A HIGH BRIGHTNESS HYDROGEN ION SOURCE FOR THE BTA AT JAERI

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Abstract

A hydrogen ion source has been developed for a high intensity proton linear accelerator. The ion source is required to produce 120 mA proton beam at 100 kV with low emittance and high proton yield. The ion source produces plasma by an arc discharge using tungsten filaments, and the plasma is confined by the multicusp magnetic field. The beam test was performed at an acceleration voltage of 100 kV. The extracted beam current was 140 mA with the beam divergence and emittance of 8.5 mrad and 0.5 πmm.mrad(90%, normalized) from a single aperture of 10 mm in diameter. The proton yield increased with the beam current, and reached more than 85 % at 120 mA, which was measured by the Doppler-shifted spectroscopy method.

Introduction

The R&D work the Basic Technology Accelerator (BTA) has been carried out since 1991 at JAERI [1]. A hydrogen ion source for the BTA is required to produce a high brightness (high current and low emittance) and high proton yield beam. The basic specifications of the ion source are listed in Table 1.

The ion source has been designed and fabricated [2]. The first beam test was performed at acceleration voltages up to 60 kV to study the basic performance of the source [3]. The second beam test was performed at full beam energy after the installation of a new high voltage power supply of 100 kV and 200 mA. The present paper reports the performances of the ion source in the second beam test.

TABLE 1 Specifications of the ion source

Energy	:	100 keV
Current	:	120 mA
Duty Factor	:	CW
Emittance	:	0.5 πmm.mrad (normalized 100%)
Proton Yield	:	> 90%
Impurity	:	< 1%

Ion Source

A cross sectional view of the ion source is shown in Fig. 1. The bucket type ion source with two-stage beam extraction system, of which type of source has proven good performance for fusion research at JAERI, is adopted. The plasma chamber is made of a copper cylinder of 20 cm in diameter and 17 cm in length. The chamber is surrounded by 10 columns of Sm-Co magnets that produce a strong magnetic field. These magnet columns are connected to four rows of magnets at the back plate. The open end of the chamber is enclosed by a plasma electrode with 10 rows of magnets. The source plasma is produced by an arc discharge using three hairpin tungsten filaments of 1.2 mm in diameter.

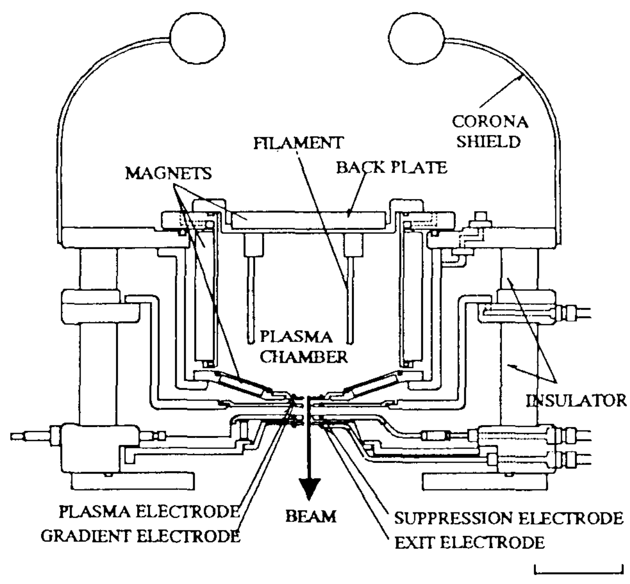

Fig. 1 Cross-sectional view of the ion source

The beam extractor consists of four electrodes with the extraction, acceleration and deceleration gap. The ions are extracted from a single aperture of 10 mm in diameter. A field intensity ratio **f**, which is an important parameter in the two-stage extractor, is defined by the ratio of the electric

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field of the extraction stage to that of the acceleration stage. By adjusting **f** to less than unity, the ion beam is focused by the electrostatic lens between the two stages [4]. As shown in Fig. 2, when **f** was small, the acceleration current decreased but the beam quality became better. We chose **f** to be 0.42 in the present experiment.

