Progress on Combined DINA-CH and CRONOS Simulator

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1. Introduction Simulation of the free-boundary evolution of ITER plasma requires both kinetic and magnetic calculations in a self-consistent manner. The free-boundary plasma equilibrium should follow the control inputs governed by the position and shape control system and the transport calculation has to provide global and local plasma properties. These requirements have not yet been satisfied fully. Therefore, we are trying to combine a free-boundary evolution code, DINA-CH [1-2], and an advanced transport modelling code, CRONOS [3], keeping their own computational performances. The first attempt at the combined simulation using DINA-CH and CRONOS revealed some critical problems [4]. Nevertheless, the previous work showed the possibility of integrating a free-boundary evolution code and an advanced transport modelling code. In this second phase, we have found solutions for those problems mentioned in the first phase and have met some new difficulties.

2. Progress on Combined Simulation Scheme

The overall coupling scheme has not changed from the previous one [4]. DINA-CH provides a free-boundary equilibrium with the response to currents in PF-coils and the vacuum vessel. A previously upgraded position and shape controller controls the PF coil voltages. It provides a wider operation range in plasma current making it possible to simulate the hybrid mode operation of ITER.

In this work, the free-boundary equilibrium calculated by DINA-CH directly substitutes the CRONOS equilibrium, instead of reconstructing it [4]. This removes the mismatch between the

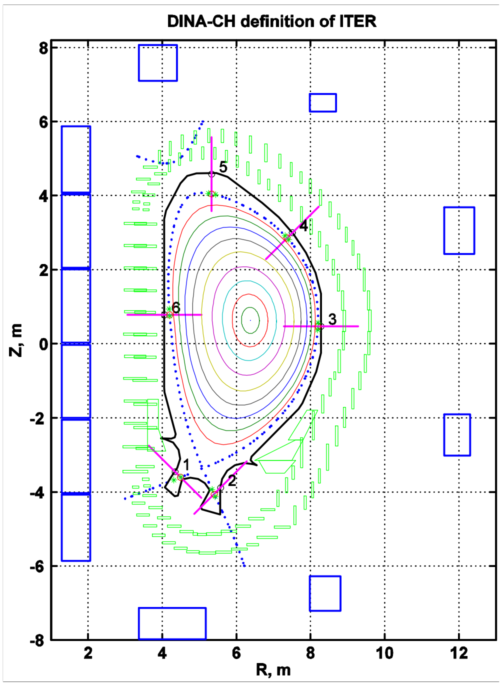


Figure 1. DINA-CH definition of ITER with 6 gap measurements

equilibria, caused by differing equilibrium reconstructions, and increases the simulation speed and the compatibility between DINA-CH and CRONOS. The substituted equilibrium is used for calculating a set of transport equations and their source terms provided by various heating and current drive modules. Updated plasma profiles and parameters are both outputs from CRONOS as well as the next time-step inputs to DINA-CH. By partitioning the functionality, CRONOS calculates transports of heat and particles with source terms and transport models, whereas DINA-CH provides current diffusion in a self-consistent manner with plasma evolution and electromagnetic responses. A problem related to the time-step delay of data exchange between DINA-CH and CRONOS has been examined with simple test models and corrected [3]. We have modified the old format of interface file between DINA code and Matlab Simulink to work properly in a higher version of Matlab. At present, the calculation sequence has no additional time-step delay. Diagnostic models for bolometry, FIR and neutron camera have been integrated into DINA-CH after correcting wrong diagnostic signals outside plasma.

While these old problems are now fixed, we have met others during test simulations. First, the profile shapes of ITER plasmas seem to cause numerical difficulties in DINA-CH. DINA-CH was usually used for plasma evolution simulation with approximated profile shapes with a view to control. Large peaks in the bootstrap current in the edge region, steep pedestal profile shapes and high beta-poloidal might require a very accurate initial equilibrium to remove possible oscillations of some physical properties at the beginning of a simulation, such as the plasma current and magnetic axis. For this, the initial equilibrium is calculated by adopting a SPIDER equilibrium component that has an adaptive grid for free-boundary equilibria [5]. However, this is not enough to resolve all numerical difficulties. There are sudden step-like jumps in the magnetic axis (< 1mm) without any detectable cause or change in plasma state. Either the coarse rectangular grid used for the free-boundary equilibrium or possible multiple free-boundary equilibrium solutions seem to cause these jumps. Having a dense grid for the free-boundary equilibrium is very expensive computationally, unless these step-like changes cause severe changes of our simulation result. Thanks to the fact that these step-like changes are small and can be distinguished from physical responses, we did not change the grid size. A second difficulty comes from the total simulation time required for a combined simulation. In a CRONOS simulation with fixed-boundary equilibrium, the general time interval for the update of heating and driven current profiles is 5sec in a steady-state flat-top phase. However, in order to see fast free-boundary features with an advanced transport calculation, it is necessary to update the heating and driven current profiles more frequently.

