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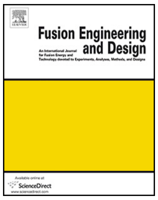

Development of long-pulse high-power-density negative ion beams with a multi-aperture multi-grid accelerator

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HIGHLIGHTS

- A long pulse acceleration of high-power-density hydrogen negative ion beams has been successfully achieved by using a 5 stage multi-aperture multi-grid accelerator.
- Improved extraction and acceleration geometries for high current density reduced heat load on acceleration grids to allowable level of long-pulse.
- Availability of 1 MeV long pulse beam has been improved by an optimization of conditioning operation for long pulse.

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ABSTRACT

A long pulse acceleration of high-power-density hydrogen negative ion beams of 184 MW/m^2 (0.97 MeV, 190 A/m^2) has been successfully achieved up to a facility limit of 60 s by using a 5 stage multi-aperture multi-grid accelerator, which is the first demonstration of the ITER relevant beam with a pulse length over the time constant of cooling capability of the water-cooled acceleration grids. In order to extend the pulse length of such high power density beams, the extraction and acceleration geometries were tuned to match the beam optics to high power density by increasing the transmission at the extractor and the acceleration electric field at the first acceleration gap. After the modifications, the available current density at the same acceleration voltage was increased by 36%, and grid heat loads at each acceleration grid were reduced to less than 3% of the electric input power, which satisfied an allowable level for long pulse acceleration. Furthermore, since the conditioning procedure has been established for long pulse acceleration, a rapid conditioning of total 16 operational days up to 1MeV, 60 s class has been achieved, which was about half of previous results. Because JT-60SA and ITER NBIs are designed by the same concept, these results are applicable to the modifications and operations toward these NBIs directly.

1. Introduction

A fusion power plant is required to generate stable electricity by operating the plant continuously. For this purpose, long pulse operational scenarios of high performance plasmas are planned in the JT-60SA and ITER projects with a pulse length from 100 to 3600 s [1,2]. To realize such plasmas, long pulse injections of heating beams from high energy neutral beam injectors (NBI) are one of key issues in the tokamak systems.

For the JT-60SA and ITER tokamaks, 500 keV and 1 MeV NBIs with a neutral beam powers of 10 and 16.5 MW, pulse lengths of 100 and 3600 s are being developed [3,4]. Both NBIs are based on negative ion/beam sources, which are still under development in the world. As for the long pulse production of negative ions, R&Ds by using an half size ITER source driven by a RF discharge [5] and the JT-60SA negative ion source driven by an arc discharge [6] are in progress to achieve high-current long-pulse negative ion beams of 22–40 A. As for the long pulse acceleration of negative ion beams, R&Ds for accelerators have been carried out jointly toward JT-60SA

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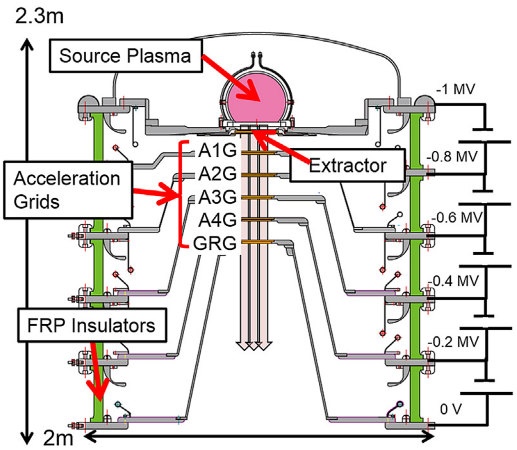

Fig. 1. Schematic view of a 5 stage accelerator for ITER R&D, called the MeV accelerator.

and ITER NBIs, because these accelerators were designed by the same concept of the Multi-Aperture Multi-Grid (MAMuG) accelerator [7].

For JT-60SA and ITER, 3-stage accelerators having a capability of 500 keV 22 A, 65 MW/m^2 H$^-$/D$^-$ beam and 5-stage accelerators for 1 MeV, 40A 200 MW/m^2 H$^-$/D$^-$ beam are being developed respectively. So far, 340 keV 30 s beam acceleration with the 3-stage accelerator and 700 keV 60 s beam acceleration with the 5-stage accelerator have been achieved for JT-60SA and ITER [3,6]. However, in these previous experiments, the available power densities for long pulse beams were strongly limited to be about 70% of the rated values due to thermal damages caused by excess heat loads on acceleration grids, which was one of remaining issues to develop these accelerators. Furthermore, because these high energy accelerators always required long conditioning time to increase acceleration voltage, current and pulse length, an operational cycle from the beginning of the conditioning up to maintenance of cesium or filaments was too short to extend the pulse length. This long conditioning time was also one of remaining issues.

