REPETITIVE GENERATION OF HYDROGEN NEGATIVE ION BEAMS WITH INITIAL TARGET PARAMETERS FOR THE ITER HNB

M. Kisaki, Y. Tanaka, K. Suzuki, J. Hiratsuka, M. Murayama, K. Tsumori, M. Ichikawa, H. Tobari and M. Kashiwagi

National Institutes for Quantum Science and Technology (QST), Naka, Japan
Email: kisaki.masashi@qst.go.jp

Repetitive generation of hydrogen negative ion (H^-) beams with 0.87 MeV and 230 Am^{-2} for 50 s, which are initial target parameters for the heating neutral beam injector (HNB) of ITER, has been achieved with a five-stage and multi-aperture electrostatic accelerator in Mega-Volt Test Facility (MTF) in QST for the first time by improvement of stabilities of plasma generation and beam acceleration. The pulse length has been extended up to 110 s with constant H^- and electron currents, and the beam divergence kept constant lower than the ITER requirement during the long pulse operations.

1. INTRODUCTION

In the ITER HNB, acceleration of high-power beams of 0.87 MeV and 46 A (230 Am^{-2}) H^- and 1 MeV and 40 A (200 Am^{-2}) deuterium negative ion (D^-) are required. The pulse length is planned to be progressively extended up to 1000 s for H^- and 3600 s for D^-. At the initial operation of the ITER HNB, the H^- beam is required to be accelerated with beam energy of 0.87 MeV and current of 46 A for 50 s. To develop such high-power negative ion accelerator, the beam acceleration experiment has been performed with the five-stage and multi-aperture electrostatic accelerator, so-called MeV accelerator in QST. In FEC 2023, it was reported that stable acceleration of the H^- beam at 275 keV for 300 s was achieved with an active control system of plasma grid (PG) temperature [1]. To realize the beam acceleration with the initial target values of ITER HNB, the stability of high density H^- production has been improved with the filament protection system, and the voltage holding capability has been improved by a new conditioning procedure. In this paper, the recent progress of long pulse acceleration in QST is reported.

2. IMPROVEMENT OF STABLE PLASMA GENERATION AND BEAM ACCELERATION

Figure 1 shows a schematic illustration of negative ion source and MeV accelerator in QST. The plasmas are ignited by filament-arc discharge. The extracted H^- ions from plasmas are accelerated by the five-stage and multi-aperture accelerator with the same design concept as ITER HNB. The acceleration gap length, the aperture diameters and intervals of MeV accelerator are tuned to 88 mm, 14 mm for A1G and A2G, 16 mm for A3G, A4G and GRG, 20 mm x 22 mm, respectively, which are the same configuration of ITER one. The number of apertures is limited due to the power supply capability, 1 MV and 0.5 A in rated values.

The fast-detection and fast-cutoff system for the protection of filaments from the abnormal discharge has been installed inside the high-voltage power supply of MTF with countermeasures for breakdown surges. As a result, the filament lifetime has been extended by three times, and total plasma discharge time became longer by seven times in the particular case of discharge power of more than 25 kW, which is necessary to meet perveance matching at more than 700 keV.

The electrical breakdown at extraction and acceleration gaps is another issue for the stable beam generation. In high-voltage conditioning without beams, the rapid increases in the dark current flowing through the gaps and the vacuum pressure in the accelerator are observed before the electrical breakdown. Then, the temporal variation of the dark current and the vacuum pressure were used as an index of the progress of the conditioning for long pulse operation, and the

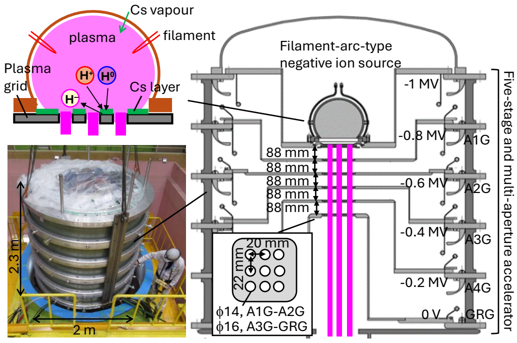

Fig. 1. Schematic illustration of negative ion source and MeV accelerator in QST.

acceleration voltage was increased up to around 10% higher than the target beam energy and sustained for more than 10 minutes until the dark current and the vacuum pressure ceased to change in time. In addition, the underperveant beam was extracted intentionally by applying higher extraction voltage than the optimal one to proceed the high voltage conditioning at the extraction gap and sputter the Cs deposited on the extraction grid surface, which seems to cause the enhancement of the secondary electron yield and to induce the electrical breakdown. These high-voltage conditionings could also be effective for the ITER HNB equipped with the multi-stage and multi-aperture accelerator and the Cs-seeded negative ion source.

