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Development of 1 MeV Accelerator for ITER; Achievement of 0.98 MeV, 185 A/m^2 Negative Ion Beam Acceleration

ITER 1 MeV加速器開発；0.98 MeV, 185 A/m^{2}負イオンビームの達成

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In a MeV accelerator test toward 1 MeV, 200A/m^2 H^- ion beam acceleration for the ITER neutral beam injector (NBI), the beam energy was limited up to 0.8 MeV due to insufficient voltage holding capability and direct interception of deflected beamlets at acceleration grids. To improve the voltage holding, local electric field concentrations were lowered by expanding gaps and increasing radii of corners of grid supports based on voltage holding tests and electric field analysis. To compensate the beamlet deflections due to magnetic fields for electron suppression and space charge repulsion between the beamlets, compensation methods were designed in a three dimensional beam analysis, so as to utilize aperture offset in the electron suppression grid (ESG) and a metal plate attached beneath the ESG, so-called a field shaping plate. As the results, beam parameters increased to 0.98 MeV, 185 A/m^2, which are almost achieving the target values.

1. Introduction

In a negative ion accelerator for the ITER neutral beam injector (NBI), it is required to generate 1 MeV, 40 A (200 A/m^2) deuterium negative ion (D^-) beams for 3600 s. Toward the requirement, beam acceleration tests are progressed in the MeV test facility (MTF) and JT-60U NBI at Japan Atomic Energy Agency (JAEA) [1, 2]. At the MTF, a five stage multi-aperture multi-grid (MAMuG) accelerator, so-called “MeV accelerator”, is tested to demonstrate 1 MeV, 200 A/m^2 (0.5 A in total) H^- ion beam accelerations. However, the beam energy was limited to 0.8 MeV till 2008 [3]. This is because of insufficient voltage holding capability and direct interception of the beams at acceleration grids, which could cause breakdowns [4].

To increase the beam parameters, the MeV accelerator was modified according to results of a voltage holding test. Moreover, compensation methods of the beamlet deflections were applied based on a three dimensional (3D) beam analysis. After these modifications, beam acceleration tests have been performed toward 1 MeV beams.

2. MeV Accelerator

A schematic view of the MeV accelerator is shown in Fig.1. The negative ions are extracted from apertures (14 mm in diameter) drilled in a lattice pattern of 5 (R_1-R_5) × 3 (C_1-C_3) in the extractor. In the extraction grid (EXG), permanent magnets are embedded between each aperture row for electron suppression. The beam is accelerated to 200 keV in each acceleration stage, and as a consequence, 1 MeV at the exit of the fifth stage. At 2.5 m downstream of the accelerator exit, a target made of one-dimensional carbon-fiber-composite (CFC) and a water-cooled copper calorimeter are installed to measure beam footprints

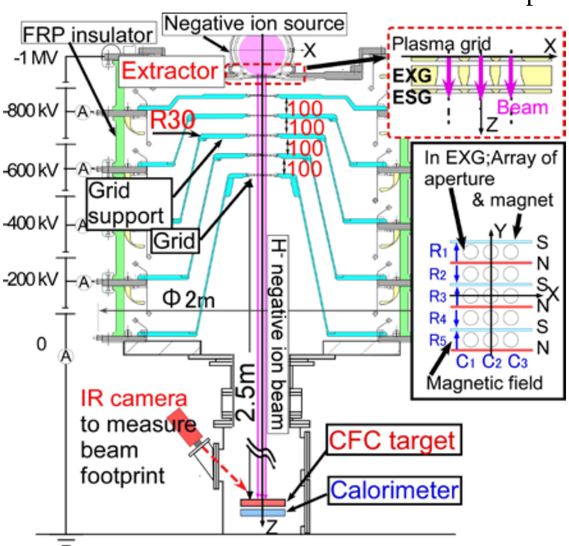

Fig.1. MeV accelerator

and beam current, respectively.

3. Modification Based on Voltage Holding Test

In the voltage holding tests and electric field analysis [4, 5], it was found that local electric fields at steps/edges of grid supporting structure should be lowered to suppress breakdowns. For this purpose, the accelerator was modified as shown in Fig.1. The minimum gap length was extended from 72 mm in the original to 100 mm so as to hold 200 kV stably (1 MV for five stages) including the margin of 20 %. A radius of the corner of the grid support was increased from 15 mm to 30 mm. After these modifications, voltage holding capability was drastically improved and achieved stable voltage holding of 1 MV without gas feeding (base pressure; 2 x 10^{-4} Pa) for 4000 s. As a result, the beam parameters increased to 0.86 MeV, 160 A/m^2.