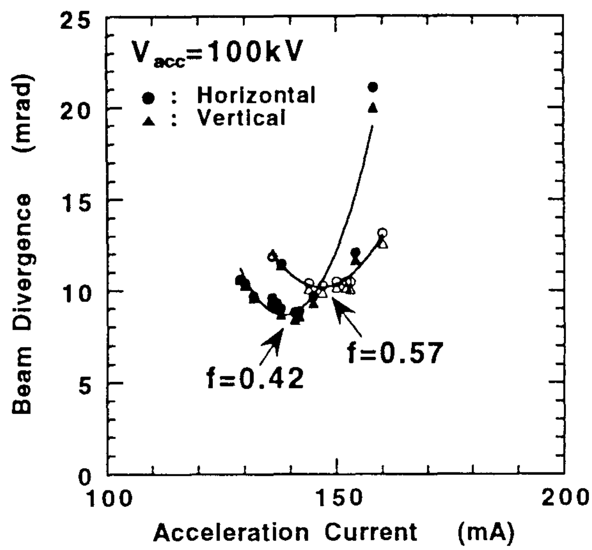

Fig. 2 Beam divergence vs. acceleration current for two field intensity ratio f of the beam extractor

Arc Efficiency

An arc efficiency η is defined as :

$$\eta = I_{acc} / P_{arc} \tag{1}$$

where I_{acc} and P_{arc} represent the acceleration current and the arc discharge power, respectively. Figure 3 shows the result of the arc efficiency for different neutral hydrogen gas flow rate fed into the ion source. The arc efficiency was high when the gas flow rate was low. It reached 18 mA/kW at 5 SCCM. Lower gas flow rate operation induced an instability of the arc discharge. We chose 4 SCCM to keep the good stability.

Beam Optics

A beam profile was measured by a two dimensional 32 channels wire type monitor installed in the vacuum chamber at 2.4 m downstream from the ion source. The distance between the wires is 2 mm in the central region and 4 mm in the outer region of the monitor area. Figure 4 shows a typical beam profile measured at the vacuum pressure (P_{LEBT}) of 3×10^{-5} Torr in the beam drift region

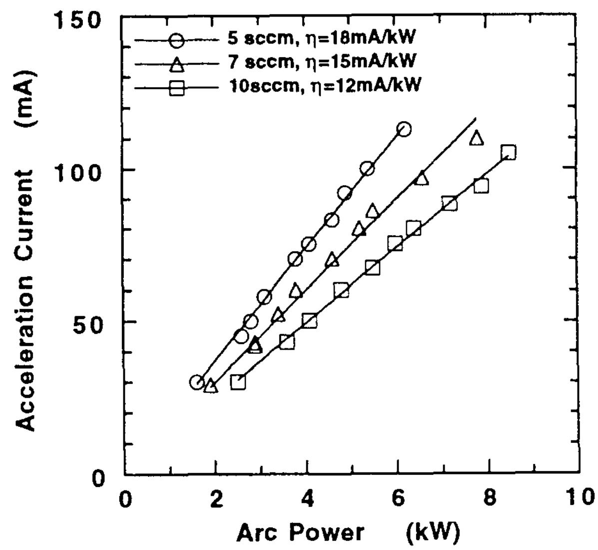

Fig. 3 Arc efficiency for different gas flow rate

without any beam focusing elements. The Gaussian fitting curves in the Fig. 4 reproduce well the data with the e-folding half width beam divergence $\omega_{1/e}$ of 8.5 mrad. Because the space charge force was neutralized by electron in beam plasma in the beam drift region, small enough of beam divergence was obtained without any focusing elements. Assuming the beam diameter at the exit of the ion source is 4 mm, which is predicted by trajectory calculation code [2], normalized emittance is estimated to be 0.5 π mm.mrad(90%). The emittance measurement performed by using a double slit emittance scanner supported the estimation above.

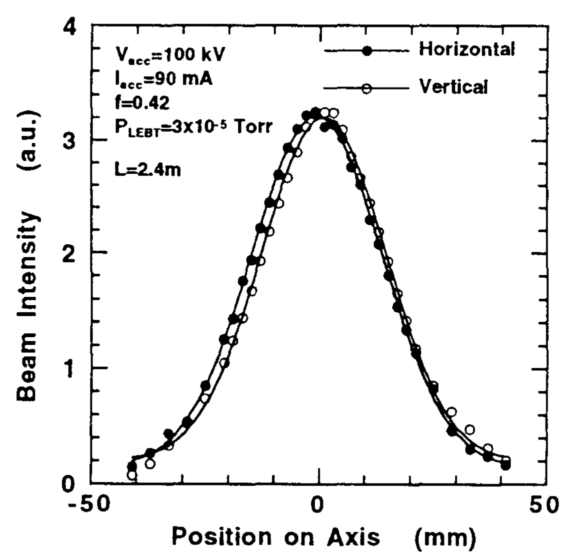

Fig. 4 Typical beam profile of the source

As shown in Fig. 5, the optimum beam current that gives the minimum beam divergence increased with the acceleration voltage, and reached 140 mA at 100 kV (closed circles). We tested to extract the helium beam from the ion source. Figure 5 shows the result of the helium (open circles). By comparing the hydrogen beam current with the helium one, the equivalent mass of hydrogen beam can be estimated. It is estimated to be 1.5 at 100 kV, which agrees well with the precise proton yield measurement described later.

