

DEVELOPMENT OF A HIGH BRIGHTNESS ION SOURCE FOR THE PROTON LINEAR ACCELERATOR (BTA) AT JAERI

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Abstract

A high brightness ion source has been developed for the 10 MeV, 100 mA, 10 % duty, proton linear accelerator called Basic Technology Accelerator (BTA), which is to be constructed at JAERI. The ion source consists of a multicusp plasma generator and a two-stage ion extractor, and is expected to produce 100 keV, 120 mA proton beam with a normalized beam emittance of as low as 0.5π mm.mrad. The design of the ion source and results of the first experiment are presented.

Introduction

A 10 MeV linear accelerator called Basic Technology Accelerator (BTA) will be constructed at JAERI [1]. The objective of the accelerator is to develop the basic technologies required for the construction of the 1.5 GeV linear accelerator, which is being proposed for use in the accelerator-driven nuclear transmutation system as one of the option of OMEGA project [2].

The target of the BTA is to accelerate 100 mA proton beams to 10 MeV with a duty cycle of 10 %. For this accelerator, it is necessary to develop the ion source that produces intense hydrogen beams with a low beam emittance and a high proton yield. Basic specifications proposed for the ion source are listed in Table 1.

A prototype ion source has been designed and fabricated. The significant features of the source are;

- 1) the plasma generator has a good particle confinement, resulting in a high proton yield and a high gas efficiency,
- 2) two-stage extractor is employed to produce a convergent ion beam.

TABLE 1 Specifications of the Ion Source

| | |
|--------------|--|
| Energy | 100 keV |
| Current | 120 mA |
| Duty Factor | CW |
| Emittance | 0.5π mm.mrad (normalized,100%) |
| Proton Ratio | > 90 % |
| Impurity | < 1 % |

First experiment of the prototype ion source was conducted at the ITS-2M Test Stand, which is usually used for the development of the high current ion sources for fusion application. In the present paper, after a description of the ion source design, we present the major results of the first experiment, especially on beam optics and proton yield.

Ion Source

The prototype ion source is shown in Fig. 1. The detailed design should be referred to the Ref. 3, where calculations on beam optics, proton yield and source plasma confinement are also presented. The source consists of a multicusp plasma generator, and a two-stage extractor. The dimensions of the plasma chamber are 20 cm in diameter and 17 cm in depth. The chamber is surrounded by 10 columns of strong SmCo magnets which form a longitudinal line-cusp configuration for primary electron and plasma confinement. The magnetic field at the inner surface is more than 2 kG. These magnet columns are connected at a back plate by four rows of magnets. The open end of the chamber is enclosed by a plasma electrode, where additional 10 rows of magnets are installed except for the central extraction region.

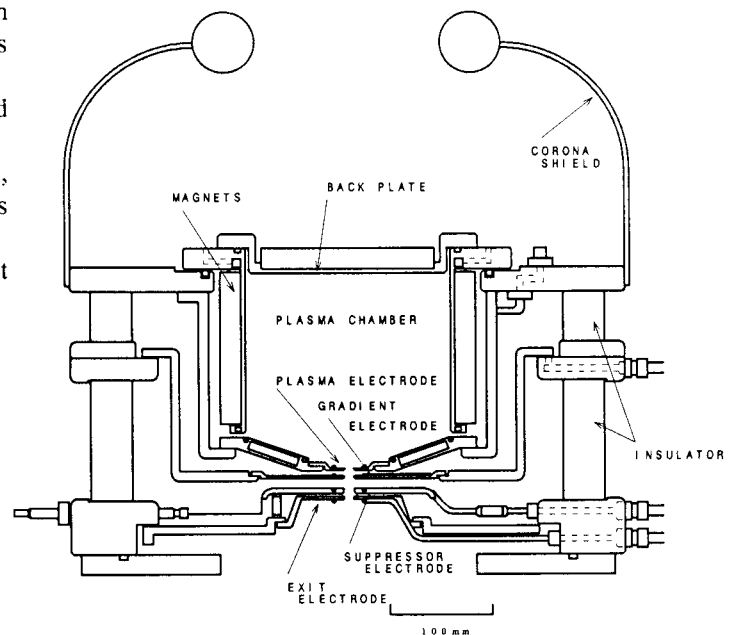


Fig. 1 Cross-sectional view of the prototype ion source for BTA.

*) On leave from Nissin Electric Co. LTD.

