A NEGATIVE ION BEAM PROBE FOR DIAGNOSTICS OF A HIGH INTENSITY ION BEAM

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Abstract

We propose a negative ion beam probe system as a new scheme to diagnose beam profiles of high power positive ion beams. In this paper, we describe the principle of the beam profile monitor using negative ion beam injection, problems to be conquered and the present status of the system development.

INTRODUCTION

Selection of plasma facing materials that endure high flux irradiation of neutrons of 14 MeV produced by D-T nuclear reactions is one of the most important issues to realize energy production by nuclear fusion reactors. ITER will play an important role to study the physical properties of thermonuclear plasmas and to develop some key technologies for that goal. However, the amount of neutrons produced in ITER will be smaller than that produced in the next stage fusion demonstration reactors (called DEMOs) by two orders of magnitude. Thus, IFMIF (International Fusion Materials Irradiation Facility) [1] is being designed to investigate materials performance under an energetic neutron exposure condition with the intensity close to DEMOs.

The IFMIF is an accelerator driven neutron source consisting of two linacs each of which provides a continuous-wave (CW) positive deuterium ion (D^+) beam. One single linac delivers a beam current of 125 mA (total 250 mA by two linacs) at the beam energy of 40 MeV. The two D^+ beams are injected into a 25 mm-thick Li jet flowing at a speed of nominally 15 m/s. Nuclear reactions between deuterons and lithium nuclei produce an intense neutron flux at the order of 10^{18} n/m^2/s with the energy spectrum simulating the irradiation conditions encountered in the DEMO. The IFMIF/EVEDA (Engineering Validation and Engineering Design Activities) project has been started in the middle of 2007, as the joint implementation agreed between Europe and Japan in the field of fusion energy research and development [2]. An accelerator prototype will be designed, manufactured and tested according to the specification details described elsewhere [3].

During the CW operations of IFMIF accelerators and the prototype, the extremely high intensity of the D^+ beams and the severe radiation environments make the beam diagnostics by conventional techniques in the transport lines next to impossible. A widely used wire-scanning type beam profile monitor can cause severe scattering of D^+ to damage beam line components. Components including the wire monitor itself become radioactive after certain period of operation. A gas cell type beam monitor deteriorates vacuum of the beam line as well as the optics of the main D^+ beam. Other existing methods also have defects in the usage of IFMIF beam line conditions.

We propose an active beam probe system to diagnose beam profiles of high power positive ion beams. A negative ion of small electron affinity is liable to lose the additional electron at the impact with a high energy beam particle. Intensity of the negative ion current altered by the electron detachment reflects the positive ion density integrated along the path of the negative ion beam. One possible configuration to achieve the spatial profile measurement for a high energy and high intensity beam is to inject a negative ion probe beam into the target beam perpendicularly, and measure the space-dependant attenuation of the negative ion beam due to beam-beam interaction at each position. We have started an experimental study for the proof-of-principle of the new beam profile monitoring system. The paper presents the status quo of the development of the beam profile monitor system aiming at the beam profile measurement in the IFMIF beam line.

HIGH INTENSITY POSITIVE ION BEAM PROFILE MONITOR BY A NEGATIVE ION PROBE BEAM INJECTION

Figure 1 shows a conceptual drawing of the negative ion beam probe system to diagnose the beam profile of high intensity positive ion beams. An H^- ion source is placed where the radiation level is low enough for hands-on maintenance. The source produces H^- beam with the beam intensity low enough not to affect the D^+ beam optics. However, it should have a high brightness to pass a long distance from the H^- source to a detector of hydrogen (H^-, H^0 and H^+) beams. The rectangular H^- beam crosses the D^+ beam perpendicularly, and the long side of the rectangle covers the entire cross section of the D^+ beam. The short side of the beam is to be thin so as to precisely measure the spatial distributions of the produced beams.

