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Theoretical Transport Code Development and Its Application to the Large Helical Device Experiment

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Abstract

The plasma transport code TOTAL (Toroidal Transport Analysis Linkage) is developed for the predictive plasma simulation and the experimental data analysis of toroidal plasmas. This is composed of three-dimensional equilibrium code with bootstrap currents and one-dimensional transport code with multi-helicity magnetic ripple effects. The predictive simulation clarified that the bootstrap current in the Large Helical Device (LHD) makes the radial axis shift smaller, decreases the neoclassical ripple transport loss and raises the attainable plasma temperature. For experimental data analysis the interface code PRE-TOTAL are developed to get self-consistent plasma profiles on 3-dimentional MHD equilibrium, and the effective thermal diffusivities of NBI-heated plasmas are obtained. It is verified that this TOTAL code is very effective in both predictive simulation and experimental data analysis.

1. Introduction

Toroidal confinement systems such as tokamak and helical systems have a great advantage for producing higher performance plasma and sustaining longer plasma operation. Both confinement properties are quite similar with each other, and it is important to develop a common transport modeling code for the optimization of toroidal confinement systems. A new simulation code TOTAL (Toroidal Transport Analysis Linkage) is developed for this purpose modifying the previous code HSTR [1]. The interface code PRE-TOTAL between this main TOTAL code and the experimental data system has been recently developed, and applied to the Large Helical Device[2].

2. Model of Transport Analysis

The TOTAL code consists of a 3-dimensional equilibrium code with ohmic and bootstrap currents[3] and a 1-dimensional transport code with neoclassical transport loss determined by ambipolar radial electric field with multiple-helicity magnetic field effects, as well as anomalous transport (empirical or drift turbulence theory)[1]. Neutral and impurity transport, neutral beam deposition and slowing down analyses are also included. Local ballooning mode analysis will be added later for obtaining the marginally stable pressure profiles in three-dimensional geometry. The interface to the experimental data has also been added. This is for the predictive simulation and experimental data analysis for both helical and tokamak systems. The flow chart of this analysis code is shown in Fig. 1. The equilibrium is iteratively solved with plasma radial profiles obtained by transport simulation or experimental measurements. The details of transport equations adopted here are described in the previous literature [1].

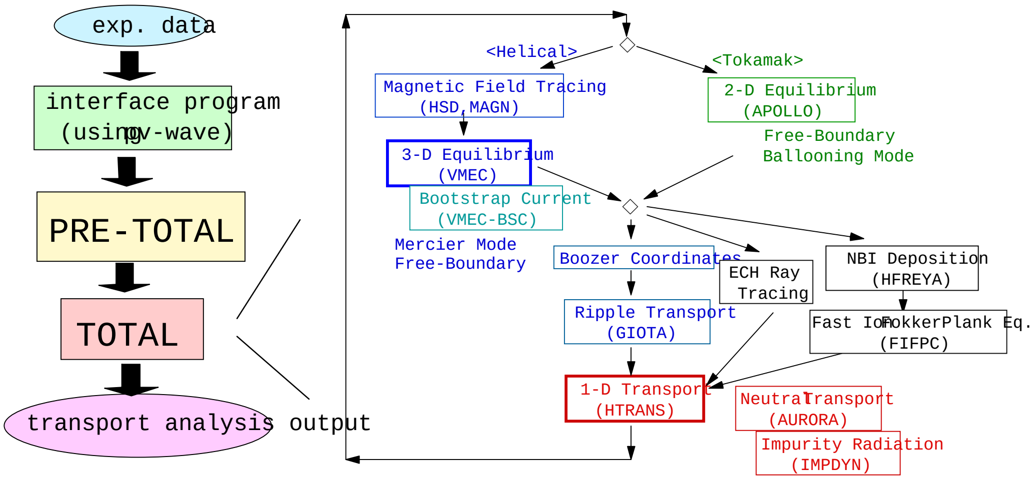

Fig. 1 Flow chart of TOTAL code

3. Predictive Plasma Simulation on LHD using TOTAL code

Recently we have developed our code to include bootstrap current (BSC) self-consistently in the TOTAL code. By including the BSC effects on the magnetic configurations at the central beta value of ~3%, the rotational transform near plasma center increases dramatically and the radial axis-shift is relaxed. The magnetic well is not stronger than the BSC-free configuration.

In the predictive simulation to clarify the BSC effects the anomalous transport is assumed with 2 times of LHD scaling prediction, which is supported in the LHD experiment [2]. The plasma density profile with BSC becomes less hollow than without BSC, and the radial electric field becomes more negative. The neoclassical ion and electron transport coefficient are reduced by the BSC effect. The finally obtained temperature reaches to ~20% higher value than that of BSC-free plasma.