To solve this problem, the update intervals in heating and current drive modules need to be variable and controllable. By controlling the update intervals during the simulation, we can keep the performance of each code and have physically meaningful results. The heating and current drive modules are presently under investigation for this application.

3. H-mode and Hybrid mode ITER Simulations H-mode and Hybrid mode ITER plasmas have been simulated for 50sec, starting from the steady-state flat-top phase of existing CRONOS simulations at 600sec [6]. In the H-mode simulation with 15MA plasma current, peaked plasma current profile contains a small fraction of driven currents and boot-strap current at the edge as shown in Figure 2. Election and ion heating profiles are also peaked in the centre region. The rapid temperature drop at the beginning of a previous simulation [3] becomes negligible in this simulation by transferring equilibrium information directly from DINA-CH to CRONOS. Initial heating and driven current profiles are kept for several simulation steps and updated later to avoid undesirable oscillations in the whole system at the very beginning of simulation. The free-boundary features are shown in Figure 3. The sawtooth activity caused by the central safety factor value less than 1 seems to produce small oscillations in pressure and current profiles. These then affect plasma position and shape parameters such as a magnetic center and gap measurements.

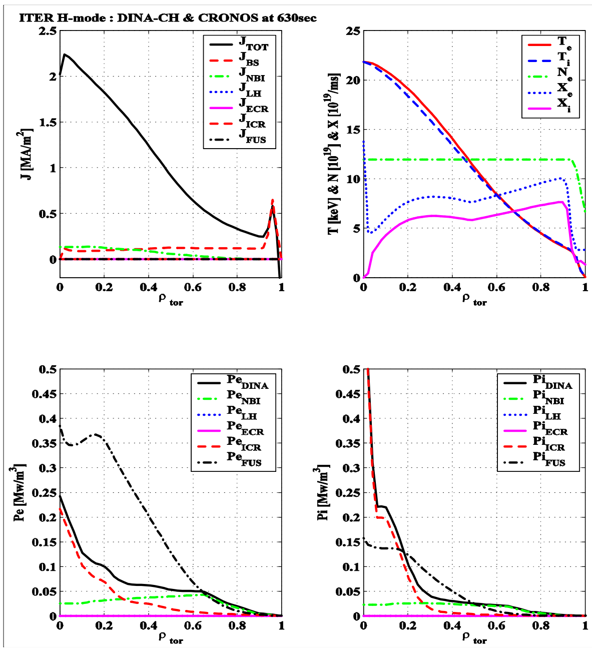


Figure 2. H-mode simulation of ITER. Current, temperature and density, electron and ion heating profiles

