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Development of a High Brightness Negative Hydrogen Ion Source

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ABSTRACT

Development of a high brightness negative hydrogen ion source has been performed for a high intensity proton linear accelerator. Negative ions are 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. As the result of the ion source beam test, negative hydrogen ion beam of 36 mA (23 mA/cm^2) was extracted from a single aperture at an acceleration voltage of 50 kV. To obtain higher ion beam current, the focusing of beamlets extracted from multi-aperture grid has been demonstrated with aperture displacement technique.

1. 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]. A high brightness positive hydrogen ion source was fabricated for the accelerator. The ion source has been successfully operated at the full design value of 100 keV and 140 mA peak [2]. At the next stage of the ion source development, a negative hydrogen ion source has been newly designed and fabricated. Negative ion beam is required mainly for basic 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.

The basic performance of single aperture beam extraction system was investigated with the volume negative ion source which has been originally developed for the neutral beam injector for fusion application [3]. The multi-aperture beam extraction with aperture displacement technique was also tested with the modification of the positive ion source which was used for previous beam performance experiments [2].

2. SINGLE APERTURE EXTRACTION

Ion Source

Figure 1 shows a cross-sectional view of the volume production type ion source. The plasma generator, whose dimensions are 340 mm in diameter and 340 mm in length, has a large semi-cylindrical volume and strong magnetic cusp field. The source plasma is produced by arc discharge using eight tungsten filaments. The filaments are supported by molybdenum chips on coaxial feedthroughs. The plasma is 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 ion. Negative ion production rate is enhanced by seeding a small amount of cesium in the plasma generator.

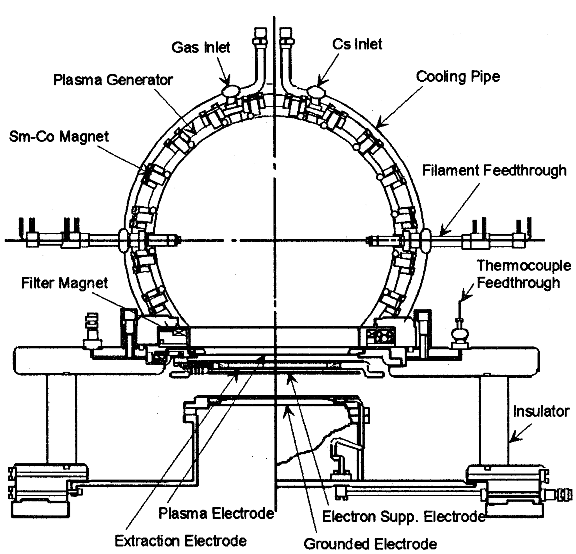

Fig.1 Cross sectional view of the negative ion source

The beam extractor consists of four electrodes such as a plasma electrode (PE), an extraction electrode (EXE), an electron-suppression electrode (ESE) and a grounded electrode (GE). Negative ion is extracted from a single aperture of 14 mm in diameter. The gap length are adjusted to 5.1 mm between the PE and EXE, 2.5 mm between EXE and ESE, and 30 mm between ESE and GE. The plasma electrode is made of molybdenum plate. There was a strong dependence of the negative ion production rate on the plasma electrode temperature. This is because the cesium coverage is optimized by the temperature rise to give a minimum work function of the plasma generator surface. The plasma electrode was heated up at 200 - 300 °C by pulsed arc discharge power and its temperature was controlled by the duty cycle of the power. The temperature was monitored by a thermocouple. The extraction electrode is made of a 11 mm thick copper plate with a water cooling channel and magnet grooves. In the extraction electrode, 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 electrode is installed for trapping the leakage electron escaping from the extraction electrode. By applying deceleration voltage of a few kV, electron leakage is suppressed efficiently.

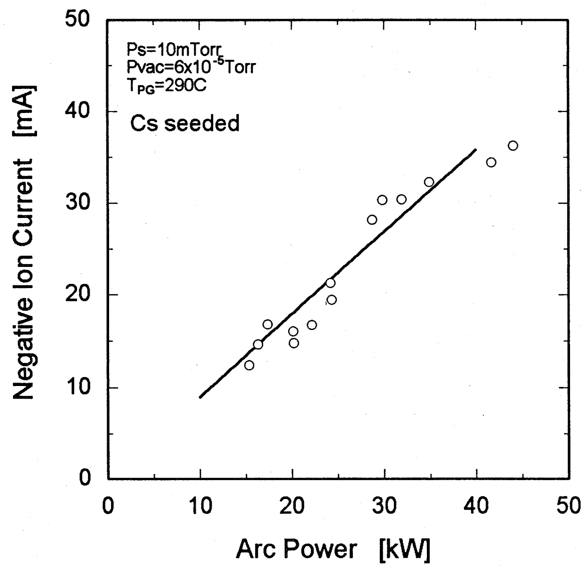

Fig.2 Negative ion beam as a function of arc discharge power

Extracted Ion Current

For measurements of 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 no electrons reached to the calorimeter. Figure 2 shows the negative ion current as a function of the arc power at filling hydrogen gas pressure of 10 mTorr. The beam current increased with the arc power and reached to 36 mA at 45 kW. The arc efficiency which is defined by the ratio of the beam current to the arc discharge power is calculated to be 0.9 mA/kW.

