Expected performances of the DTT heating systems

G. Granucci[1], S. Garavaglia[1], P. Agostinetti[2], T. Bolzonella[2], A. Cardinali[3], C. Castaldo[3], S. Ceccuzzi[3], D. Farina[1], L. Figini[1], R. Maggiora[4], D. Milanesio[4], A. Moro[1], G. L. Ravera[3], D. Ricci[1], M. Vallar[2], P. Vincenzi[4]

[1]Istituto di Fisica del Plasma, CNR, Milano, Italy; [2]Consorzio RFX, Padova, Italy; [3]ENEA, Dipartimento FSN, Frascati (RM), Italy; [4]Politecnico di Torino, Dipartimento di Elettronica, Torino, Italy

The Divertor Tokamak Test (DTT) facility has been proposed in the European roadmap to study solutions to mitigate the issue of power exhaust in conditions relevant for DEMO. The Italian DTT tokamak [1] (B_T=6T, I_P=5.5MA, R_0=2.08m, a=0.65m and pulse duration of 90-100s) is being designed to allocate and study the optimal divertor magnetic configuration under a reactor relevant power flow (P_{SEP}/R>15MW/m). A mix of three heating systems (ECH, ICH and NNBI) will equip the machine to reach the target value of 45MW at plasma. The present reference power sharing considers 20-30MW of EC power, 7-15MW of NNBI and 3-9MW of ICH with a certain level of flexibility in the final allocation due to the ongoing scenario simulations and technical considerations.

Electron Cyclotron The ECH system will be designed for: main plasma heating, MHD control, plasma start-up and current profile tailoring. According to the nominal magnetic field (6T) the frequency of 170GHz has been selected for both heating and current drive (CD) tasks. The injection of wave at different poloidal and toroidal angles is foreseen to cover all the physical requirements exploiting both equatorial and upper launchers. The EC system architecture is based on clusters, each one with eight gyrotrons fed by three High Voltage Power Supplies, one Multi-Beam Transmission Line (MBTL) and eight independent antennas. A compact and simplified design of the system is the main guideline of the project, exploiting as far as possible the ITER and W7-X experience and their mature technologies. The gyrotron is based on the ITER prototype (1MW/170GHz/100s) with depressed collector technology, assuming an efficiency of ~50% and a gaussian output >95%. The TL requirements are a target efficiency of 90% and a power handling of 1MW. The design employs the use of Quasi-Optical (QO) TL with large MB mirrors exploiting the QO propagation with up to 8 beams allocated on a single mirror. The 8 EC beams of a cluster deliver to 8 independent launchers, six on equatorial and two in an upper port (to control MHD activity) for highest flexibility. The sub set of launchers will have the real time steering capability for MHD control while part of equatorial launchers could be movable shot by shot. A first assessment of wave absorption and CD efficiency has been performed with the beam-tracing code GRAY [2] on the day 1 scenario (25MW additional heating, B_T=6T, I_P=4MA, q_{95}=4, T_{e0}=11keV, n_{e0}=1.5 10^{20} m^{-3}, Z_{eff}=1.9) The results in terms of driven current I_{CD} are mapped in Fig. 1 as a function of the toroidal (β) and poloidal (α) injection angles for a beam launched from an equatorial (R=3.15m, z=0m) and an upper (R=2.8m, z=1.1m) launch points. The equatorial launch allows good absorption and a relatively large driven current in the range $0.1 \leq \rho \leq 0.6$, where ρ is the square root of the normalized toroidal flux, while the upper launcher is better suited for localized absorption and CD at larger radii, $0.4 \leq \rho \leq 0.8$. The CD efficiency, in the radial range covered by both launchers, is comparable for the two launchers, with an advantage for the equatorial launch: I_{CD}≈30kA/MW at ρ<0.4 (η_{CD}≈0.089 $10^{20}AW^{-1}m^{-2}$) and I_{CD}≈10kA/MW at ρ=0.6 (η_{CD}≈0.028 $10^{20}AW^{-1}m^{-2}$). The toroidal injection angle to maximize I_{CD} is 15° ≤ β ≤ 25°, the exact value depending on the injection point and on the target minor radius. This value will be therefore considered the target in the detailed design of the equatorial launcher. Preliminary BKD0 [3] simulations show an increase of a factor 4 in the upper limit of D_2 neutral pressure (from 2.5 to 10mPa) at E_{TOR}=0.8 V/m with 2MW of EC power for assisted plasma start-up.

