Contribution ID: **1197** Type: **Regular Poster**

NNBI for ITER: Status of long pulses in deuterium at the test facilities BATMAN Upgrade and ELISE

Friday 14 May 2021 12:10 (20 minutes)

The two beam lines of the ITER neutral beam injection (NBI) system will deliver an overall heating power of $33.3\,\mathrm{MW}$ into the plasma [1]. The systems are based on negative hydrogen or deuterium ions generated in large ($2 \times 1\,\mathrm{m}^2$) and powerful ($\mathrm{P_{RF}}$ up to $800\,\mathrm{kW}$) radio frequency (RF) driven ion sources. The design of these ion sources is based on the small ($0.6 \times 0.3\,\mathrm{m}^2$) RF driven prototype negative ion source developed at IPP Garching and used at the BATMAN Upgrade test facility [2]. The development process toward the ion sources for ITER follows a stepwise approach defined by the European domestic agency F4E [3]. The ELISE test facility with its half ITER-size ion source ($1 \times 1\,\mathrm{m}^2$, $\mathrm{P_{RF}}$ up to $300\,\mathrm{kW}$) [2] is an important intermediate step, followed by the full size machines SPIDER (in operation since 2018) and MITICA (under construction) at the European Neutral Beam Test Facility (NBTF) [4].

Target values for these ion sources are over one hour a current density of $200\,\mathrm{A/m}^2$ negative deuterium ions, accelerated to $1\,\mathrm{MeV}$ or over $1000\,\mathrm{s}$ a current density of $230\,\mathrm{A/m}^2$ negative hydrogen ions, accelerated to $870\,\mathrm{keV}$. Assuming for both isotopes negative ion losses of $30\,\%$ by electron stripping during the beam acceleration, as calculated for deuterium in [5], current densities of $286\,\mathrm{A/m}^2$ for deuterium and $329\,\mathrm{A/m}^2$ for hydrogen have to be extracted from the ion source. Negative ions are produced at the caesiated low work function surface of the plasma grid, the first grid of the extraction system. Extraction of negative ions is accompanied by co-extraction of electrons, which are magnetically deflected out of the beam at low energy and deposited on the extraction grid; for ITER NBI, a ratio of co-extracted electrons to extracted negative ions below one is envisaged in order to prevent overheating of this grid. For a proper beam transport, the homogeneity of the accelerated beam has to be better than $90\,\%$.

In the past years, it was demonstrated at ELISE that the size increase from the small prototype source to larger sources in a modular way works. In hydrogen, for the first time ever, a large negative ion source for NBI delivered a long pulse performance that is comparable to what can be achieved during short pulses: achieved were series of reproducible $1000\,\mathrm{s}$ pulses with more than $90\,\%$ of the ITER target values for the extracted ion current density [6], limited only by technological constraints. The pulses were sampled by so-called extraction blips since only pulsed extraction is possible at ELISE. These results represent a significant step toward operation of the ITER NBI system in hydrogen, i.e. during the first operational phase of the ITER NBI system (up to 2035).

Preparing for the DT operational phase of ITER, i.e. demonstrating the target values for deuterium during pulses of up to one hour, is much more challenging. The reason is illustrated in Figure 1a, showing for the 17 extraction blips of a $2700\,\mathrm{s}$ medium RF power deuterium pulse at ELISE the extracted negative ion current density $\mathrm{j_{ex}}$ and the co-extracted electron current density $\mathrm{j_{e,top}}$ and $\mathrm{j_{e,bottom}}$ for the top and the bottom half of the beam. The electron current density shows a pronounced top-bottom asymmetry and it increases strongly, by a factor of ≈ 24 between the first and the last extraction blip for almost constant negative ion current density. This increase is particularly pronounced between the first and the second extraction blip. The power load deposited onto the extraction grid increases correspondingly.

Indico rendering error

```
Could not include image: [503] Error fetching image
```

Figure 1. *a): Extracted negative ion current density and co-extracted electron current density for the top and bottom half of the beam for a 2700 s deuterium plasma pulse with 17 extraction blips in ELISE. b): caesium density measured during the same pulse.*

The observed increase in the co-extracted electron current is correlated with a reduced caesium flux toward the plasma grid. Figure 1b shows that the neutral caesium density measured in $2\,\mathrm{cm}$ distance to the plasma grid by laser absorption decreases from extraction blip to extraction blip, most strongly between the first and second extraction blip.

Up to now, one-hour deuterium pulses with $\approx 66\,\%$ of the ITER target value for the extracted negative ion current density are possible [7] while not fully exploiting the available RF power. For reaching the performance needed during the DT operational phase of ITER, it is necessary to further increase the RF power. However, the observed strong increase in the co-extracted electrons during deuterium pulses gets even more pronounced when increasing the RF power [7]. Then, the power load on the extraction system can limit the source parameters and consequently the achievable negative ion current.

Thus, a refinement of the available tools for controlling the co-extracted electrons is mandatory. Corresponding investigations are underway and can be divided into the following categories:

- Develop alternative caesium evaporation or re-distribution techniques to keep the caesium flux onto the plasma grid at a sufficient level during long pulses.
- Reduce asymmetries of the co-extracted electrons and of the caesium distribution in the ion source by actively modifying the plasma potential or by adjusting the magnetic fields used in the ion sources.
- In order to be able to investigate the temporal behaviour during the operational mode planned for ITER, BATMAN Upgrade and ELISE will be upgraded to cw extraction.

These investigations are going hand in hand with improving the insight into the related physics by exploiting the comprehensive set of diagnostics for the plasma (particle densities and temperatures, electrostatic potential) as well as for the beam (beam intensity and divergence, locally resolved) available at BATMAN Upgrade and ELISE and they are supported by modelling.

[1]: R. Hemsworth et al., New J. Phys 19 (2017) 025005
[2]: B. Heinemann et al., New J. Phys. 19 (2017) 015001
[3]: A. Masiello et al., Fusion Eng. Des. 84 (2009) 1276.
[4]: V. Toigo et al., New J. Phys. 19 (2017) 085004
[5]: A. Krylov et al., Fusion Eng. Des. 81 (2006) 2239
[6]: D. Wünderlich et al, Nucl. Fusion 59 (2019) 084001
[7]: D. Wünderlich et al, Rev. Sci. Instrum. 90 (2019) 113304

Country or International Organization

Germany

Affiliation

Max-Planck-Institut für Plasmaphysik

Author: WÜNDERLICH, Dirk (Max-Planck-Institut für Plasmaphysik)

Co-authors: RIEDL, Rudi (Max-Planck-Institut für Plasmaphysik); BONOMO, Federica (Max-Planck-Institut für Plasmaphysik); MARIO, Isabella (Max-Planck-Institut für Plasmaphysik); MIMO, Alessandro (Max-Planck--Institut für Plasmaphysik); WIMMER, Christian (Max-Planck-Institut für Plasmaphysik); FANTZ, Ursel (Max--Planck-Institut für Plasmaphysik); HEINEMANN, Bernd (Max-Planck-Institut für Plasmaphysik); KRAUS, Werner (Max-Planck-Institut für Plasmaphysik); THE NNBI TEAM (Max-Planck-Institut für Plasmaphysik)

Presenter: WÜNDERLICH, Dirk (Max-Planck-Institut für Plasmaphysik)

Session Classification: P7 Posters 7

Track Classification: Fusion Energy Technology