

Improvement of existing solvers for the simulation of MHD instabilities

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In the context of the ASTER project ¹, we work on the high resolution simulation of the Edge-Localized-Mode (ELM) instability in tokamak fusion plasmas [1]. The ELM is a magneto-hydro-dynamic (MHD) instability which localised at the boundary of the plasma. The ELMs occur only in a plasma regime with high energy confinement (the so-called H-mode) which will be the standard operating regime in ITER. The energy losses induced by the ELMs within several hundred microseconds are a real concern for ITER.

The non-linear MHD simulation code JOREK [2] is under development at the CEA to study the evolution of the ELM instability. The code is using finite element method in the (poloidal) cross-section of the torus. This allows the accurate representation of the magnetic geometry: the finite elements are aligned with the structure of the magnetic field.

To simulate the complete cycle of the ELM instability, a large range of time scales need to be resolved. The evolution of the equilibrium pressure gradient (seconds) needs to be resolved to study the onset of the instability and the energy losses induced by the ELM instability (hundred microseconds). To resolve this wide range of timescales, a fully implicit time evolution scheme is used in the JOREK code. At each time step the non-linear system of equations is linearized and the Crank-Nicholson scheme is used for the time advance. This leads to a large sparse matrix system to be solved at every time step. This scheme has only become feasible due to the recent advances made in the parallelized direct (i.e. non-iterative) solution of general sparse matrices.

To reduce the large memory requirements of the sparse matrix solve, the PaStiX library [3] is being extended to include an iterative solver which uses an incomplete decomposition of the original matrix as a preconditioner. The resulting solver is a hybrid solution method which can greatly reduce the memory requirements compared to the direct solver. It should be noted that iterative solvers are difficult to apply to the system of equations that result from the MHD simulation due to the extremely large condition number of the matrices. Initial tests of the PaStiX solver [4] in the JOREK code show that the hybrid solver can solve the MHD matrices in the relevant regime of very high magnetic and fluid Reynolds numbers.

In the final presentation we will provide experiments on a collection of test cases and analyse the efficiency and convergence for both parallel and sequential implementations. The choice of optimal parameters of the solver is a first step before optimizing the number of elements required to achieve the high resolution simulations using mesh refinement techniques.

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The high resolution is only required where large gradients develop on a surface which is deformed in time. At a later stage during the ELM evolution, blobs of plasma are disconnected from the main plasma for which a mesh refinement technique also appears to be an optimal solution.

References

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