New Adaptive Grid Plasma Evolution Code SPIDER

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Non-linear time-evolution codes are essential tools for modeling of existing and future tokamak experiments. Now there are several well known free-boundary plasma equilibrium evolution codes, such as DINA [1], PET [2] and TSC [3]. In all existing evolution codes 2D equilibrium problem is solved on rectangular grid and special mapping technique is required to solve 1D transport and magnetic field diffusion equations self-consistently with 2D free-boundary equilibrium. To achieve high accuracy of simulations a lot of iterations between solutions of the 2D equilibrium problem and the set of 1D equations are required, that leads to a substantial increase of the computational time. Another problem arises in case of plasma equilibrium with high edge or non-monotonic plasma current density. The size of the rectangular mesh needed to resolve such equilibrium features should be increased several times leading to an order of magnitude increase in the time of simulation.

A NEW nonlinear time-evolution free-boundary equilibrium code SPIDER has been developed, in which 2D equilibrium problem is solved using adaptive grid method. As a result the coordinates of magnetic surfaces are obtained and no additional mapping is required to solve the 1D set of transport equations. Additional acceleration of the computations and high accuracy are achieved by simultaneous solution of the 2D equilibrium, 1D transport and magnetic field diffusion equations, and the circuit equations for PF coil currents and eddy currents in passive conductors. Plasma equilibrium with high edge or non-monotonic plasma current density does not require any additional increase of mesh size and does not increase the time of computation.

As an example of application of the code and demonstration of its major capabilities, the results of VDE simulation for ITER have been presented at this report. Initial free-boundary equilibrium is calculated with given PF coil and total toroidal plasma currents and current density profile parameters $dp/d\psi$ and $dF^2/d\psi$. Then plasma evolves with fixed temperature and density profiles. No plasma shape and position control is used, zero voltages applied to PF coils. Plasma moves down, its size decreases because of restriction by limiters and finally it becomes very small and simulation stops. Plasma equilibrium at the beginning and end of simulation are shown at the Figs.1-2. The SPIDER code has been tested against the DINA and the PET evolution codes. For the cases of small size plasma during ramp-up processes or at the end of VDE special “moving grid method” is used in the DINA code to be able to do simulations and the PET code at these cases requires to be tuned. No additional tuning is required in the SPIDER code and it can be used to simulate plasma discharges from the beginning of plasma initiation to the end, including its shut-down. The only limitation is that the plasma should have closed magnetic surfaces. So, the code cannot be used for disruption and Halo current simulations.

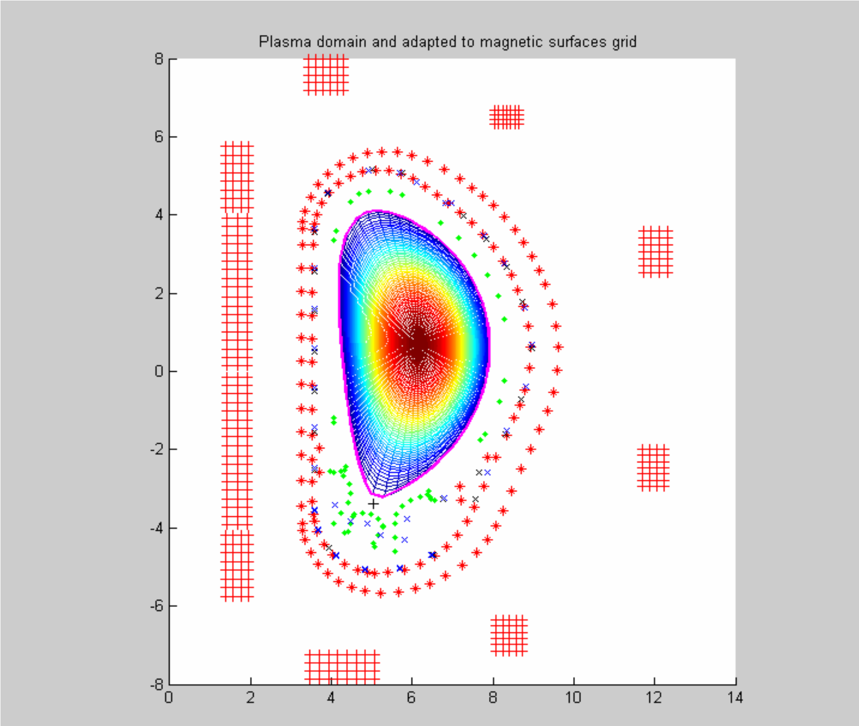

Fig.1 SPIDER –adaptive grid equilibrium for ITER at the beginning of VDE process.

