrite core permeability and accordingly the system became unstable.

As a solution to this problem, an external blower was installed to cool the isolation transformer by forced air convection. The system performance improved markedly. Since then, the ion source had been operated in cw mode at ~6 kW of rf power for over two weeks. Daily operation was maintained at two hours or longer (total integrated time for source operation >24 hours). After running for this duration, the source chamber was opened. The antenna showed no signs of deterioration with the only visible effect being a grayish coating caused by vaporization of the starter tungsten filament. There was no measurable change in the thickness of the porcelain coating. It appeared that continued operation with the same antenna was still possible for an extended period of time.

III. EXPERIMENTAL RESULTS

Multicusp generators are capable of producing large volumes of uniform and quiescent plasmas with densities exceeding 10^{12} ions/cm^3. For this reason, there was a great interest in the early 1980s in applying such devices as ion sources for neutral beam injection systems and for particle accelerators. To increase plasma penetration by a neutral beam, a high percentage of H^+ or D^+ ions is required. It has been demonstrated that atomic species as high as 85% can be obtained routinely if a multicusp source is operated with a magnetic filter [3]. The magnetic field generated by the filter magnet is strong enough to prevent the primary electrons from reaching the extraction region. The absence of energetic electrons will prevent the formation of H_2^+ in...
the extraction region, but dissociation of the molecular hydrogen ions (H$_2^+$, H$_3^+$) can still occur. As a result, the atomic ion species (H$^+$) percentage in the extracted beam is enhanced.

We have investigated the extractable current density and the hydrogen ion species composition in the rf-driven source with different source parameters. Source operating pressure was maintained between 4 to 6 mTorr. Figure 3 shows the hydrogen ion species as a function of rf power for three different filter field strengths (The B-field is measured at the mid-plane of the filter). As expected, the weaker the filter field, the higher the extracted positive hydrogen ion current density. The data indicates that a nominal current density of 150 mA/cm$^2$ can be achieved by both the 150 G and 190 G filters at about 4 kW of rf power. Source operation with the 240 G filter can produce a current density of only 100 mA/cm$^2$.

Figure 4 shows a plot of H$^+$ ion percentage versus rf power for the three different filter fields. The H$^+$ ion concentration increases as the rf power is varied from 1 to 5 kW. In the range of rf power considered, the 190 G filter provides higher proton percentage than the other two filters. According to the results shown in Figs. 3 and 4, one can conclude that by using the 190 G filter, an H$^+$ current density of ~100 mA/cm$^2$ can be obtained by operating the rf source at ~4 kW of power. The H$^+$ output current should exceed the present PSI source performance and should have a much longer source lifetime. As a result, routine source maintenance will be much reduced.

Based on the results of this source testing, we are now designing and fabricating a new rf-driven multicusp source for positive (H$^+$) ion production in cw mode for future use in the 870 keV Cockcroft-Walton preinjector at PSI. Operational characteristics of this new ion source will be reported in the near future.

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