DEVELOPMENT OF ITER HIGH-FIDELITY PLASMA SIMULATOR BASED ON JINTRAC AND DINA, AND STRATEGY FOR VALIDATION

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A high-fidelity plasma simulator (HFPS) is required to refine and complete the development of the ITER plasma scenarios necessary for elaborating the ITER Research Plan (IRP) and preparing the experimental campaigns. It will also be used to support the analysis of ITER plasmas, including in the burning regime, by enabling the application of a wide range of physics models for interpretative integrated modelling analyses. The integrated modelling of ITER plasmas necessitates coupled physics simulations including core-edge-SOL (Scrape-Off-Layer) transport and sources, heating and current drive (H&CD), fuelling, heat and particle exhaust, plasma interaction with wall and targets, integrated magnetic and kinetic controls, and plasma stability. To perform such modelling tasks, an ITER HFPS is currently being developed by combining a core-edge-SOL transport and source modelling suite, JINTRAC [1], and a free-boundary plasma equilibrium evolution code, DINA [2], following the ITER Integrated Modelling & Analysis Suite (IMAS) paradigm [3]. It includes capabilities to utilize additional external physics models within the overall workflow, e.g. via the dedicated H&CD workflow [4]. The ability to perform integrated modelling including such additional physics components is now being extended by adopting the persistent actor framework, MUSCLE3 [5], which enables a new co-simulation type of coupling between the different physics codes. This work presents the progress on the development of the ITER HFPS based on JINTRAC and DINA and discusses the currently foreseen strategy for its application and validation within the ITER Members' facilities.

The first prototype of the ITER HFPS, which enables an integration of free-boundary plasma equilibrium evolution (DINA) and core transport and source modelling (JETTO component in JINTRAC), has been developed by applying two different schemes for coupling the codes and physics, namely loose and close coupling schemes. The loose coupling scheme [6] applies an iterative process of exchanging simulation data between DINA and JINTRAC runs for an end-to-end simulation or a segment of a scenario. This iterative process is automatized within a single workflow with convergence tests satisfying specific criteria for each physics component. The converged solution of a loose coupling simulation can therefore be used to verify the validity of close coupling simulation results, where the iterative process is not implemented to accelerate the execution of simulations. The

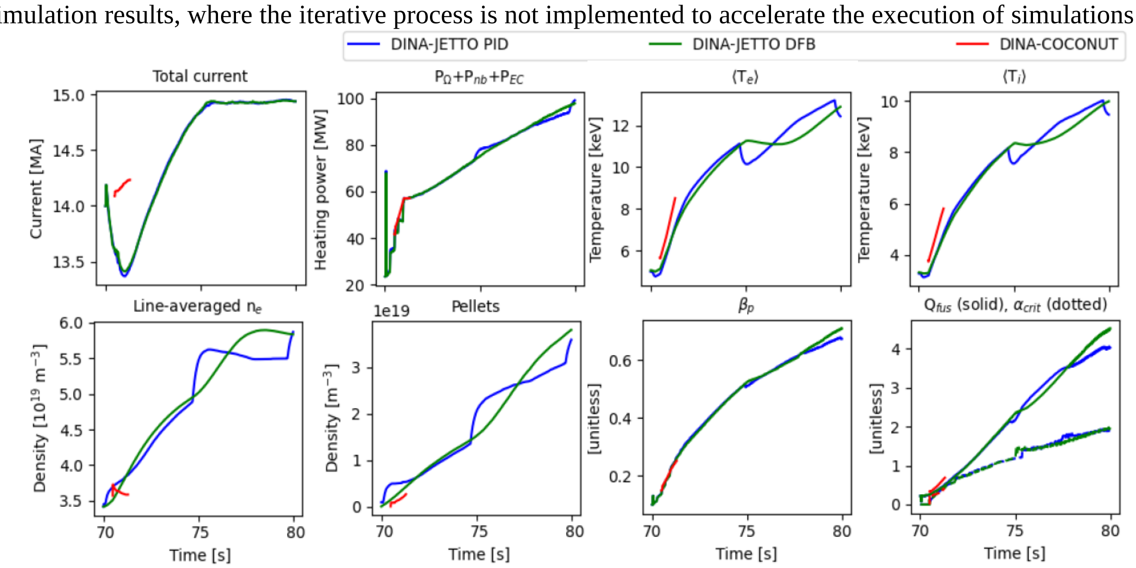

Figure 1. Time-traces of global plasma quantities in DINA-JETTO (either PID controller or default feedback controller (DFB) is used to control the line-averaged density using pellets) and DINA-COCONUT simulations (with PID) during the L-H transition phase of the I5MA/5.3T DT ITER scenario. The simulation interval of the DINA-COCONUT case is [70.5-71.3s] whereas it is [70.0-80.0s] in the DINA-JETTO cases

