Discharge recovery by means of EC assisted start-up

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Introduction. In view of an efficient pulsed operation scenario of future nuclear fusion reactors, the effectiveness of a prompt and reliable plasma start-up is essential to improve plasma performance and reproducibility, especially after a disruptive event, as well as to reduce dwell time between pulses. The foreseen solution to widen the operational window with respect to the pre-pulse conditions (background pressure and impurity content) is the use of Electron Cyclotron (EC) additional heating, which can compensate for radiation losses and sustain the plasma burn-trough phase. In order to design the operational scenario of future demonstration reactors (DEMO) it is mandatory to set appropriate codes capable of extrapolating from present experiments to future scenarios. In the framework of the MST1 program, an experimental investigation of the EC assisted start-up has been performed on TCV tokamak. The results have been reproduced successfully with simulations provided by BKD0 code [1-2] and will be used in support of JT-60SA and DEMO operations.

Experimental results. Experiments carried out on TCV are focused on testing the capability of EC power (82.7 GHz, XM2, maximum gyrotron power 750 kW) to sustain the burn-through plasma phase at low toroidal electric field (0.7 V/m), independently to the impurity content/composition as can be in the residual gas left by the previous discharge. They are designed to reproduce and validate simulation done by BKD0. The implementation of the gyrotron power feedback control on I_p was successfully used to optimize the power scan (to find the minimum power required), and it has proved to be effective also when the standard cleaning procedure (GDC glow discharge) between pulses is not applied. Different procedures have been adopted to control the pre-pulse neutral composition in order to mimic background pressure for the DEMO start-up (at reduced dwell time) and test the conditions for JT-60SA operations (with C wall). A pressure scan has been performed both changing the D_2 flux and reducing the pumping speed of 75% (Fig 1 (Left)). Furthermore, an Ar impurity scan has been performed (Ar valve not calibrated 1.5 V - 30, 50, 80 ms - 3e19 atoms/s @ t=-1s), as shown

