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DEVELOPMENT OF HIGH POWER NEGATIVE ION SOURCES FOR FUSION AT JAERI

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ABSTRACT

Technologies producing high power negative ion beams have been highly developed in these years at JAERI for use in neutral beam injectors for heating the thermonuclear fusion plasmas. At present, it is possible to produce multi-ampere H-/D- ion beams quasi-continuously at energies more than a few hundred keV with a good beam optics of beamlet divergence of a few mili-radian. Based on these technologies, two R&D projects have been initiated; one is to develop a 22A/500keV/10s D- ion source for the neutral beam injector for JT-60U, and the other is to develop a 1A/1MeV/60s H- ion source to demonstrate high current negative ion acceleration up to the energy of 1MeV, the energy required for the neutral beam injector for International Thermonuclear Experimental Reactor (ITER).

1. INTRODUCTION

Negative ion based neutral beam injector (N-NBI) is one of the most promising candidates for the current drive and heating system in steady state operation of reactor-grade tokamak fusion devices, such as the International Thermonuclear Experimental Reactor (ITER) [1]. The most crucial issue in realizing the injector is to develop a high power negative ion source which can produce negative deuterium ion beams with a current of several tens of amperes at an energy of 0.5-2 MeV. The ion source required for ITER, for example, has to produce 40A D- ion beams at an energy of 1MeV for a pulse duration of more than 1000s with a beam divergence of less than 5mrad [1,2]. The current density should be more than 20mA/cm^2 to make the size of the N-NBI system reasonable. In addition, the source should be operated at a low operating gas pressure of less than 0.3Pa to reduce the stripping loss of negative ions in the accelerator and to have a reasonable acceleration efficiency.

Although these specifications are far beyond the specifications of existing negative ion sources, basic performances have already been achieved individually by the negative ion sources developed at JAERI. Namely, H- ion beams of 10A, 50keV were extracted with an enough current density of 37 mA/cm^2 [3], and D- ion beams of 2.2A, 100keV, 5s (10 mA/cm^2) was produced in JAERI/CEA Joint Experiment at an low operating gas pressure of 0.3Pa [4,5]. Long pulse operation was demonstrated at 50keV, 0.3A (>10mA/cm^2) for a pulse duration of 24 hours in a small H- ion source [6], which has a same design concept as the 10A source. High energy H- ion beams of 350keV, 0.5A were produced using a three-stage electrostatic accelerator [7]. Beamlet divergence of as low as 5mrad was obtained at 400keV with a current density of 13mA/cm^2 [7].

Based on these successful results, two R&D projects have been initiated at JAERI. One is to develop a 22A, 500keV, 10s D- ion source for the N-NBI system for JT-60U [8]. The other is the development of a 1MeV negative ion source/accelerator for the demonstration of high energy acceleration of ampere-class negative ion beams to 1MeV [9], the energy required for ITER.

In the present paper, after a brief description of these two R&D projects, present status of the development is reviewed together with a future plan of the development.

2. D- ION SOURCE FOR JT-60U

A 500keV, 10MW N-NBI system has been constructed for studying of mega-ampere level NB current drive and plasma core heating experiments with a high density reactor-like plasma in JT-60U. It is the first neutral beam injector in the world using negative ions as the primary ions. The system is designed for injecting 10MW deuterium or hydrogen neutral beams for 10s beam duration with a duty cycle of 1/60. The N-NBI system consists of a beamline equipped with two ion sources, a power supply, a control system, and an auxiliary sub-systems that includes a cooling water system, cryogenic refrigeration system, and auxiliary pumping system. Each ion source has a cesium-seeded volume negative ion generator, a multi-aperture extractor and a three-stage electrostatic accelerator. Figure 1 shows a cross-sectional view of the ion source. The source is designed so as to produce 22A, 500keV, 10s D- ion beams with a current density of 13mA/cm^2 [10,11]. The dimensions of the plasma generator are 64cm in diameter and 122cm in length. Produced negative ions are extracted from 1080 apertures of 14mm in diameter, which distributed within the area of 45cm x 110cm.

Out of the two ion sources, first ion source has been designed and fabricated. After successful performance tests in test stands, the ion source was installed in the beamline of the N-NBI system and full power test has just started. Up to now, the source has been successfully operated and produced a 400keV, 5.9A, 0.1s D- ion beam [12], the world highest D- current and beam power.

The full power test will be finished by the end of October 1995, and the second ion source is to be installed in the beamline by January 1996. NB injection experiment is scheduled to start from April 1996.

3. PROTOTYPE ACCELERATOR FOR ITER

The negative ion beam energy required for ITER is as high as 1MeV to penetrate the beam into the high density, large core plasma of ITER. Although multi-MeV beams have been produced in the electrostatic accelerators used for high energy physics, the current is less than an order of mA. There is no experiment to accelerate ampere-class particle beams, including positive ion beam and electron beam, above the energy of several hundred keV. A demonstration of the ability to accelerate the ampere-class negative ion beams is, therefore, the most critical and urgent R&D item for ITER. Electrostatic acceleration will be employed because of its high electrical efficiency.

To develop the 1MeV negative ion accelerator, we have constructed a new test stand called MeV Test Facility (MTF) [9]. MTF has an acceleration power supply which has a capacity of 1MV, 1A, 60s, the world biggest Cockcroft-Walton circuit, and the power supplies for negative ion production and extraction. These high potential power supplies are installed in the SF6 gas vessel with the a 1MeV prototype accelerator for ITER.

