Development of a tool for validation of capability of ITER PF system to support scenarios obtained with different plasma transport codes

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During ITER design the DINA code [1] is being routinely used for validation of capability of the poloidal field (PF) system to support different plasma scenarios (see e.g. [2-5]). The simulations performed so far with the standard version of the DINA code use a rather simple one-dimensional model describing transport of the electron and ion temperatures, and diffusion of the poloidal magnetic flux, which is integrated with the two-dimensional plasma free boundary equilibrium solver implementing feedback control of the plasma current, position and shape, taking into account eddy currents in the vacuum vessel. DINA simulations also took into account numerous engineering limits imposed on ITER coils, their power supplies and plasma-wall gaps, beginning from the start of discharge of the central solenoid (before breakdown) allowing simulation of a full cycle of the PF system operation [5].

A newly developed version of the DINA code (*DINA with prescribed kinetic profiles*) allows the validation of the capability of the ITER PF system to support the scenarios obtained with other codes, which may have more sophisticated plasma transport models, but do not have the capability of: 1) detailed simulation of plasma magnetic control, 2) correct calculation of the magnetic flux linked with the plasma and 3) detailed integration of all engineering limitations. This paper shows an example of the validation of 15 MA DT scenario simulated using the JINTRAC plasma transport code [6] with prescribed evolution of the plasma current, position and shape, obtained from a standard DINA code simulation. The following profiles of plasma parameters ("*kinetic profiles*") used in the simulations with the modified version of DINA code were taken from the corresponding JINTRAC simulations: 1) the plasma electric conductivity, 2) the density of non-inductively driven current, 3) the total pressure (produced by the thermal and high energy particles), 4) the density (electron and ion) and the temperature (electron and ion).

The scenario considered has the fastest plasma current ramp-up (50 s, limited by the converter voltages) with early X-point formation at 3.3 MA, the H to L mode transition at the end of burn (EOB) and the fastest plasma current ramp-down in divertor configuration (till 1.5 MA in about 64 s after the end of the flat top). This scenario was based on a similar scenario simulated with the standard version of the DINA code described in [5].

The scenario simulation was started from the fully charged CS producing 117.6 Wb of poloidal magnetic field flux. The plasma initiation and current ramp-up till 1.6 MA (3.5 s after the start of CS discharge) were simulated using the standard version of the DINA code described in [5] and a 0-D plasma transport model. The first free-boundary plasma equilibrium obtained has a current of 0.1 MA ($t = 1.2$ s). When the plasma current exceeds 1.6 MA ($t > 3.5$ s), the simulation was performed with the newly developed DINA version using JINTRAC kinetic profiles. This was done in the following three steps:

- In the *first* step, the standard version of DINA code was used in the simulation of the plasma current ramp-up, flattop and ramp-down for the production of the waveform of the plasma current and the time sequence of the sets of (R, Z) coordinates of a number of points located on the plasma boundary. The number of points is chosen to be sufficient for a detailed representation of the plasma boundary. The EOB state was defined as the state when the current in the central modules of the central solenoid (CS1) reaches 44 kA (the engineering limit is 45 kA). In this simulation with the standard version of DINA code the EOB was achieved at $t_{EOB} = 639$ s, which corresponds to a burn length of 559 s.

- In the *second* step, the obtained sets of plasma boundaries and the waveform of plasma current (with $t_{EOB} = 639$ s) were used in the JINTRAC simulation [6] using a more sophisticated plasma transport model than that used in the standard version of the DINA code. The results of these JINTRAC simulations provided the time evolution of the plasma *kinetic profiles*.

- In the *third* step, these JINTRAC-produced kinetic profiles were used in the simulation using the newly developed version of the DINA code (*DINA with prescribed kinetic profiles*), instead of the plasma transport model of the DINA standard version. The EOB state, when current in CS1 reached 44 kA, in this DINA run was achieved at 490 s, that is, the burn length is of 410 s instead of 559 s with the simpler DINA transport model. After EOB, the H to L mode transition was simulated, which was followed by the plasma current ramp-down with the target evolution of the plasma current and plasma-wall gaps similar to those at the first and second steps. Thus, in the third step, the simulation combines the advances features of the DINA code (detailed simulation of plasma magnetic control, correct calculation of the magnetic flux linked with the plasma and detailed analysis of all engineering limitations) with the sophisticated plasma transport model and description of heating, current drive and fuelling sources in the JINTRAC code.

