Simultaneous Measurements of Proton Ratio and Beam Divergence of Positive-Ion-Based Neutral Beam in the Large Helical Device

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A spectroscopy system was installed on the diagnostic neutral beam injector in LHD. The H_α lines spectrum emitted by full, half and one-third energy component are clearly observed, and the proton ratio and the beam divergence were estimated by the line intensity and the line width, respectively. The proton ratio of 85~90 % is achieved in high arc power discharge. The beam divergence of them shows their minimum with the same perveance. It was experimentally confirmed that the spectroscopy system is useful for the monitor of the proton ratio and the divergence of the beam.

Keywords: diagnostic neutral beam, proton ratio, beam divergence, positive-ion-based neutral beam injector, beam emission

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1. Introduction

Positive-ion-based neutral beam injector (P-NBI) was installed in the Large Helical Device (LHD) at 9th experimental campaign (2005-2006). The neutral hydrogen beam with energy of 40 keV was injected into LHD plasmas perpendicularly to the magnetic field, and was optimized and utilized as a diagnostic neutral beam (DNB) for charge exchange spectroscopy (CXS) measurements. The P-NBI is useful as various experimental tools such as a particle fueling tool into the plasma and ion heating beam because the low energy beam has a higher efficiency of ion heating than that of high energy beam (180 keV) [1] produced by negative-ion-based neutral beam injectors (N-NBIs) installed in LHD [2]. In order to evaluate beam deposition in the plasma, it is necessary to know proton ratio of the beam because half and one-third energy components are included in the beam produced by P-NBI, which is often measured by beam emission spectroscopy method [3, 4]. Moreover the high proton ratio beam is preferred for CXS measurements.

On the other hand, the beam divergence is also important parameter because it is necessary for accurate estimation of port-through power of the beam, and it affects the spatial resolution of the CXS. The monitor and control of proton ratio and beam divergence are required for various fusion plasma experiments with high power NBI.

A simultaneous monitoring system of the proton ratio and the beam divergence were developed by a observation of H_α lines spectrum emitted by the beam in LHD P-NBI system. The spectroscopy system for beam emission H_α spectrum and preliminary results are discussed in this paper.

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2. Experimental

The specification of P-NBI in LHD of 40 keV beam energy was optimized for CXS of CVI spectrum. Four positive ion sources (ISs) based on hot-cathode (filaments) arc discharges were mounted on the injector and produce hydrogenous ions of 75A/IS. Total beam power and beam duration are 6 MW and 10 sec, respectively. The all axes of IS are focused on the 8.3 m far from the ISs. The beam ions are accelerated by multi-aperture single-acceleration-grids system, which is shown in Fig. 1. All grids are made of oxygen-free cupper, and cooled by cooling water. Hydrogenous ions accelerated by the voltage between plasma grid (PG) and grounded grid (GG), and the back streaming electrons are suppressed by the negatively biased deceleration grid (DG). The all beam lets are focused at 8.3 m from GG by shifted aperture of DG. The beam injector is located

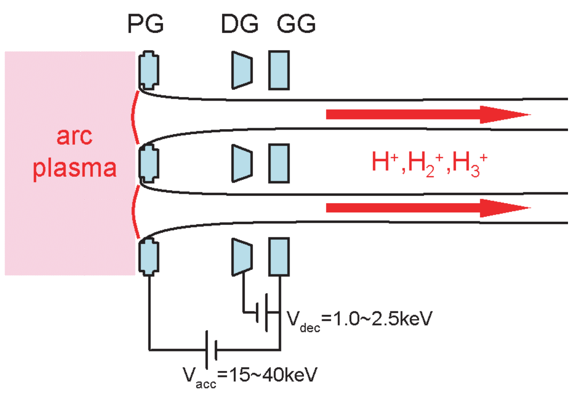

Fig. 1 The schematic of beam acceleration region. The three multi-aperture grids are biased and accelerate hydrogenous ions from arc plasma.