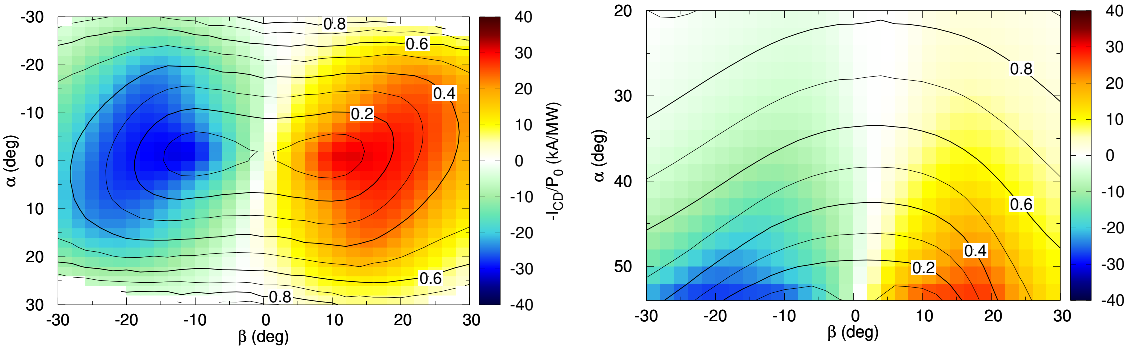

Fig. 1. Normalized deposition location ρ (black curves) and total driven current I_{CD} (color code) as a function of the poloidal and toroidal injection angles (α, β) for 170GHz. Results for the equatorial (left) and upper (right) launchers are shown for the day 1 reference scenario (B_T=6T, I_P=4MA).

Ion Cyclotron The ICH system is mainly considered to support plasma heating by energy transfer to H or ^{3}He minority species via first harmonic cyclotron absorption. For the reference DTT magnetic field of 6T and absorption at the plasma centre, the use of such heating scheme sets the ICH operational frequencies in the range 60-90MHz. The system can also support electron heating via mode conversion and wall conditioning through 2nd harmonic cyclotron heating of majority D ions. Other tasks like generation of fast particles, control of density peaking, impurity accumulation and q-profile [4] are possible too, mostly after the upgrade to full power, while current drive is not foreseen. To cope with DTT required flexibility in magnetic configurations, radially movable antennas are under consideration. Assuming a single null scenario a first assessment has been done to couple 3MW of ICH power in the day 1 of DTT operation. The power can be coupled to the plasma with two structures protruding a few centimetres from the first wall, assuming a pessimistic folding length of 5mm for the electron density in the scrape-off layer, as reported in Fig. 2. The power density per ICH launcher is chosen to be no more than 3.5MW/m^2, to be compliant with the status of the art of coupling performances in H-mode plasmas along with a voltage standoff of 40kV. To cope with fast variations of antenna loading due to ELMs and L-H transition, an external conjugate-T matching scheme [5] is envisaged. The two antennas are fed in pairs, to avoid matching problems associated with the mutual coupling between straps, by splitting the outputs of two diacrode-based transmitters fed by a single high voltage power supply (HVPS). One module of the ICH system thus comprises one HVPS, two transmitters, and two antennas. This module will be developed and installed for day 1 operation, and it will be replicated to meet the DTT power requirement of full performance.