The H^- beam is attenuated by the collisions with D^+ ions in the beam. The produced neutrals are further converted to positive ions by the following processes.

$$H^- + D^+ \rightarrow H^0 + e^- + D^+$$

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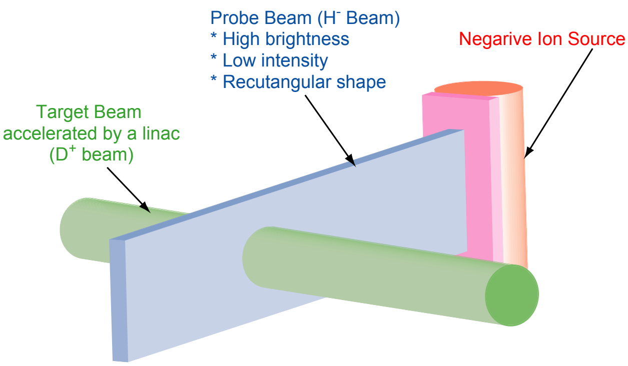

Figure 1: A conceptual drawing of the negative ion beam probe system.

The relative velocity between H^- and D^+ is so high that the cross-section of the electron capture of D^+ is negligible. At low energy regions, the cross section of electron detachment from H^- by H^-+H^+ collisions has been investigated and the results are reported [4,5]. These are shown in Figure 2. The cross section data in the high barycentral energy regions are not available, and the cross section is estimated by extrapolating the data in low energy region assuming classical energy dependence. The results show that the beam attenuation distance is larger, and a very small portion (~10^{-5}) of H^- is converted to neutrals due to collisions with D^+ in IFMIF prototype conditions.

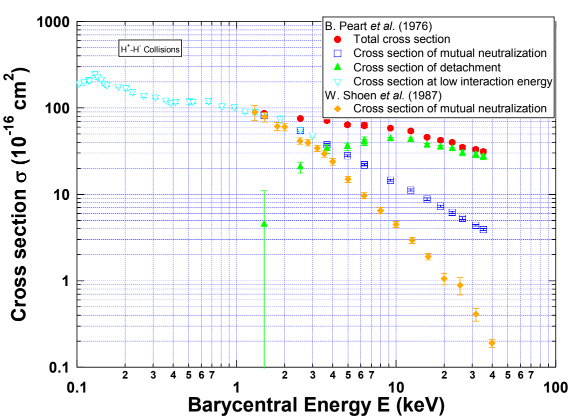

Figure 2: Cross section of electron detachment from H^- by H^-+H^+ collisions in low energy regions.

The beam trajectories of the mixed hydrogen ions and neutrals produced by interaction of H^- with D^+ beam can be separated properly by an electromagnetic field. The spatial distribution of these beams of H^-, H^0 and H^+ will form mutually correlated signals which can enlarge the signal-to-noise ratio of the measurement system. The low signal level should be further enhanced by employing phase sensitive detection.

PROOF-OF-PRINCIPLE EXPERIMENT USING A HIGH INTENSITY HE$^+$ BEAM

In order to validate the negative ion beam probe system for the high intensity positive ion beam monitor, we have started an experimental study with a low energy intense ion beam system being tested at the National Institute for Fusion Science (NIFS). A strongly focusing He^+ ion source [6] is developed to measure the spatial profile and velocity distribution of alpha particles produced by D-T reactions in fusion plasma [7]. The current ion source produces a 20 mm diameter He^+ beam of intensity as high as 500 mA/cm^2 at the focal point by using concaved extraction electrodes [8,9]. We utilize the He^+ beam as a target beam for the proof-of-principle (POP) experiment.

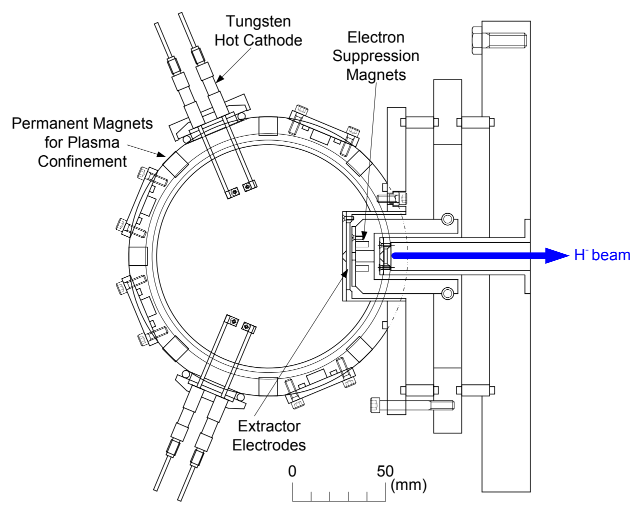

Figure 3: A schematic drawing of an H^- ion source for a negative ion beam probe system.