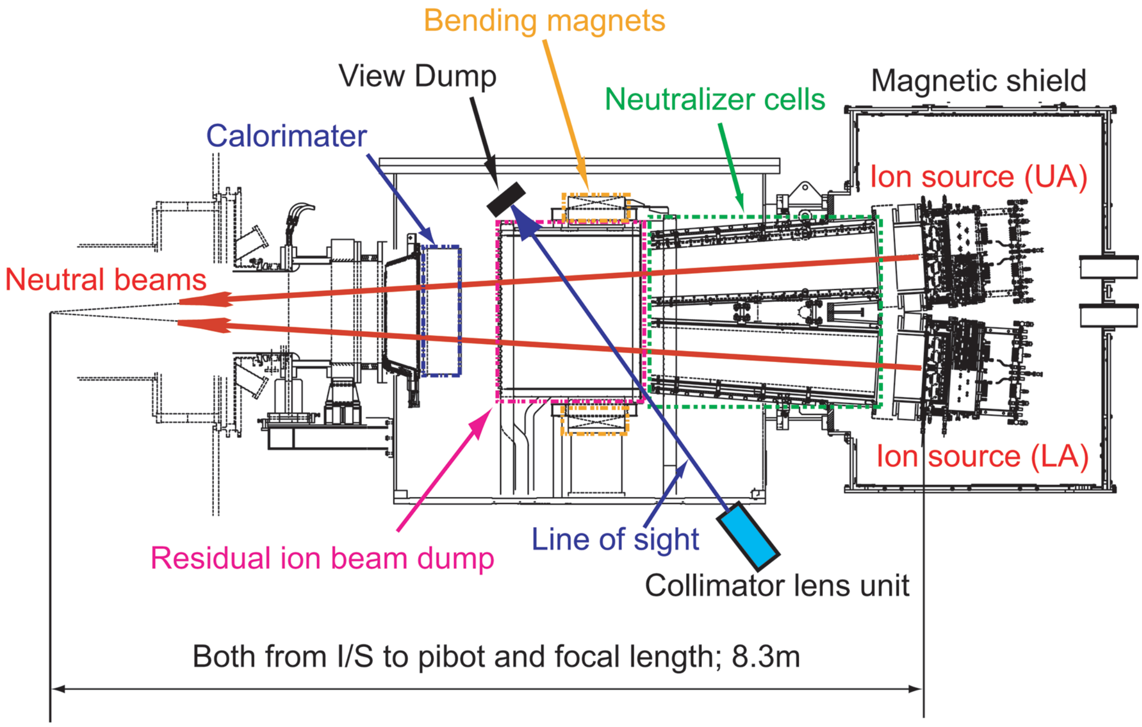

Fig. 2 The schematic of the beam injector. The hydrogenous ions are produced by four ISs mounted on the injector, and are neutralized through the gas cell with the length of 2.5 m. The residual ions are bended by the magnetic field and attack the beam dump. The neutral hydrogen beams are going straight through the drift tube, and are injected into the plasma.

at an outside port (5-O) of LHD and is shown in Fig. 2.

In order to monitor the proton ratio and the beam divergence, a spectroscopy measurement of beam emission H_α spectra was installed in the P-NBI beam line. The line of sight crosses obliquely two beams with the angle of 63.4 degree for UA and UB ISs and 56.6 degree for LA and LB ISs. The collimator lens unit and viewing dump were utilized to suppress background stray light. The optical fiber transfers the beam emission light to the spectrometer. The spectral resolution of the spectrometer is 0.15 nm with the focal length of 303 mm and holographic grating of 1800 g/mm. The charge-coupled device (CCD) detector is set at the focal plane of the spectrometer and is utilized for the detector of the light under the cooled down condition with the temperature of −50 degree in order to reduce a thermal noise.

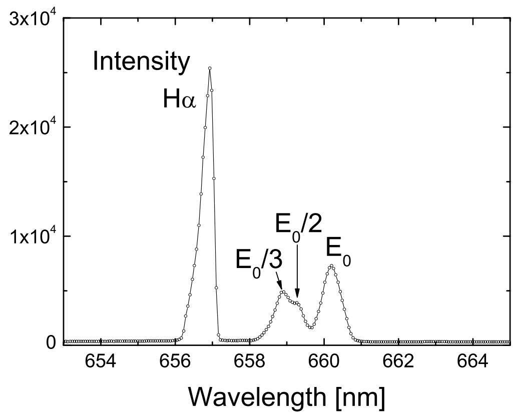

Fig. 3 The spectrum of H_α emission.

3. Experimental Results and Discussions

The spectroscopy measurements of the H_α emissions were performed in the case of only one IS operation. The H_α emission from background neutral atoms, full, half and one-third energy components are clearly observed, which are shown in Fig. 3. The line intensities are obtained by Gaussian fitting of each line, and the beam power ratio of each energy components is shown in Fig. 4 (a). The proton ratio increases as the arc power increases. It is considered that the electron temperature increases in high arc power discharge and electrons dissociate hydrogen molecules. Such species compositions depending on the arc power is similar ones in a compact bucket source analyzed by a bending magnet [5]. The maximum proton ratio of our P-IS is 88 % for high arc power operations (> 100 kW).