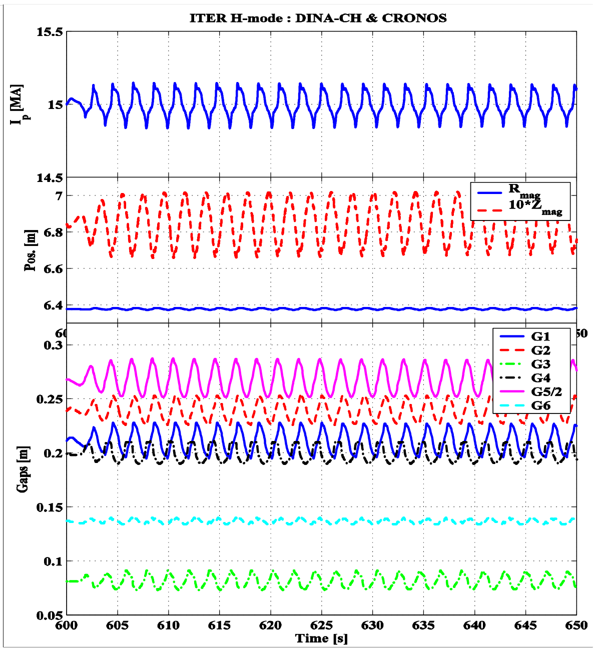
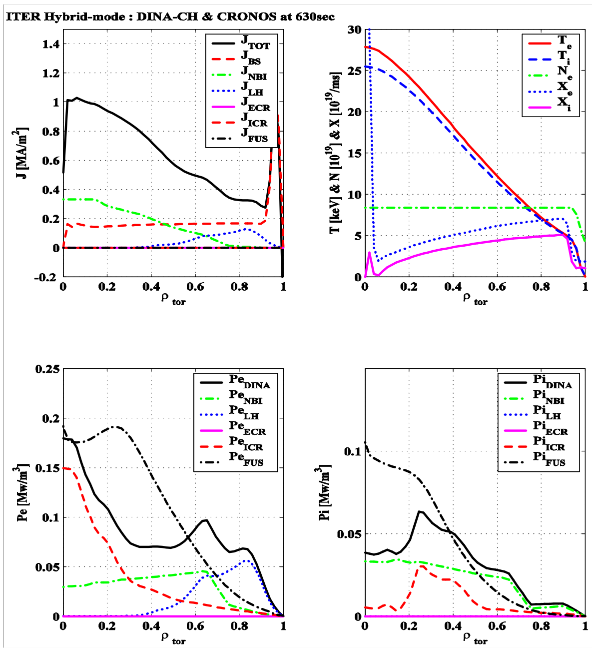


Figure 3. H-mode simulation of ITER. Plasma current, magnetic axis position and 6 gap measurements

The profiles in Hybrid mode simulation are more difficult in the numerical sense. Broad plasma current profiles with 11.3MA have a peaked edge bootstrap current profile and higher pedestal top as shown in Figure 4. Electron and ion heating profile shapes are also broad. NBI and LH heating and driven current profiles are updated every 5sec and showed step-like changes in Figure 5. A big step change at 605sec shows that heating and driven current profiles in fixed-boundary equilibrium are different with ones in free-boundary equilibrium. The current driven by LH wave generates a variation of total driven current at the edge region, then it affects the total plasma current and safety factor profiles. Though these changes are small in this simulation, they could non-linearly couple with free-boundary features.



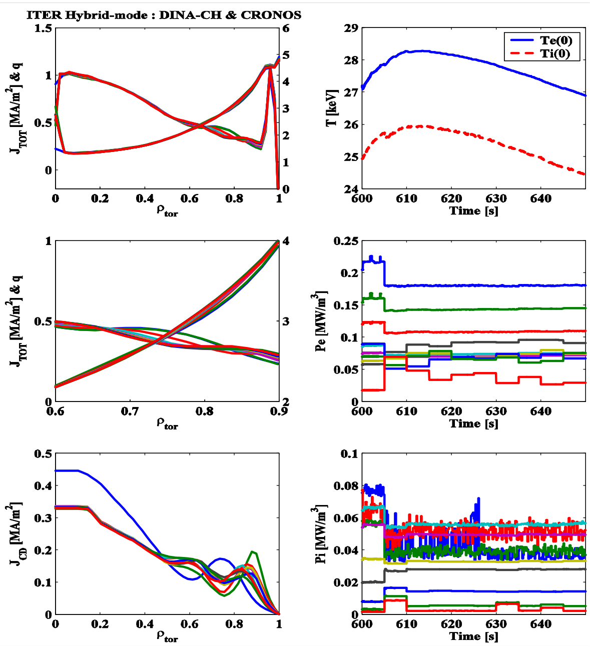


Figure 4. Hybrid mode simulation of ITER. Current, temperature and density, electron and Ion heating profiles

Figure 5. Hybrid mode simulation of ITER. Current profiles, temperature traces, electron and Ion heating traces

4. Conclusions Progress on combined DINA-CH and CRONOS simulation is presented with H-mode and Hybrid mode simulation results. Problems with equilibrium reconstruction and data exchange have been solved and new challenges on stable simulations keeping the computational performance are being addressed.

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