4. Experimental Data Analysis on LHD using TOTAL code

The initial plasma was produced in the LHD (Large Helical Device) experiment on March 31, 1998, with 1.5 T magnetic field strength and typically 100 kW ECH heating power, whose preliminary simulation results have been reported in Ref [4].

In the recent LHD experimental transport analysis, the plasma equilibrium is iteratively and self-consistently calculated using measured profiles of FIR interferometer density, Thomson scattering temperature T_e. The calculated transport properties are compared with various theoretical transport models in ECH-heated and NBI-heated plasmas. The impurity radiation analysis will be performed and compared with the experimental data of bolometric radiation and spectroscopic impurity measurements in the near future.

In the experimental analysis, the plasma boundary definition and the profile fitting are important. In the TOTAL code, the free boundary VMEC code is used to show the vacuum ergodic boundary layer by extending plasma flux outside vacuum last closed flux surface, because the temperature and density were measured beyond the vacuum plasma boundary. We are checking this assumption by the other method showing finite-beta free-boundary plasmas. The profile fitting scheme has been carried out by the iteration of VMEC code to fit the experimental data. Three-time iterations give rise to the well fitted equilibrium. Figure 2 shows the output of PRE-TOTAL code.

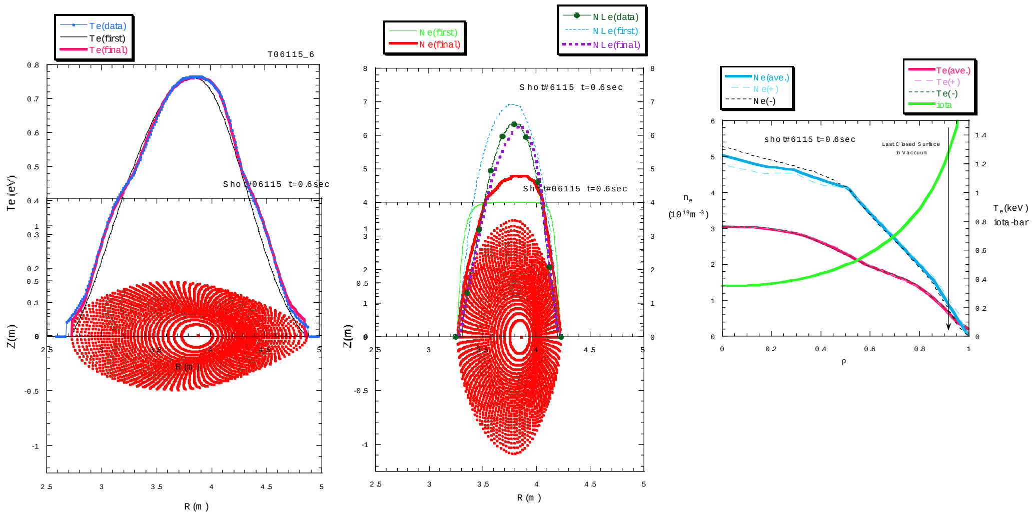

Fig.2 Output example of PRE-TOTAL code

(a) Te profile fitting based on YAG thomson scattering measurement.
(b) Ne profile fitting based on line integrated signal of FIR interferometer.
(c) plasma temperature and density as a function of normalized radius ρ.