3. REPETITIVE GENERATION OF 0.87 MEV, 230 A/M^2, 50S H$^-$ BEAM

After modification on the plasma generation and high voltage conditioning, long pulse acceleration of ITER-relevant beam was successfully achieved. Figure 2(a) shows a history of beam pulse length and amount of Cs seeded in the plasma chamber in a campaign. The H$^-$ beams were accelerated with low beam energy in an early phase of the campaign since the H$^-$ density was not enough to meet the perveance matching for higher beam energy. In a later phase of the campaign with sufficient Cs conditioning, the H$^-$ beam was generated at 0.87 MeV for 50 s repetitively for the first time. Here, the pulse length is the net beam-acceleration time excluding the interval by the plasma termination caused by the abnormal discharge in each trial. The H$^-$ current density was comparable to the ITER requirement, and the total heat load on the acceleration grids was suppressed below an allowable level of 15% in every long pulse as shown in Fig. 2(b). The time evolutions of the beam parameters such as acceleration current, electron current, and beam divergence during long pulse acceleration with and without abnormal discharge were shown in Fig. 3, where the divergence was estimated by a newly developed non-disturbing beam monitor consisting of H$_\alpha$ filter and visible camera. The abnormal discharge occurred at the hatched area, and the plasma discharge and the beam extraction were abruptly terminated. Nevertheless, thanks to protection by the fast cutoff system, the beam extraction was resumed after short interval without the filament break and sustained for 110 s in total. During the pulse duration, both the H$^-$ and electron currents kept constant. This would attribute to the stable condition of the Cs in the plasma chamber as well as the proper PG temperature since the degradation of the current was observed with steep increase in the optical emission of the Cs in the previous experiments up to FEC 2023 [2]. In addition to the stable beam current, the beam divergence was suppressed below a target value for the ITER HNB, 7 mrad without degradation.

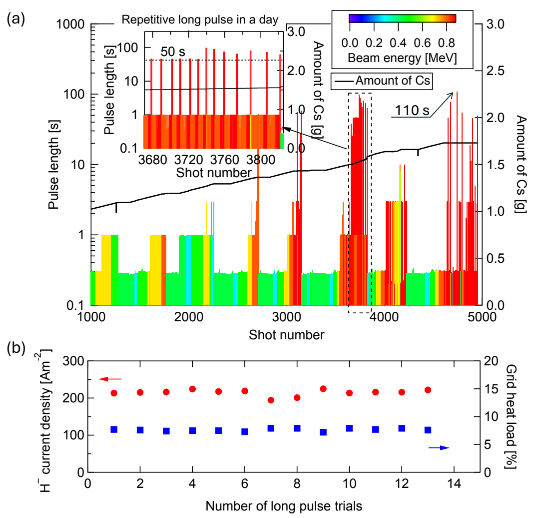

Fig. 2. (a) shot summary of beam pulse length and Cs consumption and (b) current density and grid heat load in long pulse trials.

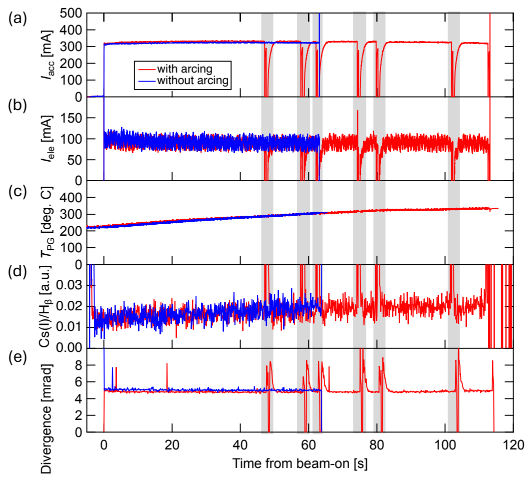

Fig. 3. Time evolution of (a) acceleration current, (b) electron current, (c) PG temperature, (d) optical emission intensity of Cs atom normalized by H$_\beta$, and (e) beam divergence.

REFERENCES

[1] Tobari. H. et al., Proceedings of IAEA FEC2023 1691 (2023).
[2] Kashiwagi, M. et al., Nucl. Fusion **62** 026025 (2022).