Beam Optics

The emittance of the negative ion beam was measured by using a double slits with a Faraday cup system. To prevent the beam from spreading by space charge force, the vacuum pressure in the beam diagnostics chamber was kept at 8 x 10^{-5} Torr where beam neutralization effect is expected for negative ion beam. Figure 3 shows a typical emittance diagram at an acceleration voltage of 50 kV and a beam current of 20 mA. As shown with solid and dotted lines in the figure, there are two beam components corresponding to those which are extracted from central and peripheral region of the electrode, respectively. These two components have different intensity distributions as a function of the beam divergence. The normalized emittance of the beam from the central region was calculated to be 1.1 πmm.mrad. Such a large amount of the beam from the peripheral region is due to aberration of beam optics and may be decreased by optimizing the beam extractor.

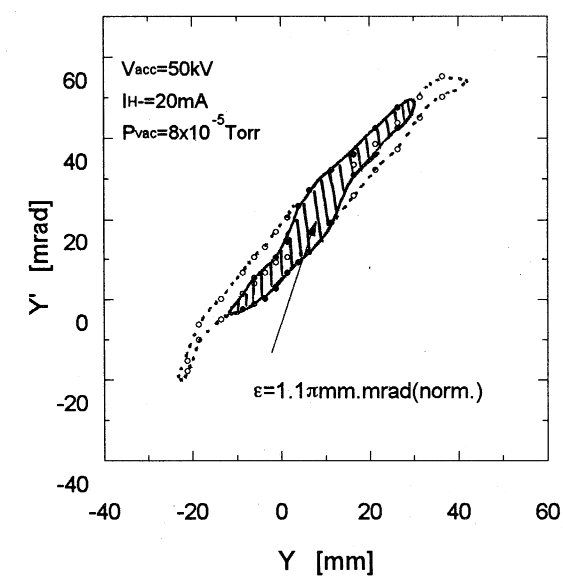

Fig.3 Emittance diagram at an acceleration voltage of 50 kV

3. MULTI APERTURE EXTRACTION

The multi-aperture beam extraction with aperture displacement technique was tested. The basic design 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. A conceptual illustration of the aperture displacement technique is shown in Fig. 4. The peripheral apertures on electron-suppression grid and grounded grid are slightly displaced, and the negative ion beams extracted from peripheral apertures are steered by electrostatic lens. Each beamlet is merged into a single beam at the entrance of the accelerator.

In the preliminary beam test, the beam trajectories were measured by observing the Balmer-alpha light emission from the negative hydrogen ion with CCD camera. It has demonstrated that the beamlets from seven apertures were successfully merged into single beam at the focusing point of about 1 m downstream of the ion source.

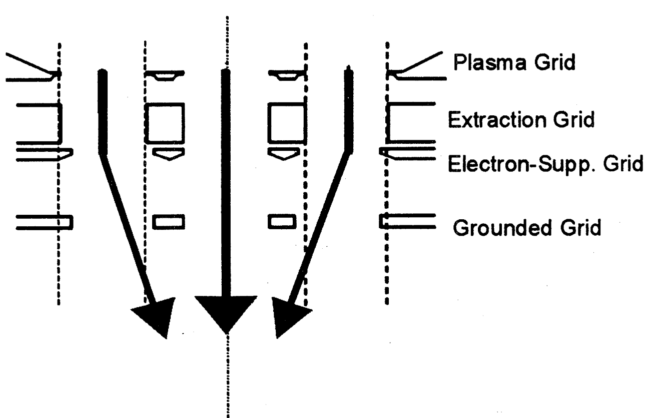

Fig.4 A conceptual illustration of the multi-aperture displacement technique

4. SUMMARY

The beam test of the negative hydrogen ion source has been performed. The extracted ion beam current (density) from a single aperture of 14 mm in diameter was 36 mA (23 mA/cm^2) at the arc discharge power of 45 kW. The test of the aperture displacement technique has also been performed. The preliminary test proved that the technique has a possibility to produce the high brightness beam. The R&D work of the technique is continued.

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