Study of magnetic field configuration effects on internal transport barrier formation in Heliotron J

Naoki Kenmochi

1. Introduction

In this study, the effects of magnetic field configuration on electron internal transport barrier(eITB) is experimentally investigated in a helical-axis heliotron configuration. In order to investigate detailed structure of eITB with higher accuracy for the typical Heliotron J plasma, a Nd:YAG laser Thomson scattering(YAG-TS) measurement system has been developed. The importance of three-dimensional magnetic field structure intended for reduction of intermittent particle transport is recently recognized in the fusion research. It is indispensable for the development of an advanced fusion reactor to understand how the three-dimensional structure affects the improved confinement mode and its transition mechanism. Heliotron J is possible to form various three-dimensional magnetic structure by controlling current ratio of five types of coils. The magnetic field structure is confirmed to affect both the transition to improved confinement mode and its improvement level in Heliotron J. It is expected to reveal the effects of three-dimensional magnetic structure on eITB formation by investigating the mechanism of eITB formation in Heliotron J. The existence of rational surface is also possible to affect the eITB formation. Heliotron J is capable to control the mode and position of rational surface by changing its magnetic field configurations. This research contributes to reveal the mechanism of improved confinement phenomena which is common issue among the magnetic confinement plasma physics.

2. The Heliotron J Device

This chapter is devoted to a description of Heliotron J. Heliotron J is one of advanced stellarator/heliotron devices, which tries to achieve the reduction of neoclassical ripple transport and to enhance the MHD stability with a helical-axis heliotron configuration. Diagnostics and heating device of Heliotron J used in this study have been introduced.

3. Nd:YAG Laser Thomson Scattering Measurement System in Heliotron J

We described the development of a YAG-TS system in Heliotron J[1,2]. Profile measurement is indispensable for the study on the mechanism of eITB formation. The YAG-TS system is possible to obtain both electron temperature(T_e) and density(n_e) profiles with high time and spatial resolution owing to the usage of Nd:YAG laser which can oscillate with high repeated frequency. To obtain detailed structure of the transport barrier with higher accuracy for the typical Heliotron J plasma, we enhance the performance compared to the conventional YAG-TS system by optimizing both the conversing optical system and the combination of transmitting wavelength region of polychromator spectroscopy. Ac- cording to these optimization, the YAG-TS system has been developed with the following measurement performance: the spacial resolution is ~ 1 cm and the measurement T_e and n_e range are 10 eV-10 keV and > 0.5×10^{19} m^{-3}, respectively. The spacial resolution is sufficient to observe the structural change of the transport barrier whose typical width is estimated at several cm in Heliotron J. We realize the time interval of measurement of ~ 100 μs which is the time scale of transport barrier formation by developing the control system of laser oscillation with high repeated frequency accurately.

4. Characteristics of Electron Internal Transport Barrier in Heliotron J

We investigate the characteristics of the eITB in Heliotron J[3]. In Heliotron J, the formation of the eITB is observed with centrally focused ECH microwaves injected into plasma for the first time by using the YAG-TS measurement. When the value of $P_{ECH} / \overline{n_e}$ is below the threshold of 3×10^{13} m^{-3}W^{-1}, both the central T_e and the core T_e gradient increase transiently. The heat transport analysis shows the significant improvement of the effective electron thermal diffusivity in the plasma with the eITB over that without the eITB. The numerical calculation by the moment method predicts that the large positive

E_r is formed in the core region. The transiently formed eITB with the formation of the large electric field has the characteristics of Core Electron Root Confinement (CERC) whose mechanism is explained by neoclassical transport theory. The time evolution of T_e obtained by the ECE measurement shows the hysteresis phenomena during the eITB formation. The comparison between the experimentally obtained effective thermal diffusivity and the neoclassical thermal diffusivity suggests that the suppression of anomalous transport contributes to the core improved confinement of the eITB plasma.

5. Effect of Bumpiness on eITB Formation

We discuss the effects of three-dimensional structure of magnetic field, especially bumpy component, on the shape of T_e profile in the eITB plasma of Heliotron J. The experiments reveal the difference in the shapes of T_e profiles of the eITB between the three bumpiness configurations(high-ε_b, medium-ε_b and low-ε_b). At the outside of the eITB foot point, the higher ε_b contributes to the higher T_e. At the inside of the eITB foot point, the T_e of the medium-ε_b configuration is the highest in the three ε_b configurations. Comparing the eITB foot point in the three ε_b configurations at the same electron kinetic energy inside of the eITB foot point, the eITB foot point of the medium-ε_b and the high-ε_b are the closest and the farthest to the plasma center, respectively. It is revealed that the ε_b has different effects for the T_e at the inside and the outside of the eITB foot point.

6. Effect of Rational Surfaces on eITB Formation

We investigate the effects of rational surface on the mechanism of eITB formation. The eITB formation is observed even in the condition that any low-order rational surface exists all the confinement region, which indicates that the eITB is formed in Heliotron J regardless of the existence of the rational surface. We observe the rapid movement of eITB foot point to the outer region during several hundreds of micro-seconds at the timing of the toroidal current exceeds the threshold. The following movement of the eITB foot point to the outer region is also observed according to the increase of toroidal current. We investigate the transition for the three configurations which have different rotational transform profiles in vacuum. As the value of rotational transform in vacuum reaches n/m = 4/7, the value of toroidal current at the timing of the movement of the eITB foot point decreases. These results reveal that the 4/7 rational surface strongly affects the movement of the eITB foot point. The toroidal current profiles, which are mainly composed of the bootstrap current, are estimated using the moment method. Using the profiles of the bootstrap current, the rotational transform profiles are calculated with the VMEC. The numerical calculations predict the formation of the 4/7 rational surface in the core region (r/a ~ 0.3) when the value of the toroidal current exceeds the threshold value. The movement of the position of the 4/7 rational surface is also estimated according to the increase of toroidal current after the formation of the rational surface. The movement occurs in sufficiently short time (several hundreds of micro-seconds) compared to the energy confinement time of the plasma (several milliseconds), suggesting the rapid phenomena such as a formation of radial electric field causes the movement. The existence of the 4/7 rational surface makes it possible to access the eITB region easily compared to the case of without the rational surface.

7. Conclusion

In this thesis, a YAG-TS system has been developed in order to investigate the detailed structure of the eITB with higher accuracy for the typical heliotron J plasma. In Heliotron J, the eITB formation is observed by the profile measurements of the YAG-TS system for the first time. The difference of bumpy component affects the T_e profiles of both outside and inside of the eITB foot point. The position of n/m = 4/7 rational surface could contribute to determine the eITB foot point. The existence of the rational surface makes it possible to access the eITB region easily compared to the case of without the rational surface. This study contributes to a performance improvement of core plasma through control of the eITB foot point which can be modified by the magnetic field configurations.

References

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