§11. Development of Integrated Simulation Code for Helical Plasma Experiments

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An integrated simulation code for non-axisymmetric plasmas is developed to draw up new experimental plans including those in a new device and to do experimental data analysis from the view point of integrated physics. The integrated simulation system to be developed has a modular structure which consists of modules for calculating MHD equilibrium/stability, transport and heating. If we need to perform an integrated simulation during the entire plasma duration, a transport module is to be a core module. In our project, an integrated tokamak transport code, TASK[1] will be extended for non-axisymmetric configurations and used as a transport module. The module structure for the integrated transport simulation is shown in Fig.1.

Major differences between transport simulations for a tokamak plasma with two dimensional MHD equilibrium and those for an helical plasma with three dimensional MHD equilibrium are the neoclassical ripple transport and its related time evolution of radial electric field. Moreover, an equation describing time evolution of toroidal current profiles is also different from that for tokamaks because of the non-axisymmetry of the MHD equilibrium. Though the net toroidal current is not necessary for MHD equilibrium in helical plasmas, finite net plasma current has been observed in actual experiments. So, as a first step of the extension of the TASK, time evolution of the plasma net current, which is consistent with the three-dimensional MHD equilibrium, is solved for LHD plasmas by using time evolution of density and temperature profiles obtained from the experiment and by taking into account of the bootstrap current and the beam-driven current.

In our previous study[2], we used $\rho = s^{1/2}$ as a radial variable in the equation describing time evolution of the rotational transform, where s is a normalized toroidal flux. But we found that the use of s as a radial variable is more suitable from the numerical point of view. The evolution of the rotational transform by the plasma resistivity in a non-axisymmetric plasma is derived as[3]

$$\frac{\partial \iota}{\partial t} = \left(\frac{\phi_a}{s}\frac{\partial \phi_a}{\partial t}\right)\frac{\partial \iota}{\partial s} + \frac{1}{{\phi_a}^2}\left[\frac{\partial}{\partial s}\left\{\eta_\parallel \mathcal{V}' \frac{\left\langle B^2\right\rangle}{{\mu_0}^2}\frac{\partial}{\partial s}\left(S_{11}\iota + S_{12}\right)\right\} + \frac{\partial}{\partial s}\left\{\eta_\parallel \mathcal{V}' p'\left(S_{11}\iota + S_{12}\right) - \eta_\parallel \mathcal{V}'\left\langle \boldsymbol{J}_s \cdot \boldsymbol{B}\right\rangle\right\}\right]$$

where S_{11} and S_{12} are susceptance matrix elements[4] calculated by the metric tensors of three dimensional equilibrium, and $\left\langle \boldsymbol{J}_s \cdot \boldsymbol{B}\right\rangle$ represents the non-inductive current. A numerical simulation is done for an LHD neutral beam heated plasma (Fig.2). In this simulation, non-inductive current $\left\langle \boldsymbol{J}_s \cdot \boldsymbol{B}\right\rangle$ (Ohkawa current and bootstrap current in this case) is calculated by BSC/FIT code. It is shown that the abrupt increase of plasma current by Ohkawa current is suppressed by the inductive component of the plasma current. Because of the finite resistivity, total net current gets close to the non-inductive current with time, but it takes more than 4s to get the stationary state.

We have also improved TASK code by adopting Fortran 95 and using module sentences and dynamic memory allocations. We are trying to incorporate the rotational transform solver module into the improved TASK.

References
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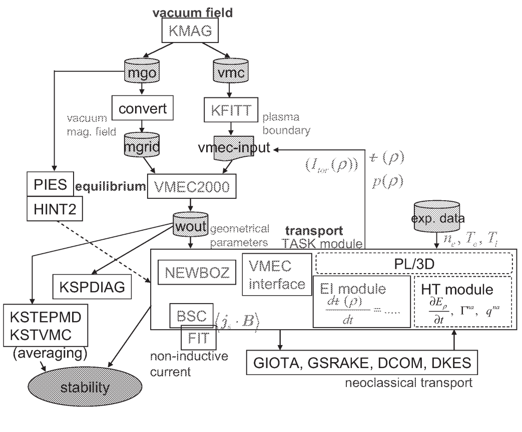

Fig.1 Module structure for the integrated transport simulation

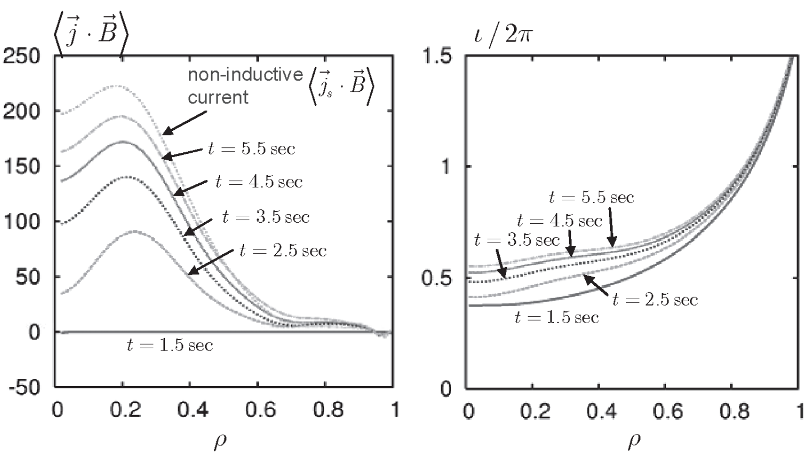

Fig.2 Time evolutions of the parallel plasma current (left) and the rotational transform (right) profiles obtained from the simulation for an LHD plasma.