DEVELOPMENT OF A NEGATIVE ION SOURCE FOR A HIGH INTENSITY LINAC

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Abstract

A negative hydrogen ion source has been developed for a high intensity proton linear accelerator. The ion source is a volume production type. Negative ion is generated in a magnetically filtered multi-cusp plasma generator. The negative ion production is enhanced by seeding a small amount of cesium in the plasma generator. It is demonstrated that negative ion beamlets extracted from multiple apertures can be focused by aperture displacement technique, which is useful to obtain higher ion beam current.

Introduction

At JAERI, construction of a 1.5 GeV/10 mA proton linear accelerator has been proposed for engineering tests of accelerator-based nuclear waste transmutation and for various basic science researches[1]. At the first stage of the ion source development for the accelerator, a positive hydrogen ion source was fabricated. The ion source has been successfully operated at the full design value of 100 keV and 140 mA peak [2]. At the second stage of the development, a negative hydrogen ion source has been newly designed and fabricated. Negative ion beam is required mainly for basic science researches to inject the beam into the storage ring which produces certain specific pulse duration and repetition rate at the high energy portion of the accelerator.

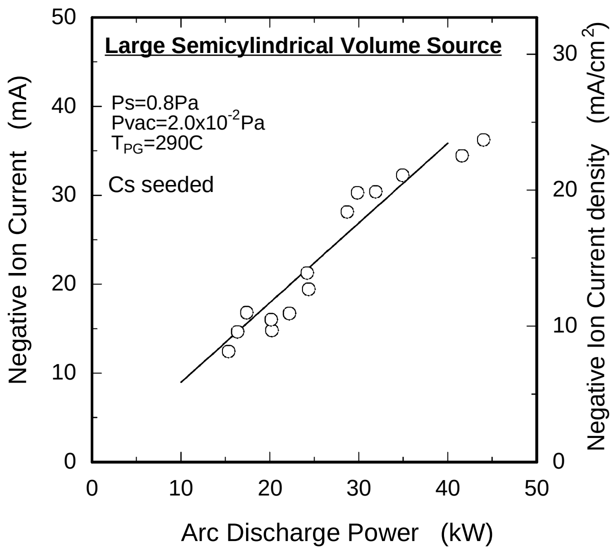

Fig. 1. Negative ion current (density) extracted from the large semicylindrical volume type source

The basic performance of single aperture beam extraction system was investigated with the volume production type negative ion source which has been originally developed for a neutral beam injector for fusion application [3]. The plasma generator, whose dimensions are 340 mm in diameter and 340 mm in length, has a large semicylindrical volume. Figure 1 shows the negative ion current (density) as a function of the arc discharge power. The extracted ion beam current (density) of 36 mA (23 mA/cm^2) was obtained at the arc discharge power of 45 kW with a low beam emittance [4]. In order to obtain higher beam current, the negative ion beam is extracted from multiple apertures and the beamlets are focused by aperture displacement technique. The positive ion source that was used for previous beam performance experiments [2] is modified to produce the negative ion beams in the present experiment.

Design of the Ion Source

Figure 2 shows a cross sectional view of the multi-aperture volume production type ion source. Negative ions are generated in a magnetically filtered multi-cusp plasma generator, whose dimensions are 200 mm in inner diameter and 170 mm in length. The dimension of the ion source is the same as the positive hydrogen ion source [2] except for the existence of the transverse magnetic field, which is created by changing the polarity of the cusp magnets near the plasma grid. The source plasma is produced by an arc discharge using four tungsten filaments, and confined by strong multicusp magnetic field. A magnetic filter, which is formed by Sm-Co permanent magnets, divides the generator into two regions and modifies electron energy distribution so as to produce negative ions. Negative ion production rate is enhanced by seeding a small amount of cesium [5] in the plasma generator.

The beam extractor consists of four grids such as a plasma grid, an extraction grid, an electron-suppression grid and a grounded grid. The plasma grid is made of molybdenum plate. There is a strong dependence of the negative ion production rate on the plasma grid temperature. This is because the cesium coverage is optimized by the temperature rise to give a minimum work function of the plasma grid surface. The plasma grid is heated up by pulsed arc discharge power. The extraction grid is made of a 10 mm thick copper plate with a water cooling channel and magnet grooves. In the extraction grid, Sm-Co permanent magnets are inserted so as to produce a dipole magnetic field. This field deflects the extracted electron and prevents the leakage of the electron to the acceleration gap. The electron-suppression grid is installed for trapping the leakage electron escaping from the extraction grid.

