Tokamak discharge simulation coupling free-boundary equilibrium and plasma model with application to JT-60SA

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A code able to integrate transport equation with magnetic equilibria is not sufficient to simulate a whole tokamak discharge. In addition, it is necessary to compute the time series of currents applied into the poloidal field coils. For this reason, a fast integrated tokamak modelling tool for scenario design, METIS [1], is coupled with a quasi-static free-boundary magnetic equilibrium code, FEEQS [2], in order to work together as a full discharge simulator.
METIS is a fast transport simulator code that allows building a realistic simulation of plasma scenarios in about one-minute computation time. In order to be faster than a 1.5D code and to keep the reliability of the simulation results, the current diffusion and plasma equilibrium equations are solved in a 1.5D scheme on a 21 points radial grid only. The modelling of heat transport is treated as a mixed 0D-1D approach to save computation time. Starting from a set of input parameters, METIS is able to compute at each time the plasma equilibrium, the current density and plasma pressure profiles.
FEEQS combines the classic Grad-Shafranov equation for MHD equilibrium in an axisymmetric system with circuit and induction equations for poloidal field coils and passive structures inside the tokamak. It gives as results the LCFS shape, coils currents for the full time-dependent simulation, voltages, forces and maximum magnetic field on coils that can ensure a given scenario. The METIS generated outputs are iteratively used by FEEQS that computes the poloidal field coils currents in order to obtain a given plasma shape. FEEQS has been satisfactorily benchmarked with the TOSCA [3] code and without METIS in the loop.
The main aim of combining METIS and FEEQS is to assess the effect of calculating the time evolution of β_p and li(3) from the plasma profiles instead of just assuming them.
To illustrate the powerful of the coupled codes, the optimization of one of the reference scenarios of the JT-60SA [4] tokamak is carried out. The scenario analyzed is a standard H-mode similar to the ITER baseline scenario, however with an improved H-factor [5]. The time behavior of coils currents computed by the coupled codes are compared to the ones computed for the benchmark [6].
From the METIS outputs, it is possible to check, for instance, whether the available flux after breakdown is sufficient to sustain the plasma current in the whole plasma discharge, if the loop voltage shows large peaks, if the line-averaged electron density is lower than the Greenwald limit, possibly leading to disruptions. From the FEEQS outputs, the coils currents and the forces on coils are computed in order to check whether they are inside the limits related to hardware capability and safety.
Since all of the obtained plasma parameters and properties are very close to the reference values established for the scenario #2 of JT-60SA, it is possible to conclude that the scenario meets the physics requirements and is well optimized up to the beginning of the ramp-down phase.

Références

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