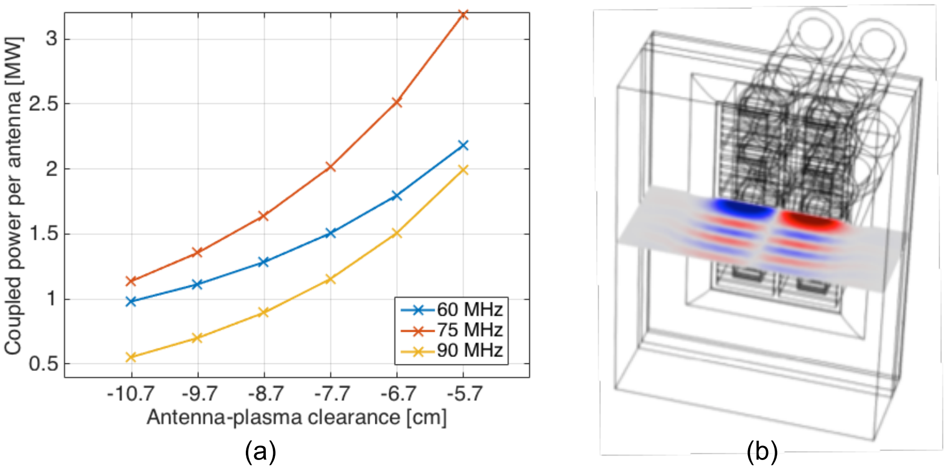

Fig. 2. (a) Coupled power versus antenna clearance from separatrix in dipole phasing, calculated with COMSOL Multiphysics for an inhomogeneous dielectric load locally matching the perpendicular propagation constant of the plasma wave. (b) Overlay of the E_{pol}-field at 60MHz, in dipole phasing for an antenna-plasma clearance of 3cm.

Negative-NBI Neutral Beam Injection (NBI) Heating primary aim in the DTT experiment is to reliably support central plasma heating during the main phase of the plasma confinement. In addition to that, NBI can be used to influence current density profile and plasma flow for scenario tailoring. Two injectors each delivering approximately 7.5MW are planned for the DTT experiment, with one of them ready from the beginning of DTT operations. In order to heat particles in the core plasma at the high density of DTT (>2 10^{20}m^{-3}), a negative NBI system at higher energies (not smaller than 300keV) is proposed. METIS [6] code simulations of the reference single null scenario have confirmed an acceptable shine-through and a deposition profile coherent with the scenario requirements, as shown in Fig. 3 (left) for three different injection angles. Although 300keV beam energy would anyway leave operational margins in case lower plasma density values will be required during DTT operations, the accelerator is designed to allow for the injection of neutrals at reduced energy (at the cost of a reduced power to be coupled to the plasma). An improvement in the flexibility is also obtained by using the modular ion source, that permits to modify the poloidal angle of injection by reducing or increasing the current extracted from each sub-source. The final values of beam energy and the injection angle are currently under discussion taking into account the various technical and physical requirements.

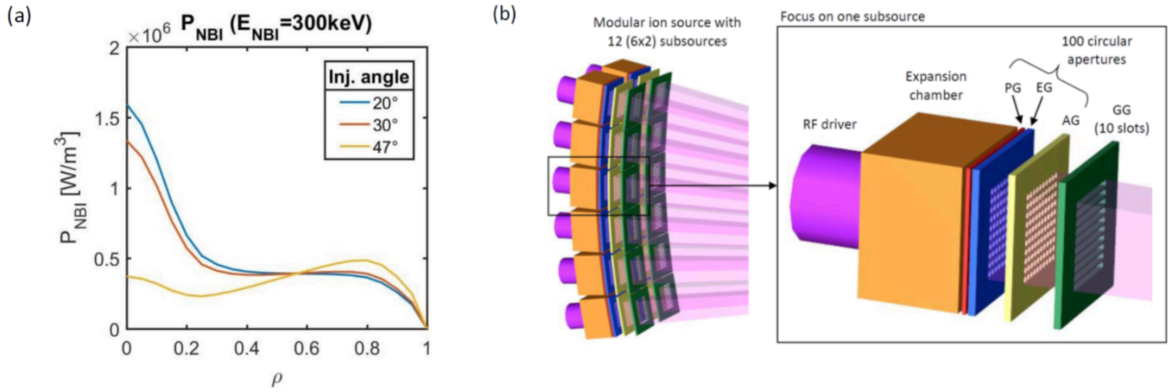

Fig. 3. (a) Power deposition considering three different injection angles. (b) NBI conceptual design: modular ion source with a focus on a single sub-source.

The current design considers an extracted current of deuterium negative ions of 50A, a beam energy of 300keV and an overall plug-in efficiency around 45%. It features a number of design solution derived by the ITER NBIs, with some significant improvements that most notably include a modular ion source (for better beam optics and increased flexibility), the Non-Evaporable Getter pumps [7] (for a more reliable operation) and the accelerator grids with increasing size and decreasing number of apertures (for a better pumping and less stripping losses inside the accelerator). A beam source conceptual design view can be seen in Fig. 3(b).

Conclusion A description of the three systems and estimations of the deposition profiles have been presented and discussed together with the specific technical solutions adopted to fulfill the requirements and maximize the performances.

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