CURRENT DENSITY = 2.4000E+02 (MA/CM2)
 TOTAL CURRENT = 9.7886E-02 (A)
 PERVEANCE = 3.0954E-09 (A/V**1.5)
 MINIMUM POTENTIAL = -2.4557E+03 (V) AT Z = 3.0034E-02 (M)
 DIVERGENCE (RMS) = 3.0405E-01 (DEG)
 ELECTRON TEMPERATURE = 0.0 (EV)
 ION TEMPERATURE = 0.0 (EV)

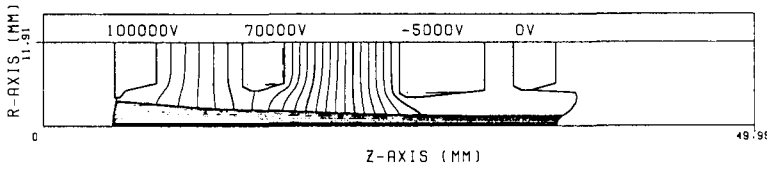


Fig. 2 An example of the ion beam trajectory in two-stage extraction system. The beam energy is 100 keV and the current is 100 mA.

In the present experiment, the plasma was created by arc discharge between four tungsten filaments of 1.2 mm in diameter and the chamber wall. Plasma production by RF is being planned in future for long life operation. In this case, an antenna or micro-wave guide will be attached in the back plate. Preliminary tests on the plasma production by 2.45 GHz micro-wave and 2 MHz RF have already started [4], and a high density hydrogen plasma of $n_e=5 \times 10^{11} \text{ cm}^{-3}$ ($J_{is}=120 \text{ mA/cm}^2$) was produced in a multicusp plasma chamber that has the same dimensions as the prototype ion source.

The extractor is composed of four electrodes called plasma, gradient, suppression and exit electrodes. The cross-sectional view of the electrodes and an example of the ion beam trajectory calculated by computer simulation code are shown in Fig.2. The hydrogen ions are extracted from a single aperture of 8 mm in diameter, and accelerated electrostatically in two stages. The field intensity ratio, f , which is an important parameter in the two-stage extractor [5] and is defined by the ratio of the electric field of the extraction stage to that of the acceleration stage, was chosen to be 0.54 in the present experiment. When $f < 1$, the ion beam is focused by the electrostatic lens between the extraction and acceleration stages.

Experimental Set-up

The ion source was installed in the ITS-2M Test Stand, where the maximum acceleration voltage was 60 kV, and operated continuously up to a pulse length of one hour. The ion beam profile was measured by a multi-channel calorimeter located at 2 m downstream of the ion source. Proton ratio and impurity content in the beam were measured both by a Doppler-shifted spectroscopy [6] and a momentum mass analyzer located about 3.5 m downstream of the source.

The operating gas pressure in the plasma generator was 0.2-1 Pa. Gas flow rate into the ion source was 0.002-0.01 Pa₃m³/s. Since the vacuum chamber was evacuated by 10 m³/s pumping system, the pressure in the beam drift region was an order of 10⁻³ Pa. At this pressure, the ion beam becomes divergent because of the space charge expansion effect. To neutralize the space charge, the gas pressure in the beam drift region was kept 0.1-0.2 Pa by regulating the pumping speed and/or injecting an additional gas into the

vacuum chamber throughout the experiment.

Experimental Results and Discussion

Beam Optics

Figure 3 shows the beam divergence as a function of beam current for various acceleration voltages. The optimum current which gives the minimum beam divergence for each voltage increases with the acceleration voltage as expected by the Child-Langmuir law, showing a good agreement with the trajectory calculation [3]. A convergent ion beam of 60 keV, 56 mA, of which perveance is higher than that of 100 keV, 120 mA proton beam, was produced with an e-folding half-width divergence of 10 mrad. Assuming the beam diameter was 4 mm at the exit of the ion source, we estimated the normalized emittance was less than 0.5 π mm.mrad (90%). This estimation was confirmed by the emittance measurement. Figure 4 shows an example of emittance diagram obtained at 50 keV, 40 mA. The normalized emittance is 0.45 π mm.mrad (90%), which satisfies the specification of BTA.

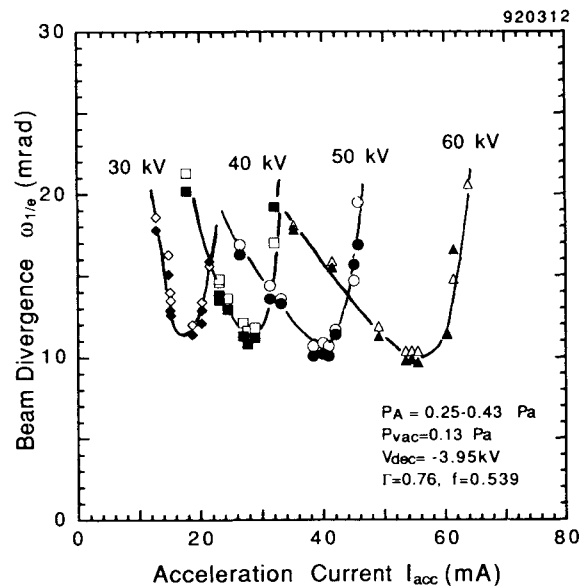


Fig. 3 Beam divergence for various acceleration voltages as a function of acceleration current. Open symbols: Vertical divergence Blacked: Horizontal