In the prototype accelerator, negative ions created in the 'KAMABOKO' type negative ion generator [13] are accelerated by five-stage electrostatic accelerator.

Up to now, the accelerator was conditioned up to the voltage of 750 kV. Hydrogen negative ion beams were accelerated after the accelerator conditioning. The H- beam was successfully accelerated up to an energy of 700 keV with an acceleration drain current of 230 mA for a duration of 1s. The highest drain current of 360 mA was obtained at 600 keV.

4. SUMMARY

Figure 2 shows the negative ion beam currents and energies achieved in the existing ion sources. Specifications at which the N-NBI system for JT-60U and MTF aim are also shown in the figure together with the final target for ITER. The large negative ion source for JT-60U and the prototype accelerator in MTF are the two critical steps for 1MeV, 40A, CW ion source/accelerator for ITER.

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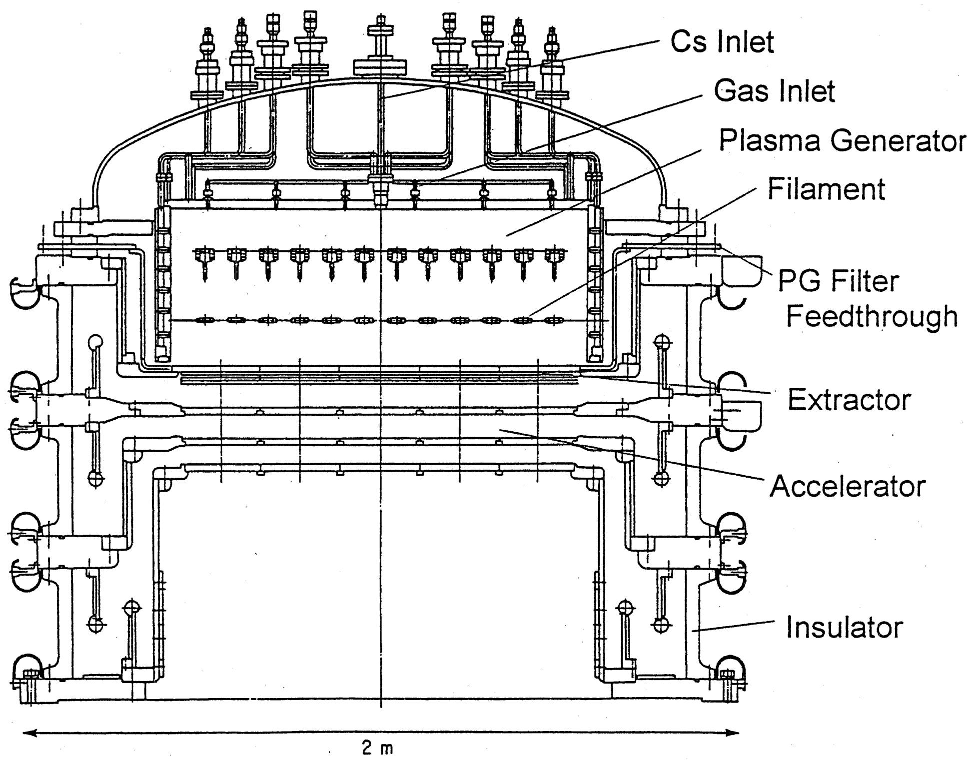

Fig.1 Cross-sectional view of D- ion source for JT-60U N-NBI

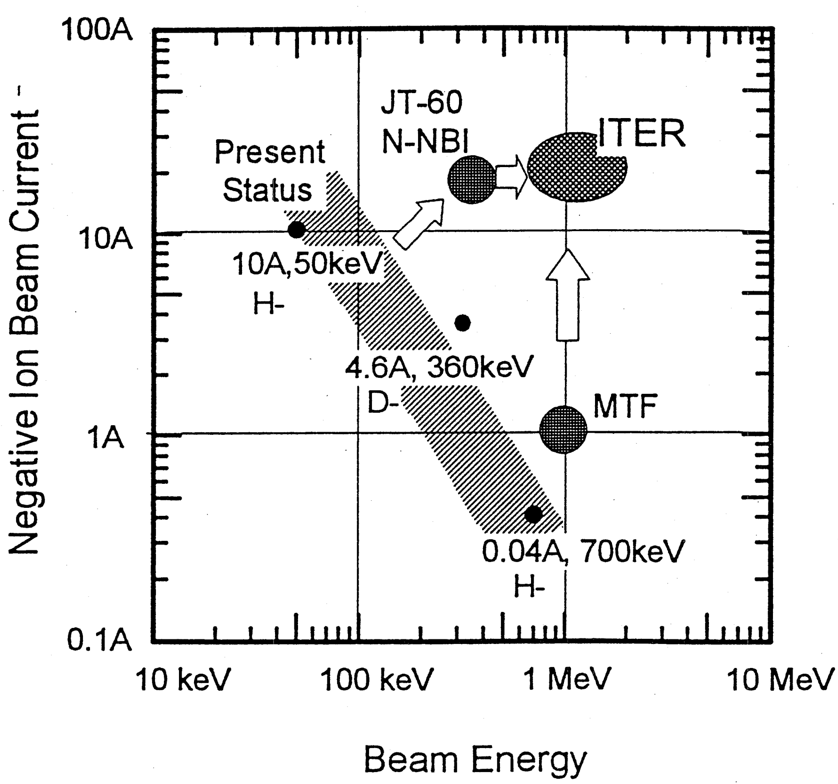

Fig.2 Status of high power negative ion beam development