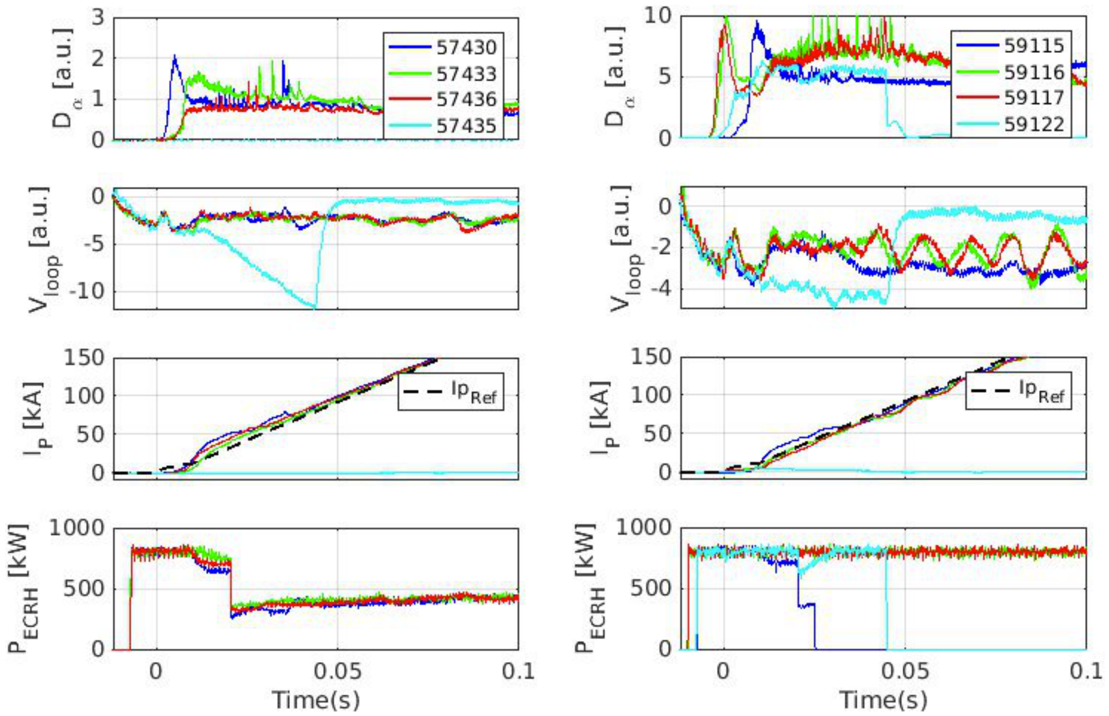

Figure 1 (Left) D_2 dominated plasma. EC assisted start-up is effective for shots with E_{tor}=0.7V/m (V_{loop}=4V). D_2 flux is 3e20mol/s for shots #57430 (pumping speed reduced of 75%), #57433 (100% of pumping speed), 0.8e20mol/s (100% of pumping speed) for shot #57436. The failed shot #57435 (100% of pumping speed, E_{tor} = 2V/m) without additional heating is reported for comparison; (Right) D_2 plasma with Ar impurity. Shot #59122 is not sustained and required more power than the maximum available. Shot #59115 without Ar is shown for comparison.

in Fig.1 (Right). In the deuterium-dominated plasma, the use of EC makes start-up effective even at higher background pressure (to mimic the DEMO requirement to minimize the inter pulse dwell time) or without GDC between shots, assuming enough power (>400KW). As expected, on this background, adding Ar as impurity (foreseen as one of the potential gas to be used for the DEMO flat top phase [3]) leads to an increased power threshold for a sustained startup. The peak of D_α emission is strongly influenced by the machine conditions. It results anticipated in case of reduced pumping speed and in case of Ar injection, while it is delayed in case of experiments performed without GDC.

Simulation results. One of the key issues in simulating the start-up phase is the correct evaluation of the EC absorbed power. Absorption is a function of n_e and T_e, which are low in the early stage of the discharge. As a consequence, only a reduced percentage of injected power is deposited at the resonance layer at each pass of the wave in the plasma, with the remaining stray radiation potentially dangerous for the device. A predictive model has been

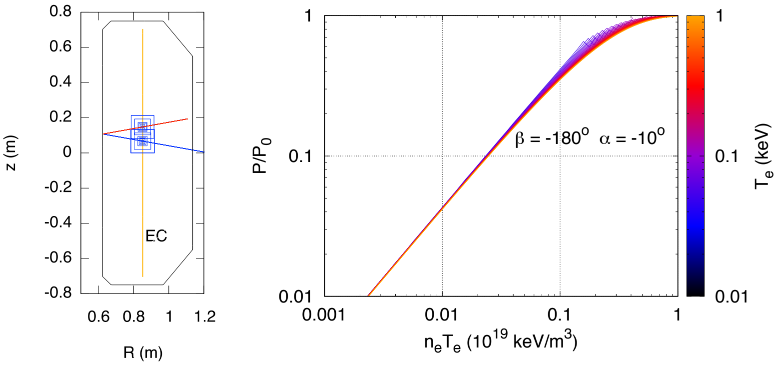

Figure 2 TCV gyrotron launching configuration used during the experiments (left). Absorption calculated by GRAY, as a function of n_eT_e, and used in the BKD0 simulations (right).

