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Plasma Current Ramp-up Phase Simulation of ITER

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Introduction

Background

- The proposed ITER reference scenarios still have **uncertainties**, mainly from the plasma transport and boundary evolution.
- Now is the time to confirm the ITER reference scenarios, **at least the reference scenario 2** (it is designed to use maximum inductive current ramp-up capability of ITER)
- **The desired flat-top tokamak operation conditions** are obtained by tailoring the plasma current ramp-up phase.
- **The ohmic flux (volt-second) consumption** during the current ramp-up phase limits the duration of the burn.

Objective : Feasibility study of the ITER reference scenario 2, focusing on the current ramp-up phase with

- **CS & PF coil current limits** : some of coil reference currents are very close to the current limits (CS1, CS2U, CS2L, PF6)
- **CS & PF coil voltage limits** : additional coil voltages are required at the beginning of the ramp-up phase (SNUs for CSs and PF1&6, booster power supplies for PF2-5)
- **Plasma shape evolution with X-point formation** : requires a virtual radial position controller and a switch to the shape controller
- **Ohmic energy confinement** : resistive ohmic flux losses are closely related to the transport

Combined DINA-CH and CRONOS simulator

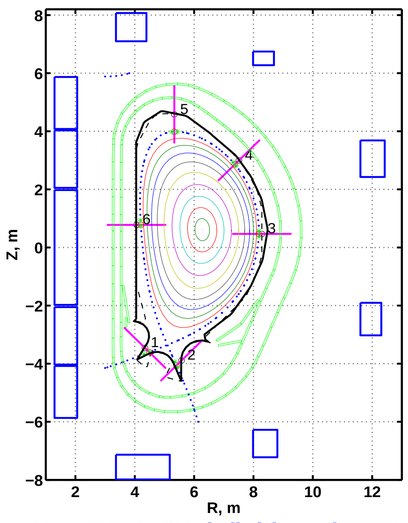
For this type of study, we need a full tokamak simulator, such as the combined DINA-CH and CRONOS simulator

DINA-CH

- **2D free-boundary equilibrium evolution**
- **Self-consistent current diffusion with the surrounding conducting systems**
- **Magnetic feedback control on PF-coil currents**
- **Diagnostic models for kinetic profile control**

CRONOS

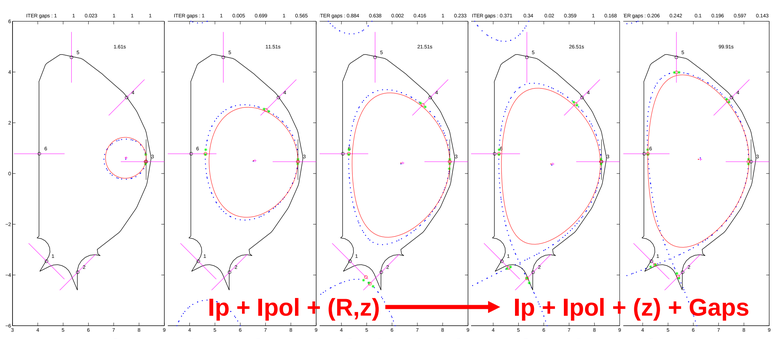
- **Transport calculation for heat and particles**
- **Various transport models (kiauto for ITER)**
- **Advanced source calculations**



New DINA-CH definition of ITER

- **Interpretive or predictive mode simulation**
- **Initial inputs from the existing CRONOS simulation**
- **MATLAB SIMULINK environment and graphic user interface**
- **Synchronized sawtooth events**

