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Towards long pulse operation of N-NBI ion sources

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Neutral Beam Injection (NBI) requires high particle energies if one of its aims is to contribute to current drive in large fusion tokamaks. For example, 1 MeV D is foreseen for the ITER NBI. At such energies, the NBI must be based on a source of negative hydrogen ions (N-NBI) due to their higher neutralization efficiency of up to 60% in a gas neutralizer. Negative hydrogen ions are produced on low-work function surfaces, for which caesium is evaporated continuously into the ion source. The strong technological development resulted in an ion source that operates technically reliably and is in principle capable of running continuously (RF plasma generation, RF coupling, high voltage for extraction and acceleration, cooling etc.), where the only technical limit for the operating time is the vacuum pumping capacity. However, the strong dynamics of the Cs layers caused by the plasma-surface interaction creates a steadily increasing amount of inevitably co-extracted electrons, limiting the pulse duration at present. The vacuum pumping and further aspects regarding the neutralizer, beam duct components, etc. are discussed in [1].

The N-NBI test facilities BATMAN Upgrade and ELISE (1/8 and 1/2 size of the ITER NBI source, respectively) contribute to the development program of the ITER NBI; while full size prototype sources are hosted by Consorzio RFX at the Neutral Beam Test Facility (Padova, Italy). Conditioning recipes and further measures (e.g. biased surfaces close to the extraction system) have been developed to stabilize and/or reduce the current of co-extracted electrons. These optimizations resulted for the first time in almost 90% of the targeted extracted negative ion current (30 A) reproducibly achievable in 600 s hydrogen pulses at ELISE, demonstrating that the requirements for the first operational phase of the ITER NBI are in reach for large scale N-NBI sources. Deuterium operation remains more challenging, since the co-extracted electrons increase more strongly during a pulse. A newly developed measurement of the work function proved that the work function degrades after long pulses. Simulations give hints that the limited flux of Cs onto the surface during the plasma discharge causes the degradation. In order to increase the flux of neutral Cs, an alternative Cs evaporation concept ("Cs shower") is tested at BATMAN Upgrade. With the Cs shower, a steady state with extremely stable performance has been reached in long deuterium pulses for the first time in a caesiated negative ion source. Further improvements of the concept are required in order to make it applicable to large sources.

This contribution reports on the significant progress of N-NBI ion sources towards long pulse operation. Results from plasma and beam diagnostics are presented and possible solutions to bring large ion sources into a steady state are discussed.

[1] C. Hopf et al., "Towards long-pulse and continuous positive-ion-based neutral beam injection", this meeting.

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