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NBI heating and current drive capability and its operation in ITER
ITERにおけるNBI加熱電流駆動と運転

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The heating and current drive (H&CD) capability of the ITER heating neutral beam (HNB) system is investigated over its designed vertical steering range. It is found that the ITER HNB provides an appropriate range to vary the deposition profiles of heating, current drive and fast ions. As in existing devices beam shine-through sets a threshold density which must be maintained to allow unconstrained HNB use in ITER. To accommodate the additional power deposition due to beam shine-through, special first wall (FW) panels with stationary power exhaust capability of 4.7MW/m^2 load are installed in regions where unabsorbed HNB neutrals can impact. Additional care must be taken in ITER operation, since, due to the complex geometry of the FW panels required by remote handling constraints, part of the unabsorbed beam can pass through the gaps between FW panels and impact on the blanket shield block, which has a lower surface power handling capability. While this is unlikely to be an issue for high-Q scenarios in ITER, the initial beam commissioning program, which is foreseen to be performed at medium currents (typically ~ 7.5MA) in the non-active phase (in hydrogen and helium plasmas), will need to be developed in detail taking into account this constraint.

1. Background

The ITER HNB system has two injectors, designed to deliver 16.5MW per injector at 1MeV for D^0 beam and at 870keV for H^0 beam. The HNB injectors reference aiming is 49.2mrad downward vertically from the horizontal plane. This vertical aiming can be changed within a range of +/-9mrad around the reference during shutdowns between experimental campaigns. This capability provides a range of H&CD deposition profiles that can be applied to control the plasma behavior/characteristics in ITER scenarios. The two key issues that result in limitations to the application of HNB in ITER scenarios are : the beam shine-through (SHT) heat load on the first wall (FW) and the beam interception and blocking in the beam duct (which is protected by a water-cooled liner). This presentation will report on the H&CD capability of ITER HNB and on an assessment of the SHT and of its influence on ITER plasma operation and initial beam commissioning.

2. HNB Heating and Current Drive Capability

The HNB vertical aiming angle for each injector can be chosen within its design range for optimum operation/performance of ITER scenarios. The H&CD profiles are modeled by using the orbit following Monte-Carlo code OFMC [1] including the description of the ITER HNB geometry [2]. Figure 1 shows profiles of the heating power and neutral beam current drive (NBCD) for various aiming angles for a 9MA/5.3T DT steady-state operation scenario [3]. The design steering range provides a reasonable variation of core and off-axis heating deposition for this scenario. The fast ion density profile (not shown in Figure 1) can be also varied from core- to off-axis deposition, which may contribute to MHD control (sawtooth, TAE), while the variation in the NBCD profile is limited within r/a=0.3.

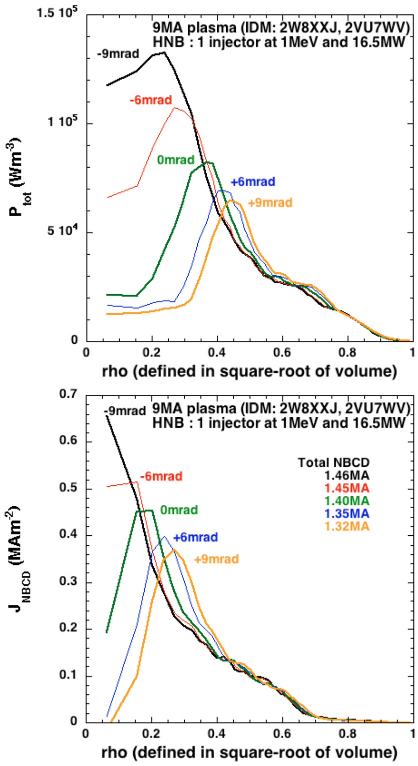

Fig.1. Variations of heating (top) and NBCD (bottom) profiles for a range of HNB aiming angles in a 9MA/5.3T DT steady-state ITER scenario [3].

3. HNB Operational Limitation by Shine-through Heat Load

The HNB shine-through heat load distribution on the first wall is evaluated with the NBSOURCE code [4] that reproduces the ITER HNB geometry and interactions with the plasma. By combining this result with a thermo-mechanical analysis [5] that evaluates the allowable cycle limit of the blanket shield module SB16DS behind the FW panels (which is the one subject to the highest loads), the number of the allowable SHT events for a given SHT heat load and its duration have been evaluated for various HNB aiming angles in a 7.5MA/2.65T Helium plasma expected to be utilized for access to the H-mode regime in the ITER non-active phase. The peak heat load on the beam axis when it impacts the first wall is found to be $5MW/m^2$ for a plasma density of $<n_e>=2.3x10^{19}/m^3$. For the reference HNB aiming (i.e. between on-axis and off-axis aiming) the heat loads on the shield block are highest ($1.9MW/m^2$), because the beam axis falls directly on the shield block and therefore the actual shine-through density limit would be somewhat higher in order to limit the heat load on the blanket module to its stationary limit of $0.3MW/m^2$. This density limit for the stationarily acceptable SHT heat load is $<n_e>=4x10^{19}/m^3$.

This result shows that plasma operation with HNB should be carefully planned to avoid excessive SHT and that, as planned in the control system design, the plasma control system (PCS) has to act on the HNB control to limit the heat load on the shield blanket module. This is likely to be most important during the initial HNB commissioning in the non-active phase if executed with 7.5MA Helium/Hydrogen plasmas for which the Greenwald density is $n_{GW}=6x10^{19}/m^3$. The highest heat loads in this case would correspond to the reference HNB steering, which minimizes the interaction with the HNB duct liner. However, excessive heat loads on the shield blanket module can be avoided by a carefully designed beam commissioning program utilizing an injection steering angle other than the reference value in which the beam acceleration energy is gradually increased as the commissioning progresses and as the capability for control of the plasma parameters develops. This commissioning program will be further developed by making an assessment of risks/benefits for the choice of HNB alignment and by determining the optimum path in terms of efficiency and risks to the overall operations plan for the non-active phase of ITER operation.

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Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References

[1] K. Tani, et al. 1981 J. Phys. Soc. Japan **50** 1726.
[2] T. Oikawa, private communication.
[3] A.R. Polevoi, private communication.
[4] P.B. Aleynikov, et al., Proc. 36th EPS Conf. Plasma Phys., Sofia, Bulgaria, 2009, P4.154.
[5] R. Bruno, private communication.