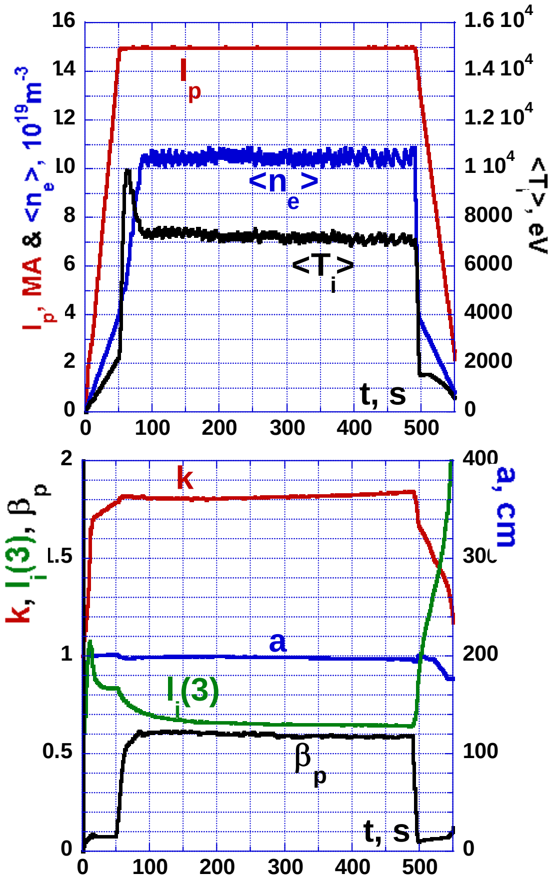

Fig. 1: Plasma parameters

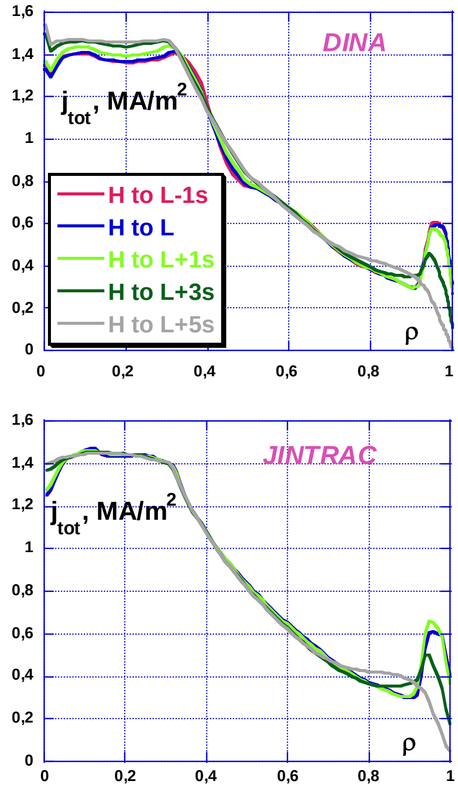

Fig. 2: Plasma current density before and after the H to L transition in DINA simulations with JINTRAC kinetic profiles (upper figure) and in JINTRAC simulations (lower figure).

Figs. 1 - 3 show evolution of the plasma parameters in the simulation of the third step. The following conclusion can be extracted from the comparison of the DINA simulations using the DINA original plasma transport model and the JINTRAC plasma transport model: The control schemes and control algorithms used in the simulations with the JINTRAC kinetic profiles allow the same quality of control of the plasma current and plasma-wall gaps as it was obtained in the simulations with the DINA original plasma transport model. The values of the plasma-wall gaps, as well as all engineering parameters (currents, voltages, forces, etc.), except for maximum value of the magnetic field on the PF6 conductor, are within the design limits.

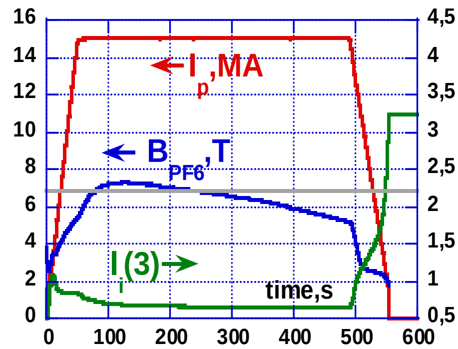

Fig. 3: Plasma current, $l_i(3)$ and magnetic field on PF6 conductor.

There are three main differences, however, in the simulations with the original DINA kinetic profiles and those obtained with JINTRAC:

- The first difference is a higher value of the bootstrap current at burn in the JINTRAC model (Fig. 2) resulting in a low value of the plasma internal inductance, l_i, which was overestimated in the DINA model due to different pedestal assumptions. Due to the low value of l_i (Fig. 1), in the scenario considered, the maximum value of the magnetic field on the PF6 conductor exceeds 6.8 T from the start of burn (80 s) till 240 s (Fig. 3). The maximum value of the magnetic field on the PF6 conductor can be reduced by modification of the plasma current ramp-up scenario (increase of the ramp-up time and/or reduction of the power of the auxiliary heating during this phase). However this modification may lead to reduction of the burn duration.

- The second difference is in the value of fusion power, which in the case of JINTRAC plasma transport model is lower that it was obtained with the original DINA plasma transport model [5] (320 MW vs. 500 MW) corresponding to a Q_{DT} = 6.5 in JINTRAC versus 10 in DINA and τ_E = 3.2 s in JINTRAC versus 3.5 s in DINA.

- The third difference is the plasma loop voltage during the burn. The plasma loop voltage in the JINTRAC simulations during burn, including the effect of sawtooth oscillations, is rather high (0.11 V). This significantly differs (it is 57% higher) from the loop voltage obtained for such scenario with the DINA code using its own plasma transport and sawtooth models (0.07 V). The reason for this difference is in part the lower plasma temperatures in the JINTRAC simulation associated with the lower Q_{DT} ($\langle T_e \rangle$ = 7.5 keV in JINTRAC versus 8.5 keV in DINA) which leads to an increased plasma resistivity by 21%. The remaining 36% could be due to differences in the flux consumption associated with the sawtooth model implemented in JINTRAC and DINA, which are presently under investigation.

In the conclusion we may note, that the simulations performed demonstrated possibility the newly developed version of the DINA code (*DINA with prescribed kinetic profiles*) to verify capability of the ITER PF system to support plasma scenarios obtained with different plasma transport models (codes) and to calculate maximum duration of the current flattop (or burn) in these scenarios consistently with the PF scenario of plasma initiation.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

References

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