Comparison of Neutral Beam Injection options for EU DEMO pulsed scenario

P. Vincenzi[1], P. Agostinetti[1], J.F. Artaud[2], T. Bolzonella[1], T. Kurki-Suonio[3], P. Sonato[1], J. Varje[3]

[1] *Consorzio RFX, Corso Stati Uniti 4 - 35127 Padova (Italy)*

[2] *CEA, IRFM, F-13108 Saint Paul Lez Durance, France*

[3] *Department of Applied Physics, Aalto University, FI-00076 Aalto, Finland*

The pre-conceptual phase of the design of a European demonstrative fusion power plant (DEMO) is ongoing within the EUROfusion Consortium [1]. At the moment two main reactor options are investigated: a pulsed reactor (DEMO1) and a steady-state reactor (DEMO2) [2]. This work concentrates on the first option, DEMO1.

Neutral Beam Injection (NBI) is one of the methods being considered to provide auxiliary power and current to DEMO plasma. In the framework of the EUROfusion Power Plant Physics and Development (PPPT) activities, a conceptual design of a Neutral Beam (NB) injector for DEMO1 has been developed by Consorzio RFX in collaboration with other European research institutes [3]. The design considers several innovative solutions aimed at improving the system efficiency, mainly regarding a new modular beam source, the integration of a photoneutralizer and the vacuum pumping system. These new solutions require an uncommon beam shape, "thin and tall". Moreover, the injector is designed to deliver neutral particles at the energy of 800 keV, lower than the ITER NBI energy, in order to relax some constraints on the NB system, allowing operations in a more efficient regime and to better cope with high voltage issues.

The proposed solutions motivate the study of the effects that different NB design options can have on DEMO1 plasma. The goal of this work is to understand the sensitivity of DEMO1 plasma on NB parameter changes and to ensure achieving of DEMO1 target parameters with the proposed new injector concept. The present work complements previous technical studies [3] and detailed fast ion confinement studies [4] by numerical simulations of beam-plasma interaction with different NB injector options for the reference flattop scenario of

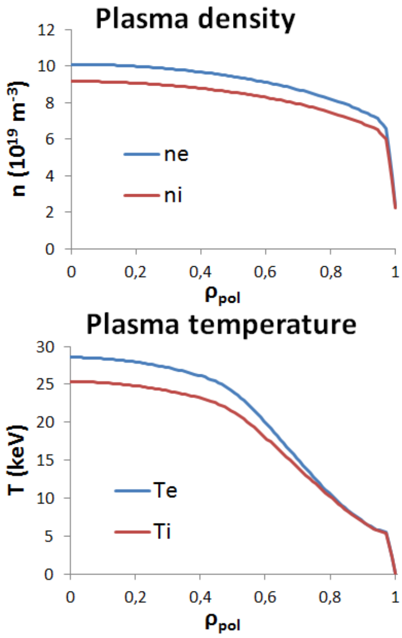

Figure 1: DEMO1 Plasma density and temperature profiles

the pulsed EU DEMO reactor (scenario details can be found in [2]). DEMO1 plasma temperature and density profiles used in this work are shown in figure 1.

Parametric study of different NB injector options

METIS code (Minute Embedded Tokamak Integrated Simulator), developed as part of the CRONOS suite [5], is a fast integrated tokamak simulator, particularly suited for parametric studies. It models the plasma evolution using scaling laws coupled with simplified source models (0.5D). For NBI, it uses an exponential decay to describe the beam absorption and an analytical solution of the Fokker-Planck equation for the fast particle slowing down. The beam is described by 3x3 parallel sub-beams. Two beams, each with P_{NBI}=25MW, have been used in the following simulations. Three different injector options have been compared: one with parameters corresponding to the new NBI concept presented in [3] ("advanced NBI", E_{NBI}=0.8 MeV, thin and tall shape, tangency radius R_{tang}=7.09 m), an "ITER-like" NB injector (E_{NBI}=1 MeV, beam shape as in ITER [6] with R_{tang}=7.09 m) and an injector used in METIS simulations for previous DEMO studies which features E_{NBI}=1 MeV, R_{tang}=8 m, a moderate vertical tilt and larger horizontal and vertical dimensions ("METIS ref.", used e.g. in [7]).

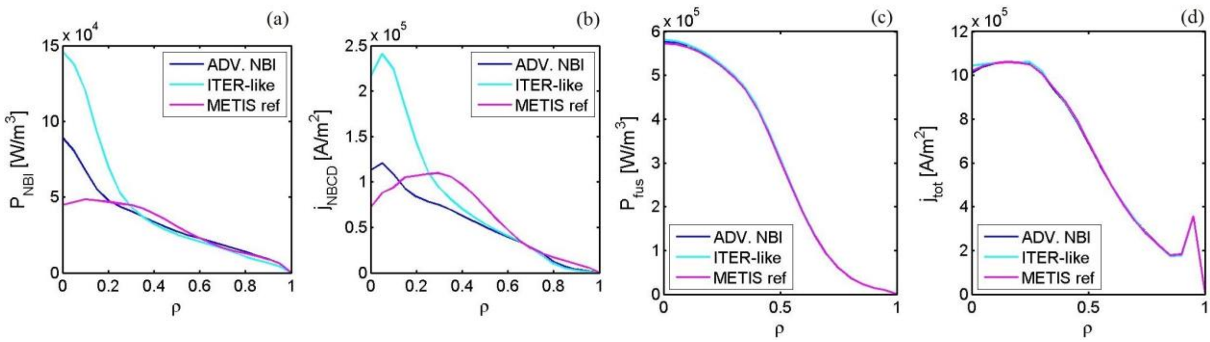

Figure 2: Comparison of different NB injectors. Profiles of NBI power deposition (a), NBI driven current (b), total fusion power (c) and total plasma current (d)