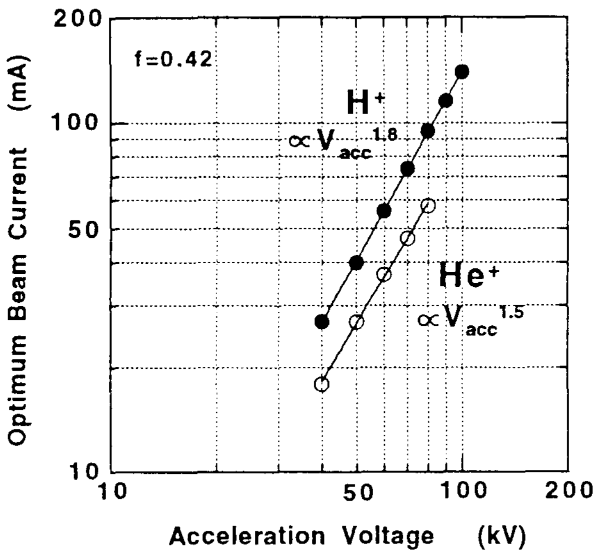

Fig. 5 Optimum current of hydrogen and helium beams

Proton Yield

Hydrogen ion beam consists of three species such as proton (H_1^+) and molecular ions (H_2^+, H_3^+), and also contains impurities; e.g. H_2O^+. In order to enhance the proton yield, the source plasma is confined by strong line cusp magnetic field for enough time to dissociate molecular ions to proton. The ion species ratio and impurities level in the hydrogen beam were measured by observing the Doppler-shifted Balmer alpha radiation emitted from fast hydrogen atoms [5]. Figure 6 shows the result of the ion species ratio as a function of the acceleration current. The proton yield increased with the acceleration current and reached more than 85 % at 120 mA. Because the proton yield can be expected to reach 90 % at 140 mA, proton (H_1^+) beam of 126 mA would be obtained. In addition, one can expect further enhancement of the proton yield by using the magnetic filter effect [2]. The proton yield was confirmed to have weak dependence on the pressure in the arc chamber.

The impurities content decreased with the conditioning of the ion source; it was less than 1 % after one day operation.

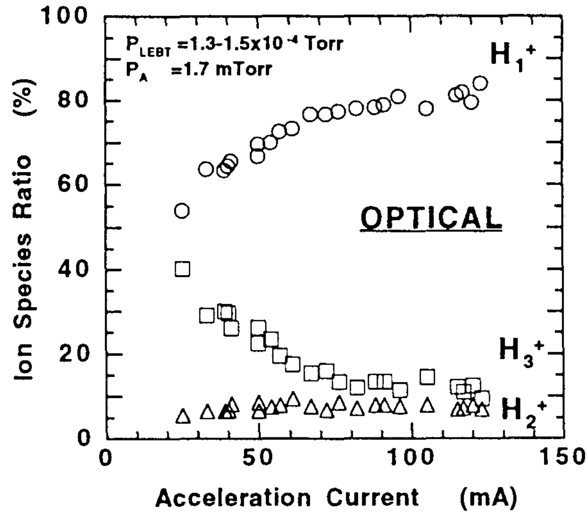

Fig. 6 Ion species ratio vs. acceleration current

Conclusion

The basic performance test at 100 kV demonstrated that the ion source satisfies the requirements for the BTA. The extracted beam current was 140 mA with the divergence and emittance of 8.5 mrad and 0.5 πmm.mrad (90%, norm.), respectively. The proton yield was measured by the Doppler-shifted spectroscopy method, and was found to be more than 85 % at 120 mA.

In this experiment, the filaments for the plasma production were worn and replaced every two months. To extend the lifetime, ECR or RF-driven plasma production would be useful.

In February 1994, an RFQ beam test was performed [6]. The ion source was successfully operated as the RFQ beam injector .

References

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