21PA-040

Analysis of the bootstrap current in Heliotron J plasma by the moment method
ヘリオトロンJプラズマにおけるモーメント法を用いたブートストラップ電流解析

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Since plasma currents give effects to the MHD equilibrium and the stability of plasmas, accurate estimation of them is one of the important works. The bootstrap current, one of the non-inductive currents, has been numerically estimated by the method in Heliotron J plasma. However, this method often become inaccurate for the estimation in plasma with the complex magnetic field configuration, such as Heliotron J. Thus, in this search, the bootstrap currents in nonaxisymmetric plasma are estimated by using the moment method with the momentum conservation in Heliotron J.

1. Introduction

In nonaxisymmetric plasmas, plasma currents are not required for generating the toroidal components of magnetic fields. However, some non-inductive currents exist in such plasmas. Since these currents often give unignorable effects to the MHD equilibrium and the stability of plasmas, accurate estimation of them is one of the important works.

The bootstrap current, one of the non-inductive currents is caused by the existence of particles trapped in magnetic ripples and radial gradients of the plasma pressures. For the numerical estimation of this current, the SPBSC code is applied for the estimation in Heliotron J plasmas [1]. This research has been shown the controllability of bootstrap currents by changing magnetic field configuration. However, some singularities are observed in this estimation. These singularities are caused by the resonance effect which often occurs in nonaxisymmetric devices with much Fourier components. Therefore, this method is inappropriate for the estimation in such plasmas.

In this research, we apply the moment method [2] for the analysis of the bootstrap current in Heliotron J plasmas. This method can be applied for the estimation even in the complex magnetic configurations. Furthermore, we also refer to the effect of ambipolar electric fields.

2. Bootstrap current analysis by the moment method

The bootstrap current is deeply concerned with the neoclassical transport theory. This current is expressed by

$$J_{\mathrm{BS}} = \sum_a e_a n_a \left\langle u_{\|a} B \right\rangle \Big/ \left\langle B^2 \right\rangle^{1/2} - \sigma_s \left\langle E_{\|} B \right\rangle \Big/ \left\langle B^2 \right\rangle^{1/2},$$

where $\left\langle u_{\|a} B \right\rangle$ is the parallel particle flow velocity and σ_s is the Spitzer's slowing time. For the numerical analysis of the neoclassical transport, the moment method [2] is a powerful method. This method has advantages such as satisfaction of self-adjoint property and Galilean invariant property and conservation of parallel momentum between different particle species. In this method, the parallel particle flows are obtained from parallel general force balance equation [3,4],

$$\left[-\begin{bmatrix} \mathbf{M}_a & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathbf{M}_N \end{bmatrix} + \begin{bmatrix} \mathbf{\Lambda}_{aa} & \cdots & \mathbf{\Lambda}_{aN} \\ \vdots & \ddots & \vdots \\ \mathbf{\Lambda}_{Na} & \cdots & \mathbf{\Lambda}_{NN} \end{bmatrix} \right] \cdot \begin{bmatrix} \mathbf{U}_a \\ \vdots \\ \mathbf{U}_N \end{bmatrix}$$
$$= \begin{bmatrix} \mathbf{N}_a & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \mathbf{N}_N \end{bmatrix} \cdot \begin{bmatrix} \mathbf{X}_a \\ \vdots \\ \mathbf{X}_N \end{bmatrix} - \begin{bmatrix} \mathbf{Z}_a \\ \vdots \\ \mathbf{Z}_N \end{bmatrix} \left\langle BE_{\|} \right\rangle - \begin{bmatrix} \mathbf{C}_a \\ \vdots \\ \mathbf{C}_N \end{bmatrix} \left\langle BF_{\|\mathrm{f1}} \right\rangle$$

where $\mathbf{M}_a$ is the viscosity coefficient matrix, $\mathbf{\Lambda}_{ab}$ is the friction coefficient matrix, $\mathbf{N}_a$ is the matrix which represents viscosity due to thermodynamic forces $\mathbf{X}_a$, $\mathbf{U}_a$ denotes parallel flow, $\mathbf{Z}_a$ is momentum driven by parallel electric field, $\mathbf{C}_a$ is

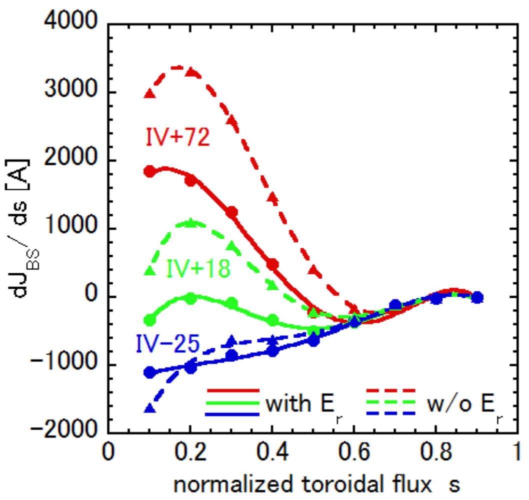

Fig.1. The bootstrap current in IV+72, IV+18, and IV-25 configurations. Density and temperature profiles are as follows : $n_e(s) = n_H(s) = 1.5\times10^{19}\left(1-s^3\right)\mathrm{m}^{-3}$, $T_e(s) = 300(1-s)^2\ \mathrm{eV}$, and $T_H(s) = 175(1-s)^2\ \mathrm{eV}$

the momentum transfer ratio to plasma particle species and $\langle BF_{\|f1}\rangle$ is total parallel momentum input. Parallel flow $\langle u_{\|a}B\rangle$ can be obtained from above algebraic equation.

For the neoclassical transport analysis in nonaxisymmetric plasmas, the ambipolar electric field should be taken into account. Neoclassical flux is determined by

$$\begin{bmatrix}\mathbf{P}_{\|a}\\ \mathbf{G}_a\end{bmatrix} = \begin{bmatrix}\mathbf{M}_a & \mathbf{N}_a\\ \mathbf{N}_a^{\mathrm{Tr}} & \mathbf{L}_a\end{bmatrix}\cdot\begin{bmatrix}\mathbf{U}_a\\ \mathbf{X}_a\end{bmatrix}$$

where $\mathbf{L}_a$ is the matrix which is concerned with the radial diffusion, $\mathbf{G}_a$ is particle and heat flux, and $\mathbf{P}_{\|a}$ is the parallel viscosity. Therefore, the bootstrap currents are obtained by these equations considering ambipolar electric fields profiles in this research.

3. Result

The bootstrap currents are estimated in three equilibrium configurations (IV+72, IV+18, and IV-25 configurations) in Heliotron J. The calculation results are shown in Fig.1. This denotes that continuous bootstrap current profiles can be obtained by the moment method even in complex magnetic configurations in Heliotron J. These results are qualitatively consistent with the experimental observation [5]. Furthermore, this denotes that the ambipolar electric field should be taken into account since it gives unignorable changes to the bootstrap currents. More detailed analyses, such as the effect of multi-ion species and external momentum sources will be analyzed in the conference.

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