The main differences seen in the beam deposition (figure 2 (a) and (b)) are due to the different injection energies and beam trajectories. Higher energies correspond to higher beam penetration, larger driven plasma current and more power deposited to plasma electrons. The latter fact implies a slightly lower fusion power coming from NBI-plasma interaction (which is actually only a minor part of the total fusion power). The "METIS ref." beam power deposition is aimed more off axis than the two other options, because of its vertical tilt which in METIS simulations is the most effective way to shift the NB power deposition. Nevertheless, variations of NBI parameters evaluated in this work do not have significant effects on DEMO1 scenario (see e.g. the total fusion power in figure 2 (c) and total plasma current in figure 2 (d)). This can be explained considering the marginal role of NBI for DEMO1: the injected power in stationary flattop phase is 50MW with respect to e.g. ~400MW of alpha power, and the NB driven current is 6-8% of the total plasma current.

Detailed Monte Carlo simulations of advanced NBI concept

One of the solutions adopted for the advanced NBI concept described in [3] foresees to focus the beam at the DEMO wall port in order to minimize the impact on the breeding blanket. Moreover two injection angles have been compared and discussed in the paper from machine-integration point of view. In order to evaluate more accurately NBI shine-through power losses for both beam trajectories and the effect of the beam focus on the interaction with the plasma, which cannot be simulated by METIS code, we decided to use two coupled Monte Carlo Codes. The first code, BBNBI [8], calculates the beam ionization in a stationary background plasma, taking into account an accurate beamlet-description of the injector source. The second code, ASCOT [9], evolves the fast particle population generated by BBNBI during the slowing down by solving kinetic equations of fast ions. One injection line with P_{NBI}=16.7 MW has been considered in these simulations.

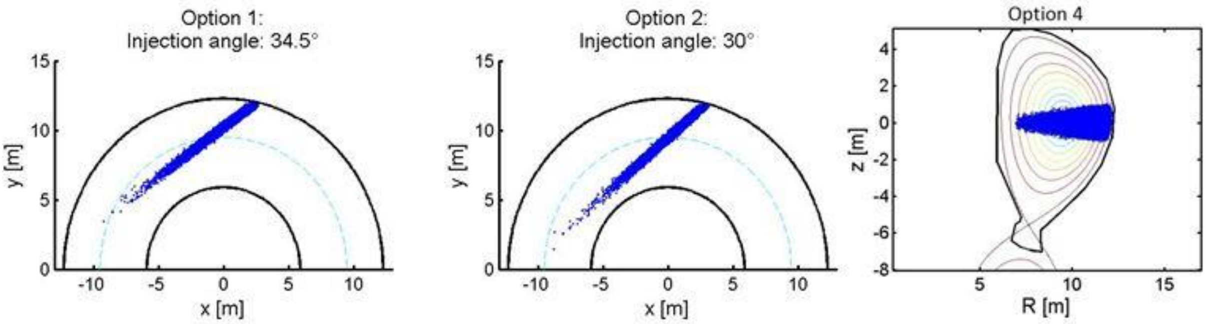

Figure 3: Ionization patterns for two different injection angles (options 1 and 2) and for the beam focus in the plasma core (option 4)

We varied the injection angles: “option1” at 34.5° with respect to the major radius, R_{tang}=8.14 m and “option2” at 30°, R_{tang}=7.09 m – same names as in [3]. We then simulated another option (named “option4” to be distinguished from “option3” in [3]) with the same injection angle of 30° (R_{tang}=7.09 m) but the beam focus (both horizontal and vertical focuses) aiming at the plasma core and not at the wall port as it is for the other two options. In stationary flattop conditions, none of the three options

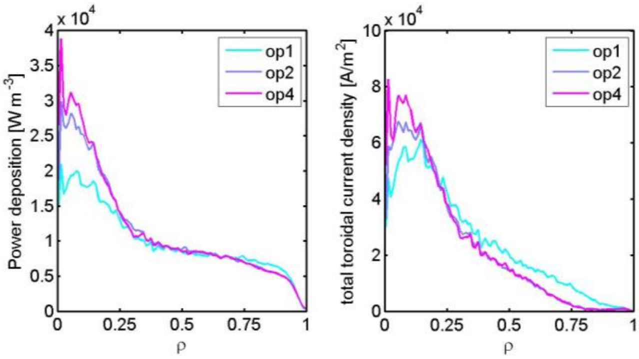

Figure 4: NB power deposition and driven current density for different injection trajectories and focuses

showed shine-through power losses. The ionization pattern of the 3 options is shown in figure 3. The resulting NB power deposition and the driven current density calculated by ASCOT code are shown in figure 4. It is possible to see that a change in the injection angle (op1 vs op2) is more effective than changing the beam focus from the wall port to the plasma core (op2 vs op4).

Conclusions

Different NBI options have been compared in DEMO1 flattop scenario and effects of changes in NBI parameters (energy, trajectory, shape) have been explored. Due to the relatively low NB contribution to the overall plasma power balance and plasma current, limited changes in NB energy (e.g. from 0.8 to 1MeV), trajectory and shape do not significantly affect the target scenario. The choice of NBI parameters will certainly be more important for the steady state scenario (DEMO2) or for transient phases (current ramp-up and ramp-down) where heating systems play a crucial role [10]. The results confirm the effectiveness of the new NB system proposed in [3] in terms of plasma scenario integration, considering the absence of shine-through power losses in flattop phase and the compatibility of the beam trajectory and shape with DEMO1 flattop scenario requirements.

Acknowledgments

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