We have designed and assembled an H^- ion source to produce a probe beam for the POP experiment. Figure 3 shows a schematic drawing of the H^- ion source. This source has tungsten-filament hot cathodes and permanent magnets forming a cusp magnetic field to confine a hydrogen plasma. It is designed to produce the H^- beam with a rectangular shape of 70 mm × 2 mm. The system is about to be installed on a small test stand to examine the efficiency of H^- production, and the brightness of the thin sheet beam of H^-.

After the H^- beam measurements on a test bench, the H^- ion source is planned to be transported and installed at NIFS to see if the system can properly yield profile data of He^+ ions extracted from a large ion source. The energy of He^+ beam and H^- beam are supposed to be 10-30 keV and 5-7 keV, respectively. Figure 4 shows a schematic drawing of the experimental setup of an H^- beam probe system to monitor the beam profile of the high current density He^+ beam formed by concaved extraction electrodes. The H^- beam crosses the He^+ beam around the focal point. An electrostatic ion separator is coupled to an einzel lens system to focus/defocus the H^+/H^- beam. At the end of the ion separator, a scintillation plate is placed

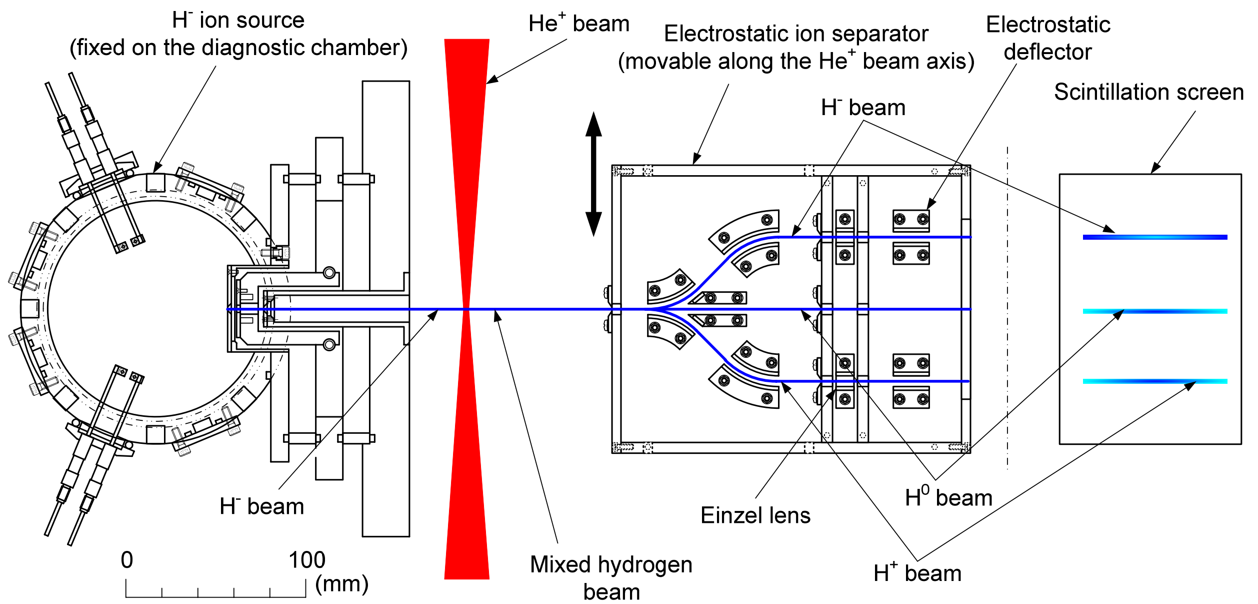

Figure 4: A schematic drawing of the experimental set up of the H^- beam probe system to monitor the beam profile of the high current density He^+ beam extracted from an extraction system with three concaved electrodes.

to observe the beam spatial profile optically. We will validate this new technique through beam profile data comparing with those obtained by the existing IR imaging monitor [8].

SUMMARY

We describe a negative ion beam probe system as a new scheme of the beam profile monitor for the high intensity positive ion beams. This system has a potential capability of fitting into a place of the conventional techniques such as a wire scanner monitor or a gas ionization/fluorescence type monitor. This scheme is an active measurement in the high vacuum level (the merits of the wire-scanning type) and non-destructive measurement (the merit of capacitive-inductive type). Moreover, the system can be located far from the target beam line. By overcoming the problem of detection efficiency, this can be an attractive and promising monitoring system of intense ion beam.

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