SAWTEETH DYNAMICS IN JT-60SA BASELINE SCENARIOS WITH EFFECTS ON NTM ONSET

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JT-60SA is a large fully superconducting new tokamak device built under the Broader Approach Satellite Tokamak Programme jointly by Europe and Japan, and under the Japanese national programme (R_0=3 m, Ip=5.5.MA, B=2.25T, a~1.17m) [1]. The study of high plasma performances in terms of high beta scenarios in support to similar ITER and DEMO tokamaks scenarios is a basic objective for the JT-60SA tokamak for extrapolating long steady-state operations [2-3]. As in the initial research phase the plasma current I_p will be gradually increased up to the full operational values, baseline plasma scenarios at reduced Ip are considered.

JT-60SA plasmas scenarios characterized by low central magnetic shear and on-axis safety factor q_0 <1, extrapolated by experimental data of JET and JT-60U, which are similar in size and operational regimes [4], are made with METIS code [5] for 4.6 MA considering hydrogen and deuterium main ions compositions with carbon and some oxygen impurities. These simulations take into account mainly 10 MW of negative Neutral Beam Ions (N-NBI), 3 MW of perpendicular P-NBI, 3 MW of tangential NBI and 1.5 MW central Electron Cyclotron (EC) heating sources with various density profiles with b_N around 1.3 in H and 1.7 in D plasmas. Simulations with these main ions can predict different loss of confinement due unstable perturbations, as the neoclassical tearing modes (NTMs), triggered at the crashes of long sawteeth (ST) periods. As it is well known [6] that the appearance of these modes should be more favoured in D plasmas than in H because the ST periods t_{ST} tend to increase with high isotope mass (τ_{ST} (H) < τ_{ST} (D)), predictive evaluations of conditions under which the sawtooth crashes occur are a key issue to indicate the better plasma performances.

The objectives of this work is first to predict the sawteeth dynamics in terms of their period and amplitude based on a critical shear extrapolated by JET similar discharges. The control of the ST frequency is also investigated using the 1.5 MW EC central auxiliary power in order to reduce any triggered large seed island for avoiding the NTMs onset [7,8]. The ST evolutions are modeled considering the different criteria for the triggering of a sawtooth crash described by Porcelli [9] with some modifications by Sauter [10]. The dependence of the ST period on the fast particles by NBI (eventually lengthening the ST period) or on resistive internal kink where the resonant layer dominates are investigated. Relaxed plasma current density J_{relax} and safety factor profile q are calculated after a ST crash based on the following theoretical arguments. More specifically, the relaxed current density can be inferred by the relaxed q profile immediately following the sawtooth crash, according to the specifications in Ref. 11 if the Kadomtsev's relaxation model is considered as valid, or in Ref. 9 if incomplete reconnection is assumed instead. We note that the relaxed current density profiles immediately after the sawtooth crash, according to these relaxation models, are likely to involve current sheets localised near the sawtooth mixing radius, which would then be smoothed out rapidly as a consequence of resistive diffusion. Sawteeth dynamics calculated for a previous JT-60SA high density scenario predicted a period of 0.47 s .

The J_{relax} can be estimated taking into account the presence of impurities and the consequences on the values of the tearing stability parameter Δ'_0 due to the equilibrium current gradient. Thus, the second purpose of this study is the simulation of the possible synchronism in time among ST crash, NTM onset and the presence of impurities due to high Zeff (~ 1.8 in the considered scenarios) for the mechanism of the seed island formation as found in JET discharges at high Ip [12]. In these scenarios there are two impurities spatially distributed and peaked on the plasma axis: Carbon with Z=6 and Oxygen with Z=8 taking into account that JT-60SA will start its operations in C-wall.

This interplay suggests, for the description of a mode onset, a phenomenological relation between the TM index Δ'_0 and a variation of the radiated power dP_{rad} associated with the global and local modification of the impurities density. This modelling seems to be reasonable because direct interaction of ST with high poloidal m and toroidal n modes is very weak, but sawteeth can affect the mode onset through an indirect modification of Δ'_0 for variations of density and current density $J \sim e(n_i V_i - n_e V_e)$. When there are low Z impurities in the plasma core, which tend to be uniformly distributed, a ST crash leads to impurities ejection with a change dn_z in their concentration which induces an electron density perturbation $dn_e = Z\, dn_z$ from the quasineutrality condition $n_e = n_i + Zn_z$. A sudden local density perturbation dn_z leads to a variation of the radiated power dP_{rad} on the ST period timescale and can modify directly the equilibrium current profile $dJ = -dn_e V_e \propto dP_{rad}$. Then an effective phenomenological criterium for the TM onset can be given assuming a linear response $r_s\, \Delta'_{0,mn} = -m + k\, dP_{rad} / P_{rad} > 0$ where P_{rad} can be taken as a threshold below which the mode destabilization does not occur and k is a coefficient evaluated in a stable point $rs\, \Delta'_{0,mn} = 0$. It can be conjectured that the net positive growth is due to the prevalent direct modification of the plasma current, while effects of island neoclassical dynamics in unsteady conditions come into play with neoclassical mode destabilization when an initial seed island w exceeds a critical width w_{cr} and the poloidal beta β_p becomes larger than a critical value β_{cr}. However, the issue if the change in current density associated with the expulsion of impurities could be destabilizing or stabilizing will be the object of our investigation.

These analysis are carried out using the European Transport Simulator (ETS) [13], a modular package solving transport equations for the modeling of plasma discharges embedding various physics modules. The ST model and a generalized Rutherford equation describing the NTM evolution [14] are integrated as well.

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