close coupling scheme exchanges simulation data between the relevant physics components at a reasonably high frequency (~*m*s), as previously demonstrated in DINA-CRONOS free boundary/core transport coupled simulations [7], to satisfy the validity of coupled simulations. The close coupling scheme is proposed as the main approach to be used for general application after verifying its validity ranges using loose coupling simulations. The coupled free-boundary/core transport modelling capability of DINA-JETTO has been demonstrated by applying it to ITER scenarios such as the 15MA/5.3T DT Baseline and 7.5MA/2.65T Hydrogen scenarios [8]. These simulations include the current ramp-up, L-H confinement mode transition, magnetic and kinetic controls using the Poloidal Field (PF) coils, H&CD and fuelling systems, and are used to confirm the validity of the coupling schemes and to identify areas of further improvements.

The first prototype of the ITER HFPS has been recently extended to enable coupled core-edge-SOL transport modelling (using COCONUT component in JINTRAC) with a dynamic update of the 2D edge/SOL grids generated by the DINA free-boundary equilibrium code. This free-boundary/core-edge-SOL transport capability (DINA-COCONUT) has been applied to a selection of ITER scenario segments around an L-H confinement transition and compared with the free-boundary/core transport simulations (DINA-JETTO). An example given in Figure 1 shows that DINA-COCONUT simulations can qualitatively reproduce DINA-JETTO simulations. The differences in the DINA-COCONUT simulations are attributed to significant modelling improvements achieved in modelling edge/SOL/divertor physics. In the DINA-COCONUT simulation the plasma parameters at the separatrix are self-consistently computed including edge/SOL transport and sources affected by gas puffing, pumping and plasma-target interactions, whereas user estimates are imposed in the DINA-JETTO simulations. In the extended prototype, dynamic updates of the 2D edge/SOL grids are also applied with the assumption that the particle content within a single cell is conserved during the grid update. This simple assumption also provides quasi-conservation of the energy and momentum if the average velocity and temperature are unchanged during the grid update interval defined by the edge transport solver (~μs). Figure 2 shows the changes of grid cell volume and main ion density during an update of 2D edge/SOL grid. As the update of the free-boundary equilibrium will be slower (~*m*s) than the typical timescale of the SOL transport, the plasma is expected to adapt quickly to the updated grid (cell volume changes) with fast parallel transport of particles and heat. An advanced scheme [9] is also being investigated in parallel to further improve the conservation of physics quantities during the update of the 2D edge/SOL grids. This is planned to be integrated in the near future.

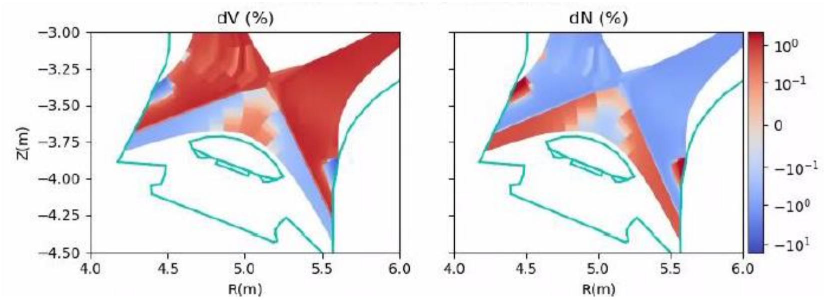

Figure 2. Changes of grid cell volume and main ion density during the update of 2D edge/SOL grid in a DINA-COCONUT simulation.

Further extension of the high-fidelity physics modelling capabilities across the plasma core, edge/SOL and target/wall areas is foreseen with the application of parallelized/reduced physics-based transport and source models, including W source from the wall, a fully consistent update of the 2D edge/SOL grids along with the free-boundary equilibrium evolution, and improved event handling across various physics components (e.g., sawtooth). The application and validation of the ITER HFPS within ITER Members' facilities is foreseen to follow a staged approach to prepare the modelling of other devices including the implementation of coil systems and magnetic/kinetic controls, as well as to properly handle the complexity of coupled physics simulations, dynamic generation of 2D edge/SOL grids, and the application of integrated controls.

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