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Experimental Validation of Grid Heat Loadings in the Five-Stage Accelerator with the ITER-Relevant Gap Lengths

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The ITER neutral beam injector (NBI) is required to inject 1 MeV, 16.5 MW neutral beams for 3600 seconds converted from 1 MeV, 40 A ($200\mathrm{A/m^2}$) deuterium negative ion (D^-) beams. In order to realize the system, a five-stage multi-aperture multi-grid (MAMuG) accelerator, so-called MeV accelerator designed with the same concept as the ITER accelerator, has been developed in the MeV test facility in the National Institute for Quantum and Radiological Science and Technology (QST) in Japan. A key subject for acceleration of the powerful beam is optimization of beam optics in the accelerator. To test beam optics on the same conditions of the ITER accelerator, the acceleration grids have 4 apertures with several diagnostics.

For long pulse acceleration of such high power beams, the design values of the ITER accelerator are < 7 mrad in divergence angle and < 5 % in a ratio of heat loading on each acceleration grid to the total electrical input power. However, in the design code, there are several assumptions to calculate the negative ion trajectory because physics of the negative ion extraction is under studying. Therefore, the experimental validation is essential to realize the ITER accelerator. The MeV accelerator has already demonstrated the acceleration of 1 MeV, $200\mathrm{A/m^2}$ hydrogen negative ion (H^-) beams for 60 seconds successfully [1]. In this time, to simulate the equivalent perveance of the ITER accelerator, which is 1MeV, $280\mathrm{A/m^2}$ in the H^- beams, the accelerator configuration was modified to optimize for this beams. Beam profiles and grid heat loadings have been investigated experimentally.

The acceleration gap length was modified by using a two dimensional simulation code. Practically, the gap length has been changed from 109 mm to 88 mm. To achieve the voltage holding capability of 1 MV in this modified gap configuration, the accelerator structure was redesigned based on the empirical scaling law obtained from voltage holding experiments [2]. As a result, a stable 1 MV holding has been achieved in this modified configuration.

To measure the beam distribution on the acceleration grid, a specially developed grid was installed. The grid has apertures with precise heat load profile measurement sensors. The accelerated beam profile was measured at a one-dimensional CFC (Carbon-fiber-composite) target.

Beam acceleration test up to 0.7 MeV has been performed at present. The heat loading on each acceleration grid was lower than 5 % of the electrical input power, which satisfied with the ITER requirement. The beam divergence angle was less than 5.6 mrad, which also satisfied with the ITER requirement. In this paper, the detailed comparisons between the beam acceleration test and the analysis are described in the beam optics and the grid heat loadings.

This is the first demonstration of MeV-class negative ion beam acceleration with the ITER-relevant acceleration gap lengths. These results can contribute to the direct prediction of the performance of the ITER accelerator.

References

[1] J. Hiratsuka et. al., Proceeding of IAEA Fusion Energy Conference 2016, FIP/1-3Ra.

[2] A. Kojima et. al., Rev. Sci. Instrum. 87, 02B304 (2015).

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