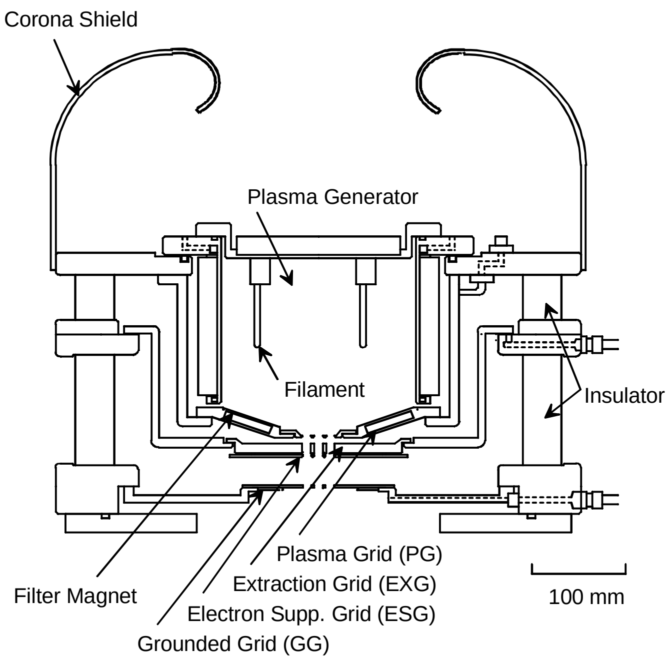

Fig. 2. Cross sectional view of the multi-aperture volume type negative ion source

In the present experiment, produced negative ions are extracted from seven apertures of 9mm in diameter. Figure 3 shows the cross sectional view of the extractor. The distance between the position of the central aperture and that of the peripheral ones are 13 mm on the PG and the EXG. The peripheral six apertures in the ESG and GG are displaced by 1mm to the direction of center axis. A strong electrostatic lens is formed by the electric field applied in the gap between the ESG and GG. The beamlets extracted from the peripheral apertures are steered by the electrostatic lens to merge into a single beam.

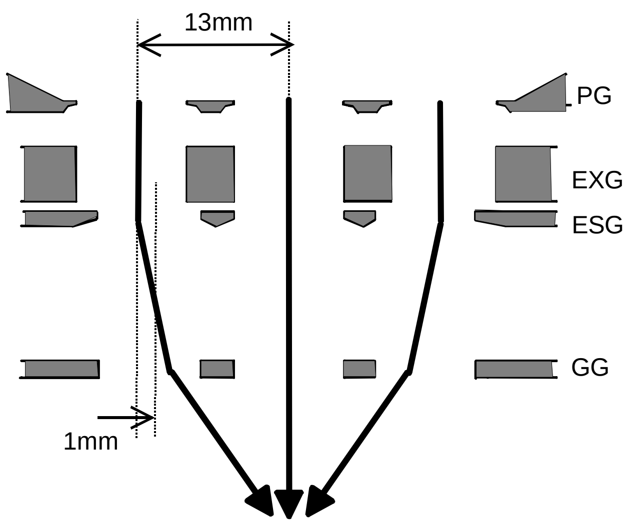

Fig. 3. Cross sectional view of the beam extractor with the aperture displacement technique

Experimental Results

To measure the beam current and profile, a multichannel calorimeter was installed at 1.4 m downstream from the ion source in the beam diagnostics chamber, where we confirmed no electrons reached to the calorimeter. The calorimeter is made of copper buttons placed on a water cooled copper plate in two perpendicular directions. Temperature distribution of the buttons gives the beam profile and beam current.

Figure 4 shows the negative ion current as a function of the arc discharge power for the operations with and without cesium. The filling hydrogen gas pressure in the plasma chamber (Ps) was 0.8 Pa. In the pure volume operation, the ion current tended to saturate at high arc discharge power and was limited to be 20 mA. In the cesium-seeded operation, on the other hand, the beam current was enhanced by about three times and increased lineally with the arc discharge power. The negative ion current (density) of more than 70 mA (16 mA/cm^2) was obtained at 25 kW. The current density is defined by the beam current divided by the total beam extraction area of 4.45 cm^2.

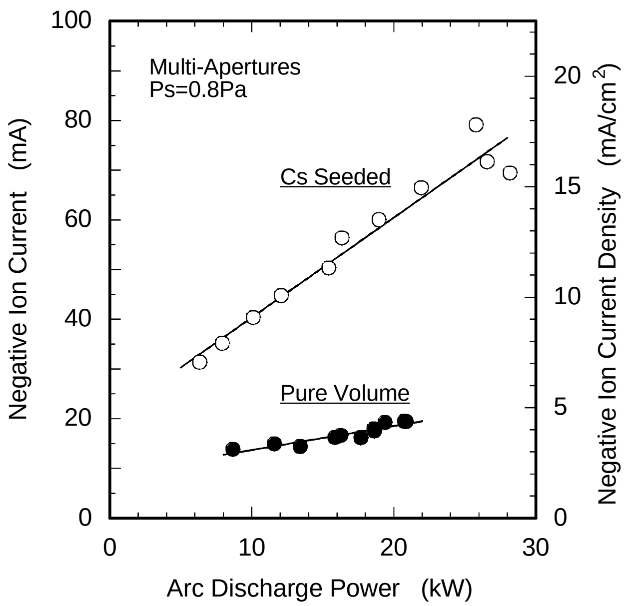

Fig. 4. Negative ion current (density) as a function of the arc discharge power for the operations with and without cesium

The single beam extraction test was also performed using the ion source by covering the peripheral apertures on the plasma grid with a thin molybdenum plate. Figure 5 shows the negative ion current and the beam divergence from a single aperture as a function of the beam energy. To prevent the beam from spreading by space charge expansion effect, the vacuum pressure in the beam diagnostics chamber was kept at 3.7 x 10^{-2} Pa where the space charge of the negative ion beam was neutralized by the positive ions in the beam plasma. The small beam divergence $\omega_{1/e}$ of less than 6 mrad was obtained at a beam energy of 40 keV. The beam current density was 12 mA/cm^2 at the arc discharge power of 20 kW.