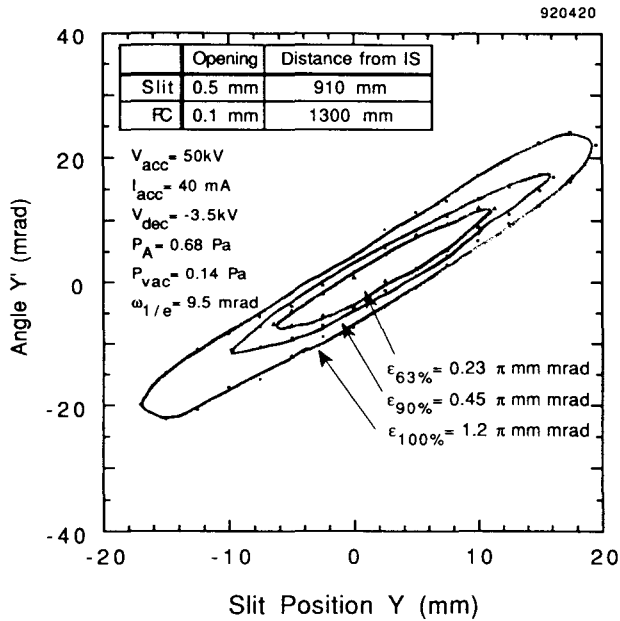


Fig. 4 Emittance diagram at 50 keV, 40 mA. The emittance was measured by a set of the slit and the Faraday cup located at 910 mm and 1300 mm, respectively.

Proton Ratio

The hydrogen ion beam contains not only H^+ ions (protons) but also molecular ions such as H_2^+ and H_3^+ . Higher proton ratio is preferable for the accelerator application. To enhance the proton yield, the ion confinement in this source is improved by strong magnetic line cusps so that the produced molecular ions are confined for enough time to dissociate to protons. The confinement of the atomic hydrogen (H_1^0) is also important so that the H_1^0 has enough time to be ionized to protons.

Figure 5 shows the ion species ratio measured by the momentum mass analyzer, where the arc discharge current was increased to increase the acceleration current. The proton ratio increases with the acceleration current, and reaches 80 % at $I_{acc} = 52 \text{ mA}$. Same dependence was observed by the Doppler-shifted spectroscopy, while the proton ratios were about 5 % lower than the values measured by the mass analyzer; e.g. 76 % at $I_{acc} = 60 \text{ mA}$.

The reason why the proton ratio increases with the arc current is that the dissociation of molecular ions and H_2 molecules are enhanced because of the higher electron density and temperature. Therefore, the proton ratio will increase at higher beam current. We expect that proton ratio of 85–90 % will be achievable at $I_{acc} = 120 \text{ mA}$. This proton ratio agrees well with the prediction based on the scaling law of the proton ratio [3,7].

The impurity content was very high at the beginning of the operation. After the conditioning of the source with continuous operation, the impurity content was decreased to less than 1 %.

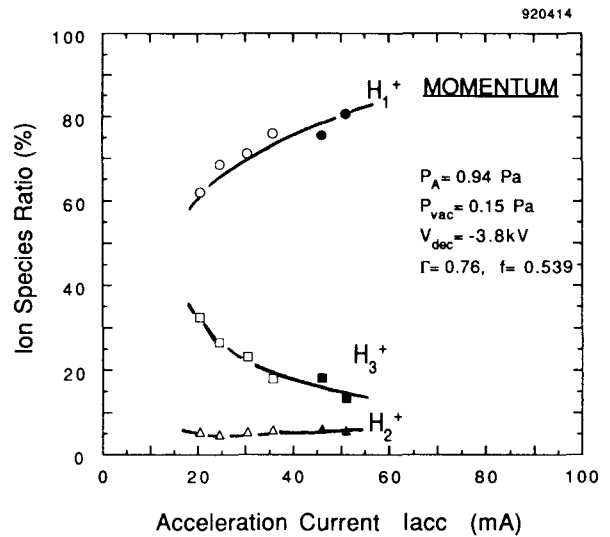


Fig. 5 Ion species ratio measured by the momentum mass analyzer. The proton ratio increases as the ion beam current increases.

Conclusion

A prototype ion source for the BTA was designed and tested using a 60 kV test facility. A convergent ion beam of 60 keV, 56 mA, of which perveance is higher than that of 100 keV, 120 mA, was produced continuously with an e-folding half-width divergence of 10 mrad. The normalized beam emittance of $0.45 \pi \text{ mm.mrad}$ (90%) was obtained. The proton ratio was measured by the Doppler-shifted spectroscopy and the momentum mass analyzer, and was found to be 80 %.

We are now constructing a new test stand that has a power supply of 100 kV, 200 mA. Using this test stand, full energy test will be conducted in the end of 1992.

References

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