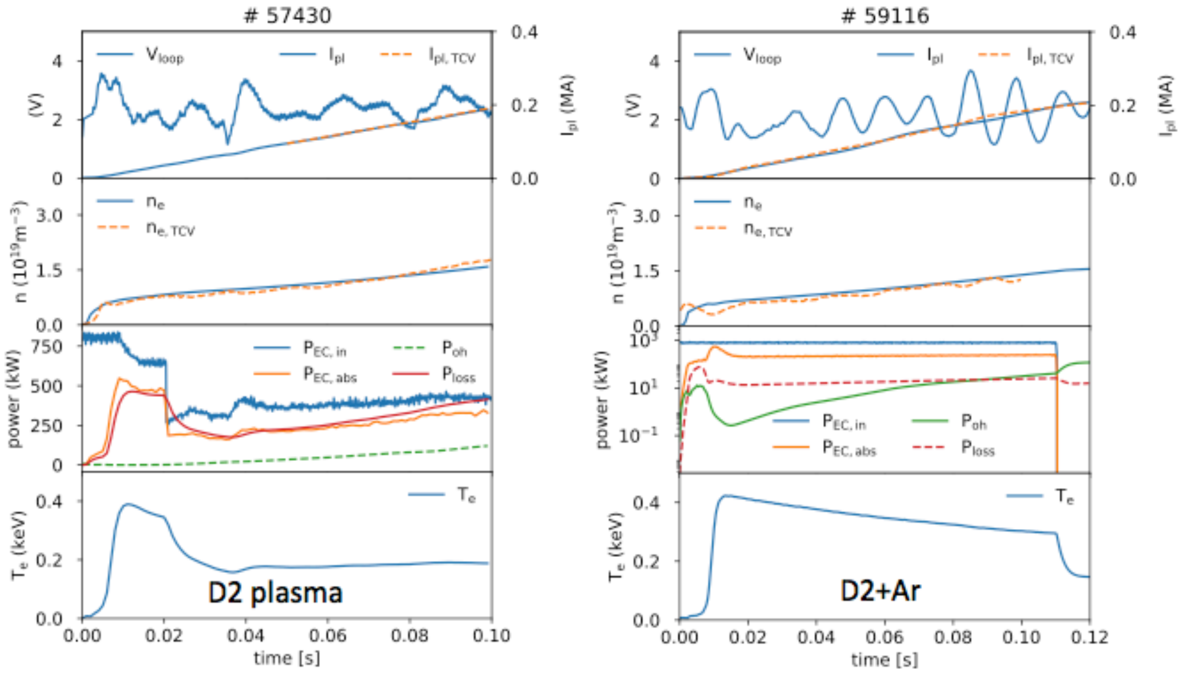

Figure 3. BKD0 simulations in case of D2 dominated plasma (left) and in presence of Ar impurity (right). The V_{loop} and $P_{EC,in}$ are inputs of the code, taken from experiments, all the other quantities are outputs. The n_e and I_{pl} are compared with the measured ones.

parameters, performed by means of the BKD0 code [1-2] and based on [4], coupled with the self-consistent calculation of the EC power absorption (including EC localization, polarization effects and wall bouncing effects) by means of the quasi-optical beam tracing code GRAY [5]. The launching configuration has been chosen in order to maximize the XM2 absorption (Fig. 2 (Left)) for the experiments performed. The EC deposition occurs in the magnetic field null. Fig 2 (Right) shows the EC absorption calculation (including the proper polarization mix after reflection at the inner wall) as a function of (n_eT_e). Experimental results have been successfully reproduced with simulations provided by BKD0 code (Fig.3). Fig. 4

shows the percentage of Ar density used in simulations to reproduce the correspondent discharges. When n_{Ar} /n_{D2} is more then 2.5%, the radiation losses due to impurity (Ar, C_2, O_2) are not compensated by 750 kW of additional EC power and the start-up is not effective as verified during the experiment.

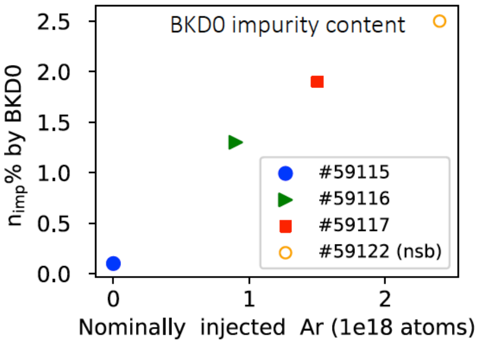

Figure 4 Percentage of n_{Ar} / n_{D2} used in BKD0 simulation to reproduce the corresponding shots, plotted as a function of the nominal injected Ar atoms. A value higher then 2.5% at t = 0 s determines unsuccessful start-up, as occurred in shot #59122, with 750 kW of EC power injected.

Conclusions. The BKD0 has been used to reproduce experimental results obtained on TCV tokamak. The validation activity makes BKD0 a useful tool to be used in support of future devices operation. The required additional power and impurity impact on startup determined for TCV and based on BKD0 can be confidently extrapolated to set-up a similar procedure for ITER[2], JT-60SA and DEMO.

A further step, that is an operational issue of interest for JT-60SA and ITER, is the analysis of the dependence the start-up effectiveness on the resonance position with respect to the poloidal magnetic field null. A first activity is foreseen on TCV in the framework of the MST1 program in 2018.

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