Comparison of electron internal transport barrier formation between CHS and Heliotron J

T. Minami[1], N. Kenmochi[2], C. Takahashi[1], K.Nishioka[2],S. Kobayashi[1],
Y. Nakamura[2],H. Okada[1], S. Kado[1], S. Yamamoto[1], S. Ohshima[1], S. Konoshima[1],
G. Weir[1], Y. Ohtani[2], K. Nagasaki[1], T. Mizuuchi[1], F. Sano[1]

[1] *Institute of Advanced Energy, Kyoto University, Kyoto, Japan*

[2] *Graduate School of Energy Science, Kyoto University, Kyoto, Japan*

Introduction

The electron internal transport barrier (eITB) of helical devices plays an important role on plasma confinement[1, 2]. This barrier is known to be formed due to the radial electric field and the electric field shear is created by the bifurcation of radial electric field (E_r) with the electron cyclotron resonance (ECR) heating. The positive radial electric field formation is consistent with the electron-root solution of the ambipolarity condition for E_r of the neoclassical transport. In previous results of Compact Helical System (CHS), the barrier is easily formed in larger effective helical ripple configuration[3]. The barrier formation depends on the magnetic field configuration through the neoclassical transport characteristics.

Recently, the phenomena that have similar characteristics as the eITB by the ECR heating have been observed on Heliotron J, and the steep electron temperature gradient has been observed in the core region[4]. Both the Heliotron J and CHS belong to helical type devices, and both the devices have similar size (The major and averaged minor radii of Heliotron J are 1.2 and 0.17m and that of CHS are 1m and 0.2m, respectively). On the other hand, both the devices have different magnetic configurations. Heliotron J is helical axis heliotron type, and CHS is heliotron/torsatron type, and the periodicity of Heliotron J is $(l,m) = (1,4)$ and that of CHS is $(l,m) = (2,8)$. Therefore, comparative study of the phenomena is carried out between CHS and Heliotron J to investigate the effect of the magnetic configuration on the eITB formation.

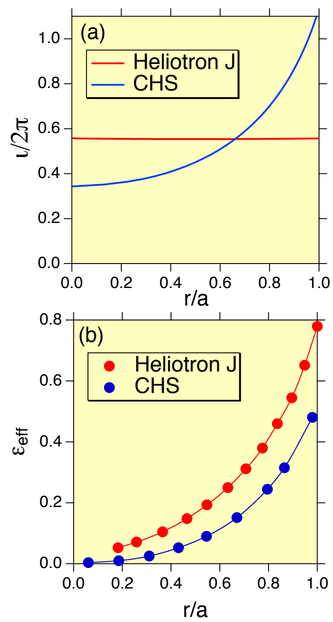

Figure 1: *Rotational transform (a) and effective helical ripple profiles (b) of standard magnetic configuration in Heliotron J and CHS.*

In this paper, the electron temperature and density profiles with eITB are compared between Heliotron J and CHS to clarify the transport characteristics. Differences of the eITB formation dependence on plasma density are presented. And the effect of the magnetic helical ripple on the eITB formation is discussed.

Magnetic configuration characteristics in Heliotron J and CHS

The experiments have been performed on the standard magnetic configuration of both Heliotron J and CHS, and the magnetic field strength on the magnetic axis of Heliotron J is $B_{ax} = 1.25T$, and that of CHS is $B_{ax} = 0.88T$. The important difference in the magnetic configuration between both the devices is rotational transform profile[5, 6, 7]. Figure 1(a) shows the rotational transform profiles of the standard magnetic configuration of Heliotron J and CHS. The shear of the magnetic field in CHS is positive, while the shear is close to zero in Heliotron J.

The neoclassical transport of the helical plasma is characterized by the effective helical ripple (ε_{eff}), which characterize the helical $1/\nu$ electron transport[8]. The hypothesis of the eITB formation is that the eITB is easily formed in the larger ε_{eff} magnetic configuration, because the access of the electron-root regime is easy as predicted by the neoclassical transport theory[9]. The difference of the effective helical ripple is shown in Fig.1(b)[7, 10]. The value of the ε_{eff} of Heliotron J is 2-10 times larger than that of CHS.