The widths of the spectra emitted by the beam are larger than that of background neutrals (see Fig. 3), and this implies that the line width of the beam includes information about the beam divergence. The spectral width of each energy components depends on the perveance ($I_{beam}/E_{beam}^{3/2}$), which is shown in Fig. 4 (b). The minimum spectral width of full, half and one-third energy components are given by same perveance, which is reasonable because the beam divergence is dominated by the beam optics

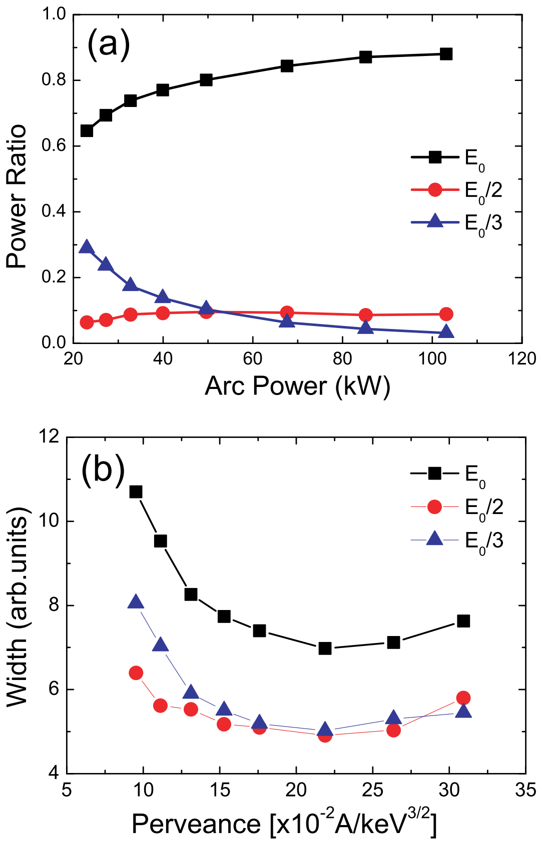

Fig. 4 (a) The power ratios of full, half and one-third energy components as a function of arc power. (b) The perveance dependence of line width of the H_α emissions.

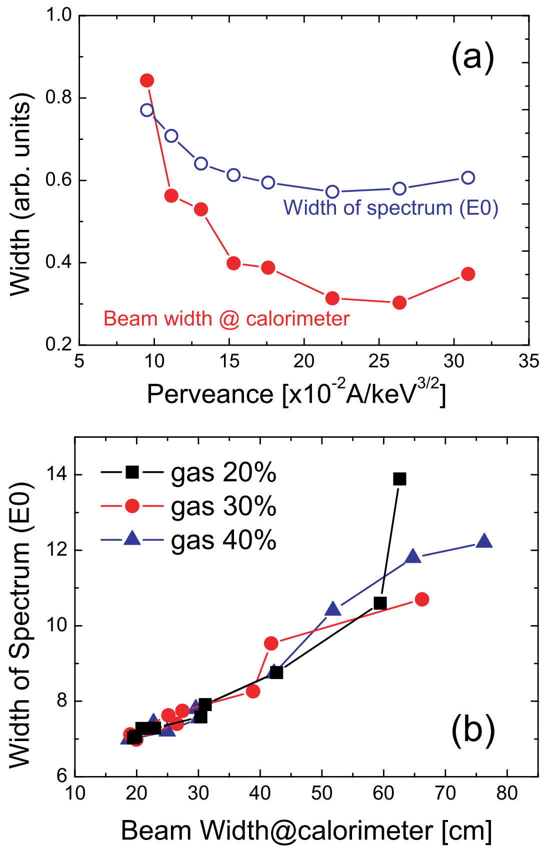

Fig. 5 (a) The beam width measured by the calorimeter and the line width of full energy beam component. (b) The correlation of them in the cases with the gas fueling rate of 20 %, 30 % and 40 %.

in the acceleration region. The electric field between PG and DG penetrates into the plasma and produces a convex lens structure. The charged-ions fall the potential slop perpendicularly crossing the equipotential surface (see Fig. 1). It is important to monitor and control the perveance condition for keeping the beam quality.

The beam profile can be measured by a calorimeter installed in the beam line as shown in Fig. 2. The beam width on the calorimeter and spectrum width of H_α emission depend on perveance, which are shown in Fig. 5 (a). The optimum perveance for beam width measured by calorimeter gives also the minimum spectrum width. This indicates that the calorimeter and the beam emission spectrometer can observe the optimum perveance which gives the minimum beam divergence. The beam width measured by the calorimeter has almost linear relation to the spectrum width observed by the spectroscopy, which is shown in Fig. 5 (b). It was demonstrated and experimentally confirmed that the spectroscopy measurement of the beam emission is useful for simultaneous monitoring of the proton ratio and the beam divergence.

4. Conclusion

The spectroscopy measurement system of H_α emission from neutral beam was developed and installed in the LHD P-NBI injector. The experimental demonstration was performed. The proton ratio and the beam divergence are estimated by the intensity and width of the beam emission H_α. The preliminary results show that this spectroscopy system is useful for simultaneous monitoring of the proton ratio and the divergence of the beam. The development of the automatic measurement of the proton ratio and the estimation of deposition power taking into account the result of the proton ratio observation are left for future study.

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