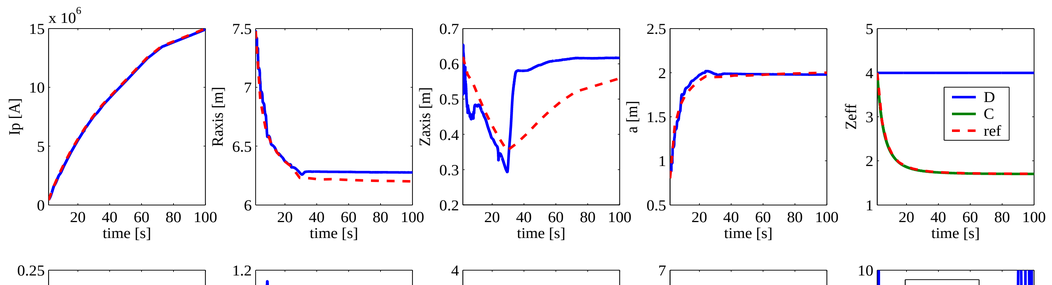
Simulation of ITER reference scenario 2



Plasma boundary evolution and X-points formation

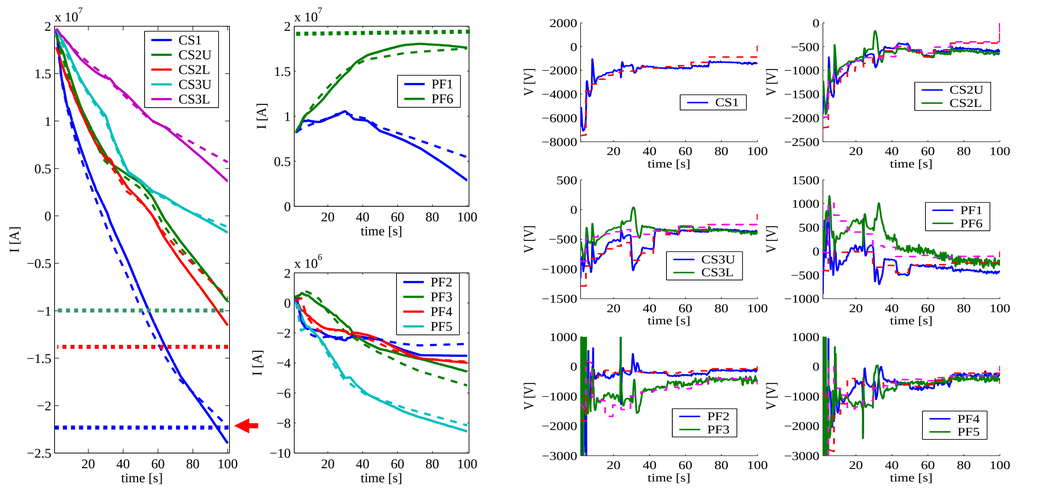
- Ip(t=1.6s) = **0.4MA**
- Ip(t=100s) = 15MA
- No ECRH
- Linear density ramp-up
- β_p^{ref} = 0.1
- li^{ref} = 0.85

• R control is necessary to stabilse the plasma boundary evolution



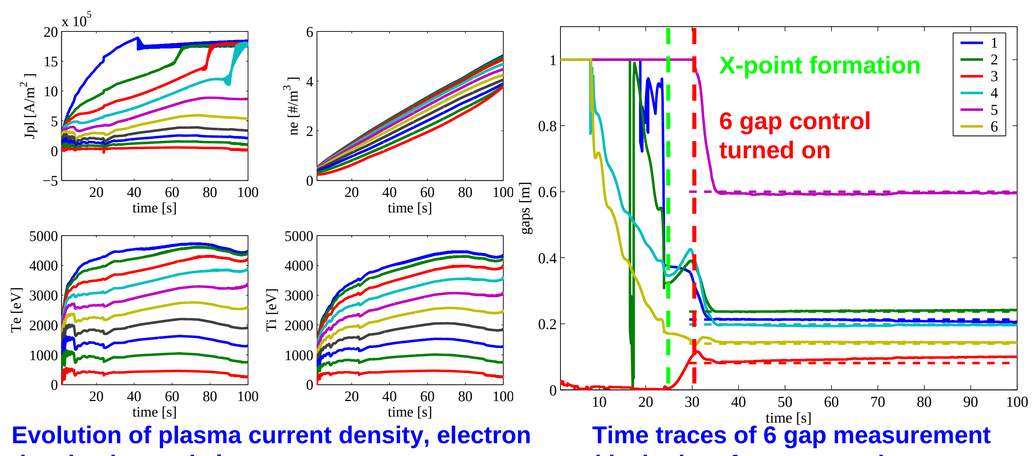
Time traces of plasma parameters (dashed red : ITER reference scenario 2 except tauE)

• The ITER reference scenario 2 seems to be developed with slightly promising assumptions (high β_p, low li, no sawtooth)



Evolution of coil currents and voltages (dashed : ITER reference scenario 2)

• CS1 currents cross the coil current limit (red arrow)