Comparison of eITB formation in Heliotron J and CHS

The plasma with eITB is produced by the ECR heating. The Heliotron J and CHS are equipped with 70GHz (Injected ECR power: $P_{inj} \sim 120 - 330kW$) and 53GHZ ($P_{inj} \sim 120 - 160kW$) gyrotrons, respectively [5, 6]. The single path absorption of the ECR heating is $\sim 90\%$ in both the experiments. Both the gyrotrons can heat exactly at the magnetic axis by focusing optics. In some CHS experiments, the neutral beam ($P_{inj} \sim 620kW$) is injected (NBI) into the plasma, however, the characteristics of the eITB formation is not different from the ECR heating only plasma, because the deposited power of NBI to the electrons is smaller than the absorbed ECR power due to the low plasma density. The electron temperature and density profiles were measured with Nd:YAG laser Thomson scattering

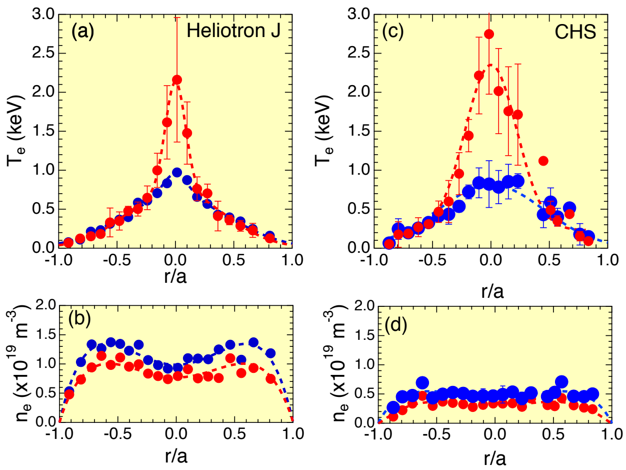

Figure 2: *Typical electron temperature (a)(c) and density profiles (b)(d) with eITB in the Heliotron J (a)(b) and CHS (c)(d). Red points denote the profiles with eITB and blue denote the profiles without eITB.*

system using the same analysis procedure[11, 12].

Figure 2 shows the typical electron and density profiles of Heliotron J and CHS with the eITB formation. Both the profiles have same characteristics. When the eITB is formed, steep electron temperature gradient is created, and peaked temperature profiles are produced in the plasma core, as shown in FIg.2(a)(c). The central electron temperature increases up to similar level of $2-2.5keV$ by the barrier formation. On the other hand, the temperatures on the outside of the peaked profiles with and without eITB are almost equal in both the CHS and Heliotron J. The peaked electron temperature is formed by small reduction of the plasma density, as shown in Fig.2(b) (d). These results show the confinement improvement by the barrier formation in the core region and the confinement degradation due to the profile resilience on the outside of the peaked temperature region[4]. However, both the results have the different electron density when the eITB is formed. The density ($\bar{n_e} \sim 1.2\times10^{19}m^{-3}$) of the Heliotron J is approximately two times larger than that ($\bar{n_e} \sim 0.5\times10^{19}m^{-3}$) of the CHS.

Density dependence of eITB formation in Heliotron J and CHS

Figure 3 shows the density dependence on the temperature gradient in the core region and in the outside region of the peaked temperature region. In both plasmas, when the line averaged density is lower than the threshold value, the temperature gradient in the core region increases. However, the threshold electron density in Heliotron J ($1.2\times10^{19}m^{-3}$ at $P_{inj} \sim 330kW$) is two times larger than that in CHS ($0.5\times10^{19}m^{-3}$ at $P_{inj} \sim 130kW$). Consequently, the plasma density regime in which eITB is formed is expanded in Heliotron J.