Therefore, in this paper, a tuning of extraction/acceleration geometries to match high power density beam is carried out to reduce the grid heat loads. And also the optimization of conditioning procedure was studied to enhance the operation of the accelerators.

2. Tuning of extraction/acceleration geometries

2.1. Accelerator for ITER R&D

A 5-stage electrostatic accelerator designed by MAMuG concept for ITER R&D, called the MeV accelerator, was used in this experiment as shown in Fig. 1. Negative ions are produced in a cesium-seeded negative ion source driven by an arc discharge up to 30 kW and extracted by an extractor [8] with a current density of 200 A/m^2. The extracted negative ion beams are accelerated up to 1 MeV with 5 stages acceleration grids each of which is insulated by a fiber-reinforced plastic insulator. These acceleration grids are equipped with 49 apertures, however, only 9 apertures with a diameter of 16 mm were used in this experiment due to the limitation of the available current in the acceleration power supply. However, by using this accelerator, the beam acceleration with the same power density of 200 MW/m^2 and multi-apertures as the accelerator for ITER can be demonstrated.

In the past R&Ds, as for the accelerator, low voltage holding capability has been solved by adjusting the gap lengths between acceleration grids [9]. As for the extractor, magnetic deflections and interactions of multi-beamlets due to magnetic fields and a space charge effect have been compensated by the aperture displacement technique and field shaping plates, respectively [10]. As these results, 1 MeV, 200 A/m^2 beam has been accelerated up to 0.4 s. However, in a case of high current density beam, the heat load on the grounded grid was still high and marginal to achieve long pulse beam.

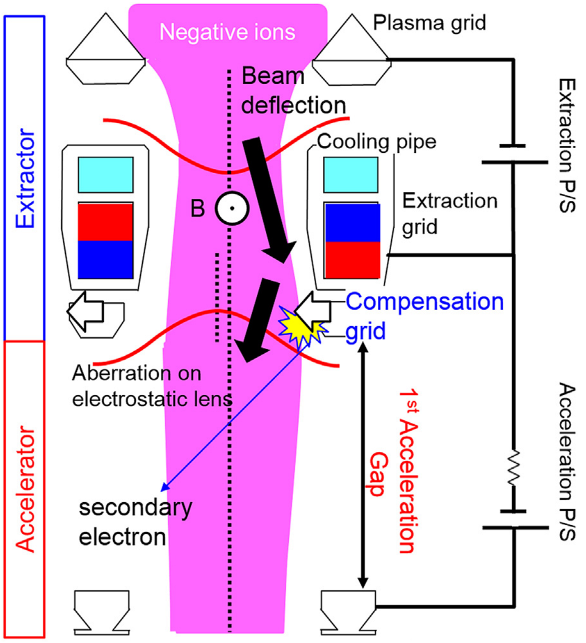

Fig. 2. Schematic view of extraction/acceleration geometry with beam trajectory.

2.2. Reduction of grid heat loads

In order to reduce the grid heat load, an extraction/acceleration geometries have been tuned to match the beam optics to high power density. Particularly, the extractor and 1st acceleration gap have been modified as shown in Fig. 2, because the beam optics is mainly determined by a trajectory in these regions.

In these regions, the extracted negative ions are deflected by magnetic field and compensated by the aperture displacement of the compensation grid [10]. And then, the extracted negative ion beam is accelerated and focused by an acceleration field in the 1st acceleration gap.

As for the extractor, a beam expansion due to high power density caused loss of a beam current and generation of secondary electrons which were accelerated to downstream [11]. Therefore, based on the experiment and a beam analysis, a diameter of the aperture on compensation grid has been optimized from 14 to 16 mm for high current density beam, which was designed to satisfy both of the transmission of the grid and the capability of the compensation [12]. As a result, the available current density has been increased from 110 A/m^2 to 120 A/m^2 at the same beam energy of 800 keV as shown in Fig. 3(a), and the grid heat load has been reduced mainly at upstream grids (A1G-A3G) as shown in Fig. 3(b).

As for the 1st acceleration gap, the acceleration field was previously tuned to 200 kV/112 mm for the improvement of a voltage holding capability. In order to apply the high power density acceleration, the acceleration field has been increased by 14% by adjusting the gap length from 112 mm to 109 mm (−3%) and suppressing an undesired voltage drop due to protection resistors connected in series with the 1 MV potential from the acceleration power supply. As a result, further increase of the available current density has been

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