4. Compensations of the Beamlet Deflections

To study the beamlet deflections and the compensations, a 3D beam analysis has been carried out using OPERA-3d code [6]. The magnetic field generated by the permanent magnets was taken into account. The stripping loss of negative ions in the course of acceleration was also included to provide a practical accuracy in the space charge repulsion. The detailed grid support structure was included in the model to study influence of electric field distortions formed by the steps/edges of the grid supports on the beamlet deflection.

Figure 2 (a) and (b) show the calculated footprints of 1 MeV beams on the CFC target position before and after the compensations of the beamlet deflections, respectively. The beamlets are deflected alternatively in the horizontal direction in each aperture row due to i) the magnetic field formed by the permanent magnets in the EXG. Hence, the beam footprint shows a zigzag pattern on the CFC target position. Moreover, the peripheral beamlets are deflected outwards due to ii) the space charge repulsion between beamlets. The beamlet deflection angles are 4.7 mrad in the center beamlet (R_3C_2) due to i) and 9.5 mrad in the peripheral beamlet (R_3C_3) due to superposition of i) and ii). As a compensation method, the aperture offset [7] of 0.8 mm in the electron suppression grids (ESG) was designed for the beamlet deflection due to i). In addition, the field shaping plate (FSP) [8], which is a metal plate of 1 mm thick attached beneath the ESG, was designed for the peripheral beamlet deflected due to superposition of i) and ii). After applying these methods, the calculated beamlet deflections are compensated as shown in Fig.2 (b). In the experiment, the measured deflection angles of the beamlets were in good agreement with the calculated ones. Finally, the beam accelerations were demonstrated at around 1 MeV.

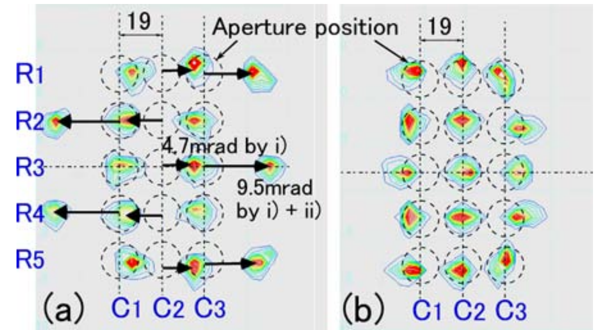

Fig.2. Calculated beam footprints on the target position. (a) Before and (b) after the compensations.

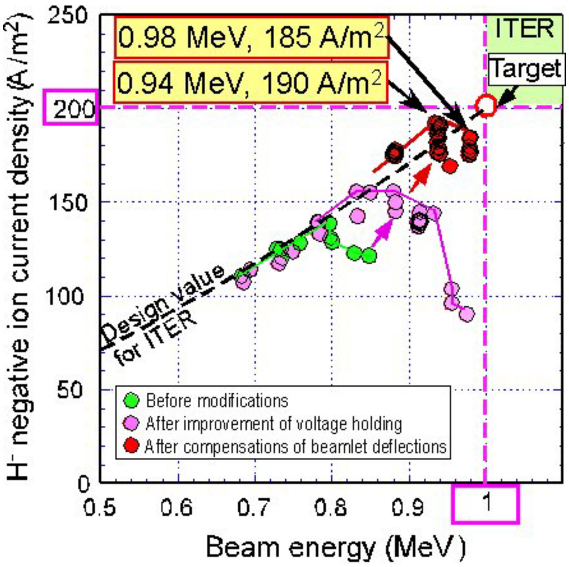

Fig.3. Progress of beam accelerations

5. Summary

As a result of improvement of the voltage holding and the compensations of the beamlet deflections, the beam parameters increased from 0.8 MeV to 0.98 MeV, 185 A/m^2 and 0.94 MeV, 190 A/m^2 as shown in Fig.3. These are almost achieving the target values. The modifications are applied to the ITER accelerator design.

References

[1] T. Inoue et al., Nucl. Fusion **46(**6) (2006) S379.
[2] A. Kojima et al., Nucl. Fusion **51** (2011) 083049.
[3] M. Kashiwagi et al., Nucl. Fusion **49** (2009) 065008.
[4] M. Taniguchi, et al., AIP Conf. Proc. **1390** (2011) 449.
[5] N. Umeda et al., 22P156-P in this conference.
[6] M. Kashiwagi, et al., AIP Conf. Proc. **1390** (2011) 457.
[7] T. Inoue, JAERI-Tech.2000-051 (2000).
[8] M. Kamada et al., Rev. Sci. Instrum. **79** (2008) 02C114.