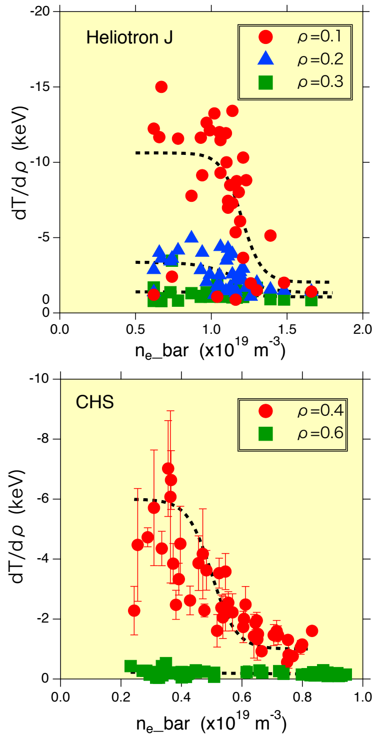

Figure 3: *Density dependence on the temperature gradient in the core region and the outside of the peaked temperature for Heliotron J (a) and CHS (b)*

It is important to take account in the power difference between both the experiments, because the barrier formation depends on the ECR power[4, 9]. Figure 4(a) shows $T_e(0)$ dependence on the injected ECR power (P_{inj}) that is normalized by the line averaged density ($\bar{n_e}$). In this figure, the closed and open circles show the Heliotron J and CHS results and the red and blue circles show the profiles with and without the peaked temperature, respectively. Although the threshold value of $P_{inj}/\bar{n_e}$ for the barrier formation is almost equal in both the results, the larger $T_e(0)$ is achieved by the smaller $P_{inj}/\bar{n_e}$ in Heliotron J compared to CHS.

Figure 4(b) shows $T_e(0)$ dependence on the electron collisionality normalized by the bounce frequency at $\rho = 0.2$ (ν_h^*). The ν_h^* is associated with the ion-root to electron-root transition[2]. The ν_h^* of the Heliotron J plasma easily reach the collision-less regime compared to CHS due to the larger ε_{eff}. This is because the bounce frequency is higher in Heliotron J due to the higher ε_{eff}. Accordingly, there is a possibility that eITB is easily formed in Heliotron J. However, the eITB formation is realized in higher collisionality in CHS compared to Heliotron J. It shows that the eITB formation is not dominated by the collisionality alone.

Summary

The comparative study of the eITB formation is carried out between CHS and Heliotron J to investigate the effect of the magnetic configuration on the barrier formation. The threshold electron density for the barrier formation in Heliotron J is two times larger than that in CHS, and the larger $T_e(0)$ is achieved by the smaller $P_{inj}/\bar{n}_e$ in Heliotron J. These results show the possibility of the threshold density increase by the collisionality which related to the effective helical ripple. However, the results also show that the eITB formation is not only determined by the collisionality.

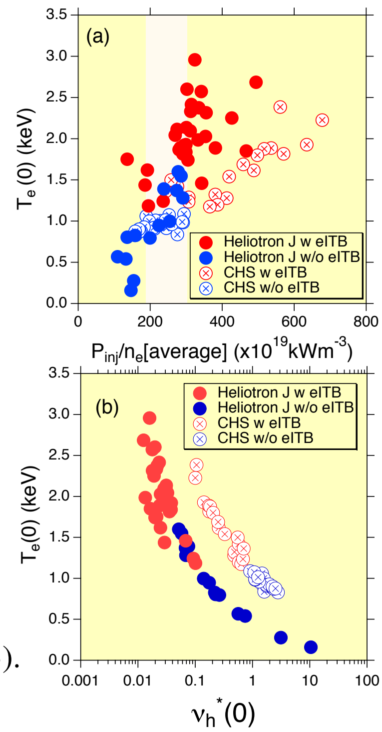

Figure 4: $T_e(0)$ *dependence on the* $P_{inj}/\bar{n}_e$ *(a) and* $\nu_h^*(0)$ *(b). Closed and open circles show Heliotron J and CHS results, red and blue circles show plasma with and without eITB, respectively.*

Acknowledgments

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