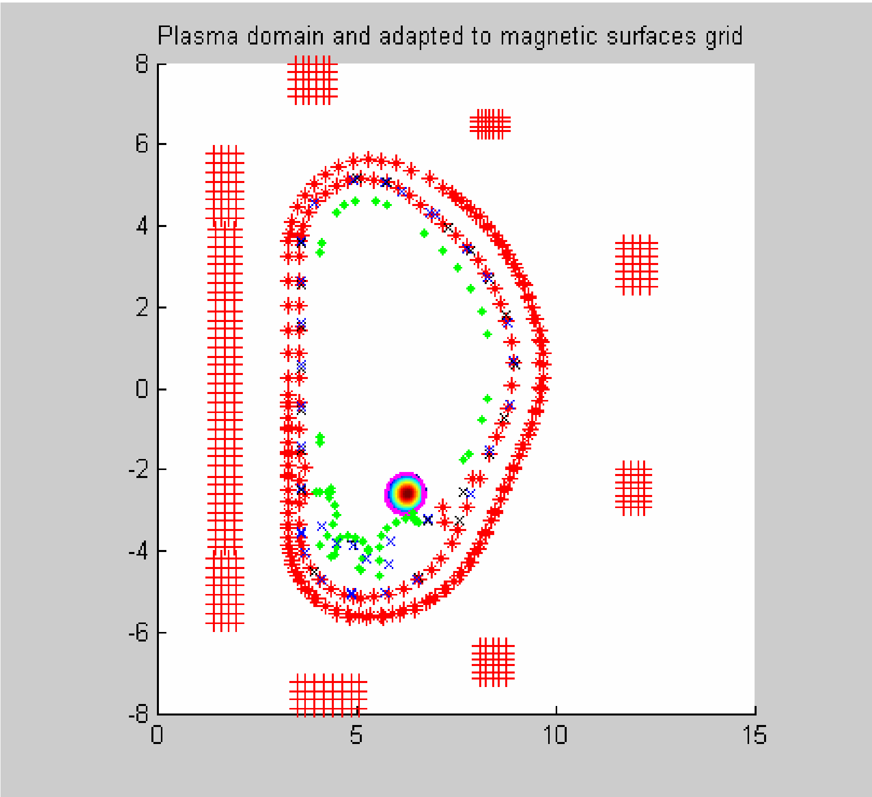

Fig.2 SPIDER –adaptive grid equilibrium for ITER at the end of VDE process.

SPIDER Code has several modules, which can be called as:

- SPIDER - **free**-boundary equilibrium solver
- SPIDER – **fixed**-boundary high-resolution equilibrium solver
- SPIDER - **free-boundary** plasma **evolution** simulator
- SPIDER - free-boundary equilibrium **reconstruction code**

Future developments of SPIDER Code:

- SPIDER – **fixed**-boundary equilibrium solver as a "mapping tool" module of DINA and PET codes
- SPIDER - **free-boundary** plasma **evolution** simulator as S-function in the Simulink tool of Matlab for plasma control modeling

SPIDER - free-boundary equilibrium solver:

This module of the code has the following capabilities:

1. Direct 2D-equilibrium solver, in which PF coil currents, toroidal plasma current and current density profile parameters $dp/d\psi$ and $dF^2/d\psi$ are specified.
2. 2D-equilibrium solver, in which plasma boundary, toroidal plasma current and current density profile parameters $dp/d\psi$ and $dF^2/d\psi$ are specified and PF coil currents are calculated.
3. 2D-equilibrium solver, in which plasma boundary, total plasma current, pressure profile p and averaged on magnetic surfaces current density profile (or q-profile) are specified and PF coil currents are calculated.
4. Direct 2D-equilibrium solver, in which PF coil currents, total plasma current, pressure profile p and averaged on magnetic surfaces current density profile (or q-profile) are specified.

SPIDER – fixed-boundary high-resolution equilibrium solver:

This module of the code has the following capabilities:

1. Fixed-boundary equilibrium solver, in which total plasma current and current density profile parameters $dp/d\psi$ and $dF^2/d\psi$ are specified.
2. Fixed-boundary equilibrium solver, in which total toroidal plasma current, pressure profile p and averaged on magnetic surfaces current density profile (or q-profile) are specified.

One of the advantages of the fix-boundary solver is that computation time is increased linearly with the mesh size due to special computational technique and solution iterations converge up to machine accuracy $\sim 10^{-12}$.

SPIDER - free-boundary plasma evolution simulator:

This module of code has the following capabilities:

1. It solves free-boundary 2D equilibrium a computational grid on adaptive to magnetic surfaces self-consistently with 1D transport equations for electrons and ions temperature, plasma density, diffusion of polodial flux and circuit equations for PF coil currents and eddy currents in passive structures.

2. During plasma evolution, the boundary of the computational grid is adjusted to plasma boundary at each time step, so that an equilibrium with a very small size of plasma can be calculated without lost of accuracy.
3. Evolution of equilibrium with skin or reversed shear current density can be calculated self-consistently with currents in PF coils and passive structures.

SPIDER - free-boundary equilibrium reconstruction code:

This module of code has the following capabilities:

1. It solves free-boundary 2D equilibrium on the computational grid adaptive to magnetic surfaces. Signals at magnetic loops and probes and experimental PF coil currents are used as input parameters. As a result of reconstruction, current density profile parameters $dp/d\psi$ and $dF^2/d\psi$ are calculated and plasma equilibrium is reconstructed.
2. Signals at magnetic loops and probes and experimental PF coil and total plasma currents, pressure profile p are used as input parameters. As a result of reconstruction, current density profile parameter $dF^2/d\psi$ is calculated and plasma equilibrium is reconstructed.
3. Signals at magnetic loops and probes and experimental PF coil and total plasma currents, and q-profile are used as input parameters. As a result of reconstruction, current density profile parameter $dp/d\psi$ is calculated and plasma equilibrium is reconstructed.

SPIDER – fixed-boundary equilibrium solver as "mapping tool" inside of DINA and PET codes:

1. To accelerate convergence of iterations and improve accuracy of simulations it will be used as a module of evolution codes for mapping between 2D equilibrium and 1D transport equations.

SPIDER - free-boundary plasma evolution simulator as S-function in the Simulink tool of Matlab for plasma control modeling;

1. Similar to the DINA-CH code [4] it can be used as S-function of Simulink in the Matlab environment for plasma control and evolution simulations.
2. High accuracy equilibrium solver for post-processing of the regular evolution code outputs needed for stability calculations.

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