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Analysis of a current density diagnostic using a small Rogowski coil in the TST-2 spherical Tokamak

球状トカマク TST-2 における小型ロゴスキーコイルを用いた電流密度計測の解析

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A Rogowski probe consisting of a small Rogowski coil and magnetic pick-up coils has been developed for the TST-2 spherical tokamak. The current density profile in the toroidal-poloidal plane was measured in Ohmic discharges. The experimentally obtained angular profile was broader than the effective cross sectional area of the central hole of the Rogowski coil. The effect of the sheath around the probe is suggested as a possible explanation. Electron orbits in the vicinity of the probe were calculated with a given sheath potential around the surface of the probe, and a thoretical angular profile which is consistent with the experimental profile was obtained.

1. Introduction

Study of tokamak equilibrium is important for controling the tokamak plasma. Since the tokamak equilibrium is expressed in terms of the current density profile, development of a current density profile diagnostic is one of the main subjects for tokamak equilibrium study. In the TST-2 spherical tokamak device (R = 0.38 m, a = 0.25 m, B_t = 0.3 T, I_p = 0.1 MA), a small multi-layer Rogowski coil with high precision windings has been developed [1,2]. The Rogowski probe consists of the Rogowski coil, five magnetic pick-up coils and one Langmuir probe. The probe is set on the equatorial plane of TST-2, and can be moved along the major radius and can be rotated around its own axis. This allows measurement of the direction of current in the toroidal-poloidal plane [2,3]. The obtained angular profile was different from that determined from the probe geometry. It is suggested that the effect of the sheath around the probe may be responsible for the difference. In order to evaluate this effect quantitatively, electron orbits in the vicinity of the probe were calculated under a given sheath potential around the surface of the probe

2. Sheath model

The Rogowski probe is covered by ceramic plates and a ceramic cylinder to isolate it from the plasma. When an insulator is inserted into the plasma, a sheath is formed on the surface, and its potential becomes the floating potential.

Due to the strong magnetic field of the tokamak, the sheath consists of not only the Debye sheath but also the magnetic presheath [4]. The following sheath model used in [5] is used:

$$\psi(r) = \psi_1 \exp(-r/2\lambda_d) + \psi_2 \exp(-r/\rho_i) , \quad (1)$$

$$f_d = 1 - \psi(6\lambda_d)/\psi(0) , \quad (2)$$

where ψ is the sheath potential, λ_d is the Debye length, ρ_i is the ion Lamor radius and r is the distance from the surface. The values of λ_d and ρ_i were calculated from typical measured parameters. The parameter f_d represents the contributing fraction of the Debye sheath term.

3. Potential distribution around the surface of the Rogowski probe

In the orbit calculation, the potential distribution around the surface was given, and the surface potential $\psi(0)$ was set to be the floating potential. Examples of the potential contour plot are shown in Fig. 1.

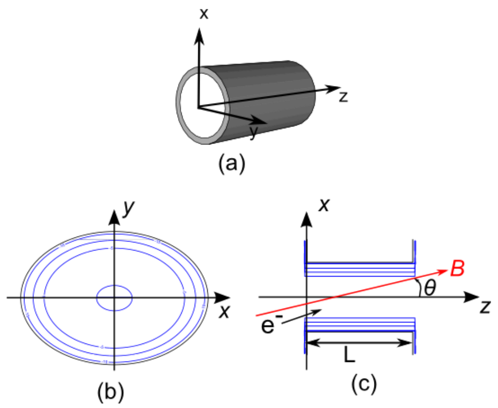

Fig. 1. Contour plots of the potential distribution: (a) 3D image of the central hole of the probe, (b) the potential distribution in the *x*-*y* plane ($0 < z < L$) and (c) the potential distribution in the *x*-*z* plane ($y = 0$).

In the *x*-*y* plane ($0 < z < L$), the potential is axially symmetric around the *z* axis using Eqs. (1) and (2). In the regions $z < 0$ and $z > L$, the magnetic field is nearly perpendicular to the surface. Therefore, we assume that the magnetic presheath effect is small [4], and the potential is given by the Debye sheath.

4. Orbit calculation and angular current profile

For the orbit calculation, Newmark's beta method [6] was adopted to solve the equation of motion under given magnetic and electric fields (i.e., the sheath field). A large number of electron orbits with a Maxwellian initial velocity distribution were calculated. The initial locations in the *x*-*y* plane were distributed uniformly using random numbers. The initial location in *z* was fixed as $-\rho_i$. The number of electrons which pass through the central hole for each θ was calculated, where θ is the angle between the *z* axis and the magnetic field *B* direction, as defined in Fig. 1(c). A comparison of the experimentally obtained angular current profile and those obtained from the calculation is shown in Fig. 2. The experimentally obtained profile becomes maximum at the angle of *B*. Both the experimentally obtained profile and those calculated from the electron orbits are broader than the curve determined by the probe geometry. The calculated profile becomes broader with the decrease of f_d (i.e., the increase of the magnetic presheath effect). Furthermore, the shape of the experimental profile can be reproduced well by the calculated profile when $f_d = 0.8$. This agreement suggests that the sheath effect is important in deducing the local current profile from the current measured by the Rogowski probe.

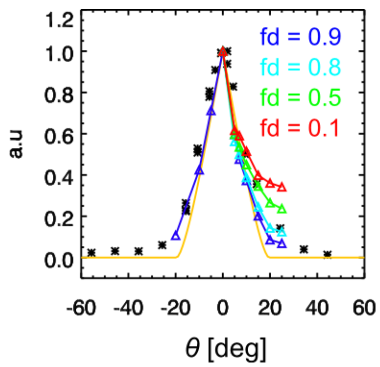

Fig.2. Comparison between the experimentally obtained angular current profile (black symbols) and calculated current profiles (blue, light blue, green and red). The geometrical curve (orange) is also plotted.

5. Summary

The electron orbits around the Rogowski probe were calculated to evaluate the effects of the Debye sheath and the magnetic presheath on the angular current density profile. It was found that the experimental profile can be explained by taking this effect into account.

Acknowledgement

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