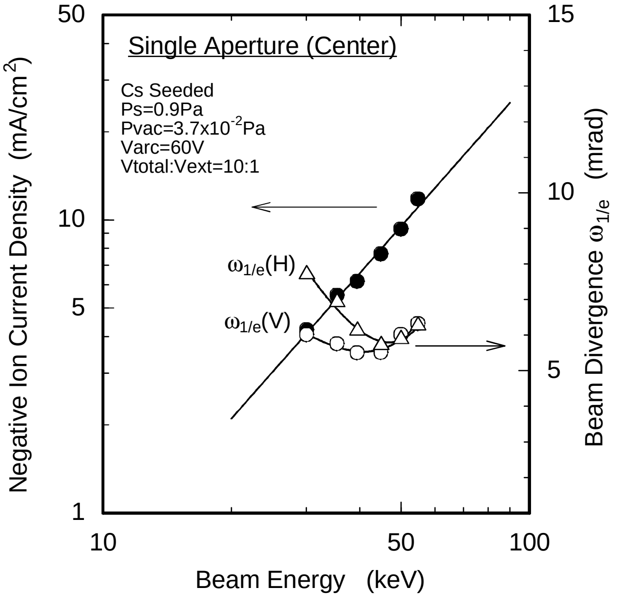

Fig. 5. Negative ion current density and beam divergence extracted from a single aperture

In the multi-aperture extraction experiment, the emittance in vertical plane was measured using a double slits with a Faraday cup system at an acceleration voltage of 30 kV. The distance between the slits is 390 mm. The size of the first and second slits are 0.5 mm x 50 mm and 0.1 mm x 50 mm, respectively. Figure 6 shows the emittance diagrams at the ion source position. These three diagrams corresponding to those which were extracted from central aperture (closed triangles) and lower aperture (closed circles), upper aperture (closed squares), respectively. The normalized 90 % emittance of each beam was calculated to be about 0.8 πmm.mrad. The beam steering angle is determined by comparing the angle of the peripheral beam axis with that of the central one. Because the beam from the lower (upper) aperture has the steering angle of + (-) 15 mrad, the beam trajectory was found to be deflected towards the center of the ion source. The focal point of the merged beamlets is estimated to be 800 mm downstream from the ion source. The beam trajectory measurement by observing the Balmer-alpha light emission from the negative hydrogen ion with CCD camera supported the result of the emittance measurement.

The R&D work is to be continued so as to investigate the dependence of the steering angle on the various type of the displacement. The steering angle is 1.5-2 times larger than the value predicted by the linear theory using thin lens approximation [6]. The experimental result is to be compared with the value calculated by the 3-D beam trajectory code, which is under preparation.

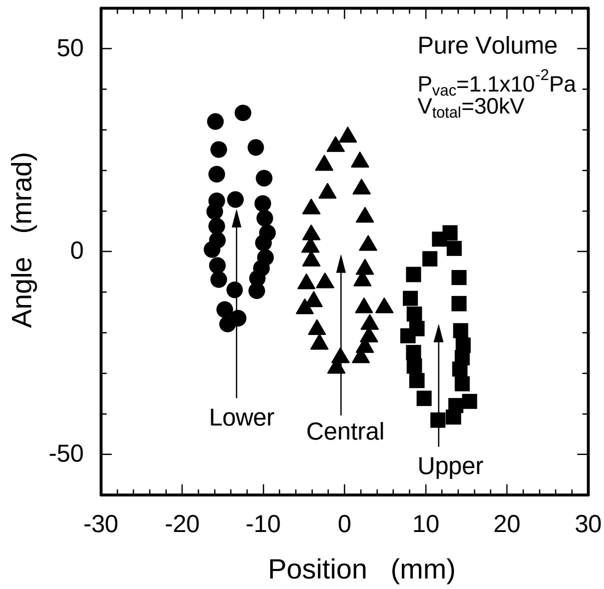

Fig. 6. Emittance diagrams from the multi apertures at the ion source position

Conclusion

The beam test of the negative hydrogen ion source has been performed. The negative hydrogen ion current extracted from seven apertures was about 70mA with a current density of 16 mA/cm^2 at an arc discharge power of 25kW. The measurement of the beam emittance and the Balmer-alpha light emission showed the beamlets from the multi aperture were successfully merged. The result proved that the aperture displacement technique has a possibility to produce the high brightness beam.

We are now preparing to perform the negative ion beam acceleration test by using the ion source and the 2 MeV RFQ which has been developed for the proton acceleration [7].

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