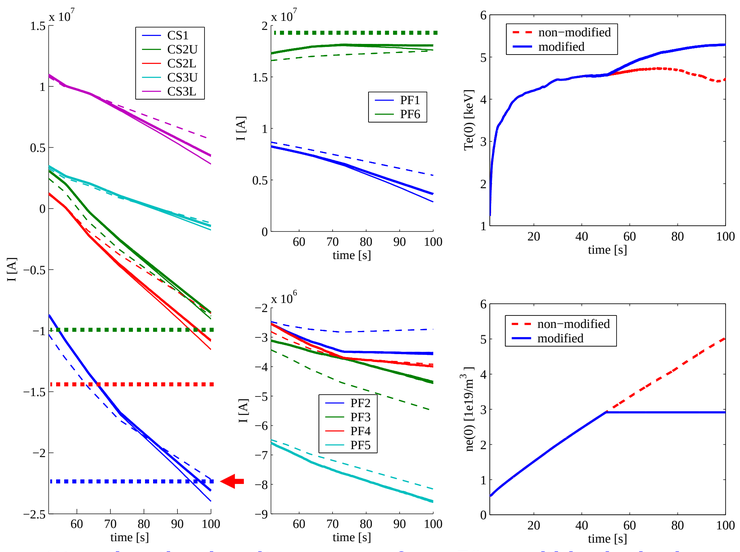


Evolution of plasma current density, electron density, ion and electron temperatures

Time traces of 6 gap measurement (dashed : reference gaps)

• Ohmic confinement time scaling law ➔ low plasma temperature (low beta)

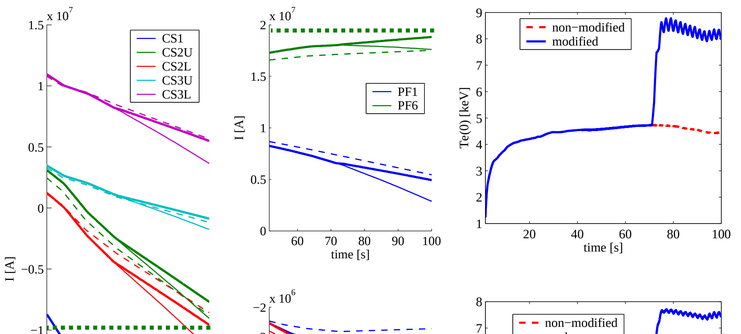
Simulations with modified conditions



Stopping the density ramp-up from 50 sec (thin dashed : ref., thin : simulated, thick : simulated with the modification)

1. Stopping the density ramp-up

- Density ramp-up stops from 50 sec
- Plasma temperature increases
- Resistive ohmic flux losses decrease
- A slight improvement of CS1 current evolution : the increase of the plasma temperature is limited by the degradation of the energy confinement



Application of 8MW NBI from 70 sec (thin dashed : ref., thin : simulated, thick : simulated with the modification)

2. Application of additional heating

- 8MW NBI from 70 sec (similar scheme to the ITER reference scenario 1)
- Plasma temperature and β_p increase
- Non-inductively driven currents increase
- Resistive ohmic flux losses decrease
- CS1 coil current does not cross the coil current limit

3. Modified reference current waveforms

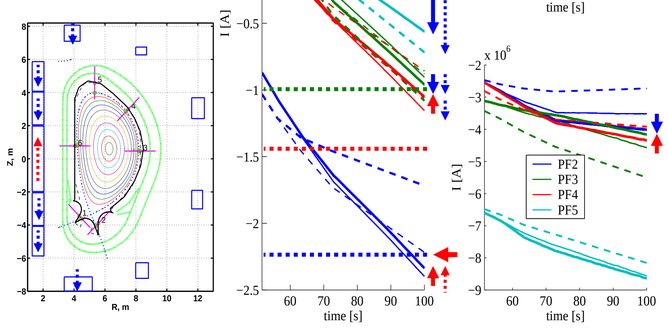
- Provide additional ohmic flux from CS2U&L, CS3U&L and PF1&6 to slow down the decrease of CS1 current
- A slight improvement of CS1 current evolution : the control of Ip is much stronger than the control of coil currents during the current ramp-up

Dotted arrow

: reference current change

Thick arrow

: simulated current change



Modified waveforms of reference coil currents (thin dashed : ref., thin : simulated, thick dashed : modified ref., thick : simulated with the modified ref.)

Conclusions and remarks

1. Combined DINA-CH and CRONOS full tokamak simulator has been improved for the plasma current ramp-up simulation
2. The feasibility of the current ramp-up phase of the ITER reference scenario 2 is studied using the Combined DINA-CH and CRONOS full tokamak simulator
3. Strongly coupled effect between the plasma transport and boundary evolution is observed
4. The time-step of data exchange between two codes is reduced to 1ms to guarantee the stability of the simulations
5. The ITER reference scenario 2 seems to be developed with slightly promising assumptions
6. Application of additional heating seems to be a good choice to reduce the resistive loss of ohmic flux and to avoid the coil current limits