On the possibility of neutral beam heating on the TCV tokamak

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The TCV tokamak broadens the explored parameter range in fusion reactor relevant plasma regimes using the main experimental tools: flexible plasma shaping together with high power real time-controllable electron cyclotron heating (ECH) and current drive (ECCD) systems. Direct ion heating upgrade on TCV [1] with the installation of a 15-30 keV neutral beam injection (NBI) with a total power of 1-3 MW would allow the extension of the present range of ion to electron temperature ratio (T_i/T_e~0.1-0.8) to well beyond unity, depending on the mix of NBI/ECH and on the plasma density. An NBI system would also permit TCV to study plasmas in the reactor relevant T_i/T_e ratio ~1 and to investigate fast ion and MHD physics in these regimes as well as the effects of plasma rotation and high plasma ß scenarios.

The feasibility studies for NBI heating on TCV presented in this paper are aimed at developing a specification for the neutral beam injectors, determining the experimental geometry and modeling the possible operational scenarios.

The installation of a low energy (~20 keV), low divergence (≤0.7 deg.), 0.6-1 MW neutral beam injectors should significantly increase the experimental capability of the TCV tokamak by extending the operational domain at higher T_i/T_e ratio and plasma pressure (ß) and enlarging the H-mode operational domain (especially at high densities). A set of two balanced near normal and another near tangential injectors are proposed with a total injected power of 2.0-3.0 MW which allow the investigation of the effects of NB induced plasma rotation [2], fast ion behavior and MHD physics in scenarios such as stationary ELM free H-modes [3] and fully non-inductive electron internal transport barriers.

For a given injection energy, the fast ion orbit width (proportional to Larmor radius) and corresponding orbit losses are smaller for hydrogen than for deuterium. This is offset by the lower charge-exchange cross section at higher E_B/m, increasing the shine-through although the neutralization efficiency in the injector is significantly lower for hydrogen. With these contradictory effects, NBI operation with both hydrogen and deuterium is essential.

Furthermore, adjustable beam energy of 15-25 keV for near normal NBI and an even wider range for near tangential injector would enhance the accessible ranges of plasma configuration and density whilst simultaneously minimizing the heating efficiency reduction due to orbit losses at lower plasma current.

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