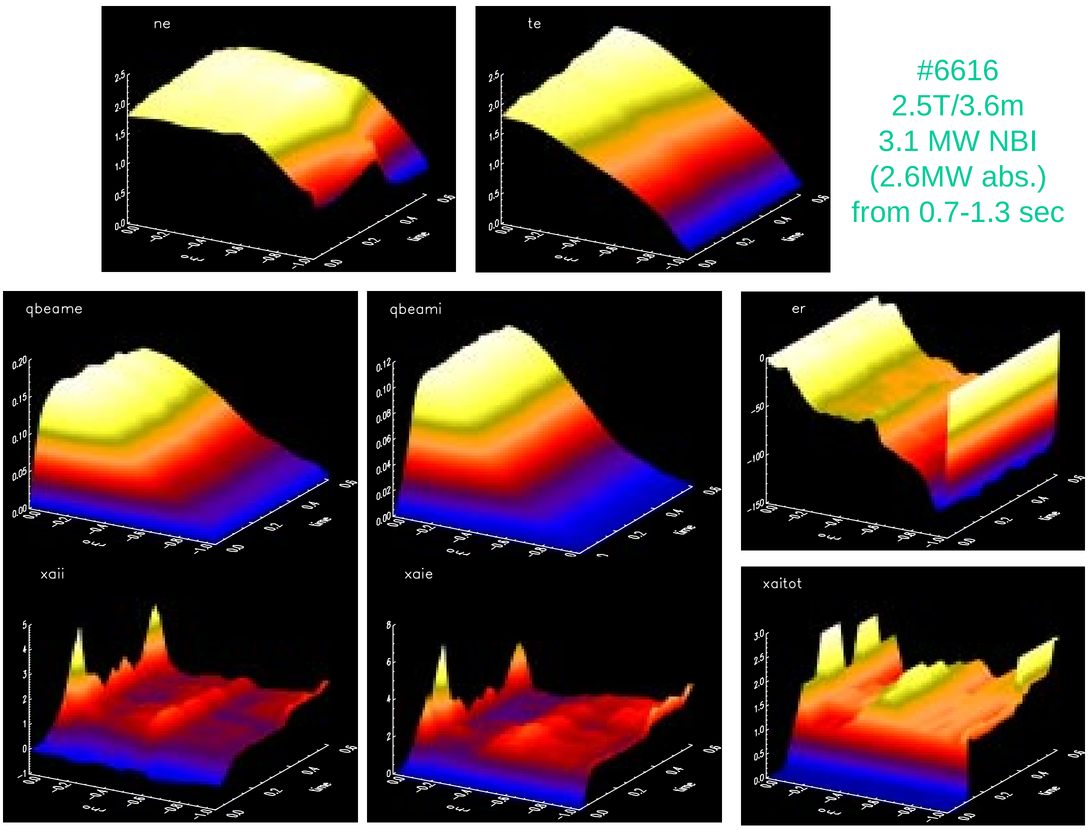

Fig. 3 Typical results of TOTAL code showing electron density(input) ne, electron temperature (input) Te, deposited beam power to electrons and ions qbeame & qbeami, thermal conductivities of electron and ion Xaie & Xaii, effective total thermal conductivity Xaitot, and radial electric field Er.

In the previous experiment, the ion temperature measurement is not always available, and the ion temperature profiles are assumed same as those of ions. In addition to each (electron and ion) thermal diffusivities, the effective thermal diffusivity X_{eff} was defined as

$$X_{eff} \quad = \quad - (Q_{NBI}+Q_{RF}+Q_{OH} - dW/dt)/(2.5ndT/dr)$$

to avoid the ion temperature uncertainty. Figure 3 shows the time evolution of density, temperature, thermal diffusivities and radial electric field. The NBI heating with 100keV-3.1 MW input was introduced at t=0 sec in this analysis. Density and temperature profiles obtained from the PRE-TOTAL code are use as inputs for TOTAL code. In this code the fine structure of the thermal diffusivity profile based on the experimental data can be clarified. Figure 4 shows a summary of thermal diffusivities of various discharges. More detailed analysis will be carried out using real ion temperature data in the near future.

5. Summary and Future Plan

We developed a new code TOTAL (Toroidal Transport Analysis Linkage) consisting of three-dimensional equilibrium and one-dimensional transport code with effects of ambipolar electric field, ripple transport, bootstrap currents, impurities, and experimental data analyzing interfaces were prepared. This was applied to the LHD predictive simulation and experimental data analysis. The bootstrap current effect in the LHD was found favorable in the neoclassical ripple transport. The preliminary data analyses show the spatial and temporal profiles of thermal conductivity, and suggest the effects of plasma density, heating power and magnetic configuration on plasma confinement.

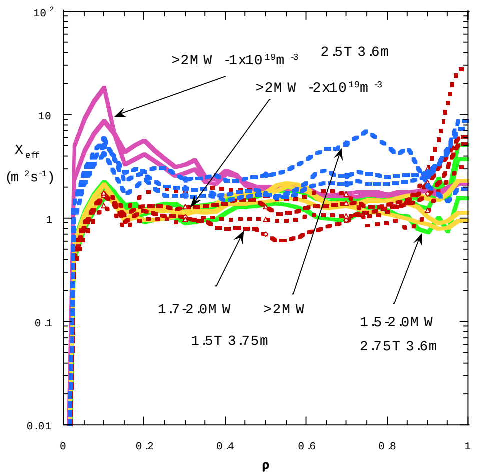

Fig. 4 Analyzed thermal diffusivities of NBI-heated LHD plasmas

It is verified that this TOTAL code is very effective in both predictive simulation and experimental data analysis. In the near future this TOTAL code will be utilized to clarify the details of LHD confinement properties, focusing on magnetic configuration control, radial electric field, impurity dynamics, higher beta effect, plasma edge effect and long-pulsed equilibrium relaxation phenomena.

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