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Long-pulse acceleration of 1MeV negative ion beams toward ITER and JT-60SA neutral beam injectors & Towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system

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A. In order to realize the negative-ion-based neutral beam (NB) systems for ITER and JT-60SA, development of the Multi-Aperture and Multi-Grid (MAMuG) electrostatic accelerator is one of common critical issues. For these NB injectors, 5- and 3-stage MAMuG accelerators are being developed to achieve the acceleration of negative ion beams up to 1 MeV, 40 A (200 A/m²) for 3600 s and 0.5 MeV, 22 A (130 A/m²) for 100 s, respectively. However, there were no experiments of long-pulse MeV-class beam acceleration. Though JAEA achieved the rated beam energy of 1 MeV, the pulse duration was limited to be less than 1 s [1] due to a low voltage holding capability and high grid power loads. After the last FEC conference, following issues were investigated such as multi-grid effect on the voltage holding capability and reduction of the grid power loads. New accelerators have been designed to realize stable voltage holding by taking into account the multi-grid effect on voltage holding capability, which satisfies the requirement of beam energy for ITER and JT-60SA with 5-stage and 3-stage, respectively. The grid power load has been suppressed less than a half of the design values of the accelerators by modifying the geometry of the extractor and the acceleration grids to suppress generation of secondary electrons. By applying the developed techniques based on the R&D results, the hydrogen negative ion beams of 0.97 MeV, 190 A/m² have been successfully accelerated up to 60 s from the ITER prototype accelerator. The pulse duration of such high power density negative ion beams (~184 MW/m²) has been extended from 0.4 to 60 s, which is the longest pulse length in the world. There is no limitation to extend the pulse duration, since no degradation of the voltage holding has been observed during the long-pulse operations neither by cesium accumulation nor by thermal damage of the acceleration grids. This achievement is one of breakthroughs toward the realization of the high-energy NB systems. [1] A. Kojima, et al., Nucl. Fusion 55 (2015) 063006.

B. The negative ion source test facility ELISE represents an important step in the European R&D roadmap towards the neutral beam injection (NBI) systems at ITER. ELISE provides early experience with operation of large RF-driven negative hydrogen ion sources. Its source area is 1x0.9 m² and the net extraction area of 0.1 m², formed by 640 apertures, corresponds to a half-size ITER source. The test facility aims at demonstrating large-scale extraction and acceleration of negative hydrogen ions (H⁻, D⁻) for pulses of up to 1 h with half the current required on ITER. Additionally, the ratio of co-extracted electrons to ions must be kept below one, which is quite demanding in particular for deuterium operation. Starting with first plasma pulses in March 2013, ELISE has meanwhile demonstrated stable 1 h plasma discharges in hydrogen with repetitive 10 s extraction every 3 min with 9.3 A extracted current and an electron-to-ion ratio of 0.4 at the pressure required by ITER of 0.3 Pa but using only one quarter of the available RF power. At half of the available RF power a stable 400 s plasma discharge was achieved with 18.3 A beam pulses at an electron-to-ion ratio of 0.7. Linear scaling towards full RF power predicts that the target value of the negative ion current can be achieved or even exceeded. Issues in long pulse operation are the caesium dynamics and the stability of the co-extracted electron current. Newly developed magnetic filter field configurations allowed achieving for the first time 1 h pulses in deuterium with an electron-to-ion ratio below one, however only at a quarter of the available RF power. Advanced beam diagnostics such as beam emission spectroscopy and a sophisticated diagnostic calorimeter reveal that the requirement on the uniformity of these large beams (deviations < 10%) can be met.

For a DEMO fusion reactor, the requirements of a heating and current drive system will strongly depend on the

DEMO scenario and are presently assessed within EUROfusion WPHCD. As NBI systems based on negative ions are regarded as one candidate, ELISE could serve in a later stage as a test bed for concepts concerning RF efficiency, operation without caesium or with largely reduced caesium consumption, and neutralization by a laser neutralizer in order to improve efficiency and reliability. IPP's present small scale experiments show promising results.

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