§26. Study on the Confinement Optimization and Stability Control for an Advanced Helical System

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The main subject, which is assigned to Heliotron J Group for the NIFS bilateral collaboration research during the 2nd period of the six-year plan, is "Study on the confinement optimization and stability control for an advanced helical system", From FY 2011, two additional subjects are also promoted for strongly linked studies among multi research-centers; (a) "Study of ECH/EBW heating and current drive" and (b) "Study of heat/particle control (edge plasma control)".

The six sub-groups towards the goal of the collaboration research have been organized; (1) confinement improvement by controlling magnetic configuration and related plasma self-organization, (2) ECH/EBW heating physics, (3) plasma production by micro-wave assisted NBI heating and high beta plasma confinement, (4) boundary plasma control in an advanced helical device, (5) instability regulation through magnetic configuration control, and (6) plasma current control in an advanced helical device. Each group joined the plasma experiment and data analysis including the usage of fast internet for data exchange and analysis. In this report the

Results from three topics are introduced broadly; "Study of three-dimensional magnetic field configuration effects on the electron internal transport barrier" concerning categories (1) and (2), "Fast plasma production using neutral beam injection heating with assistance of none-resonant micro waves" concerning category (3), and "Fast ion generation using combination heating of ion cyclotron range of frequencies (ICRF) and NBI" concerning category (1). The first topic is also relating to the multi research-center subject (a) and the second one is relating to the subject (b).

Study of three-dimensional magnetic field configuration effects on the electron internal transport barrier (eITB) [1]

The eITB is considered to play an important role for the helical plasma confinement improvement. In Heliotron J, the eITB phenomena are observed in ECH plasmas, where the radial gradient of electron temperature T_e becomes steep at a radial position. This gradient substantially depends on the line-averaged electron density $\bar{n}_e$. The gradient near $\rho = 0.1$ of the normalized minor radius clearly increases for $\bar{n}_e \leq 1.2\times10^{19}\ m^{-3}$ under the ECH power of ~ 0.33 MW. The similar phenomenon was reported in other helical devices with different configurations such as CHS in NIFS. The gradient is not so steep in CHS and the gradient change is observed at a larger ρ position. In a high Te helical plasma, eITB is considered to be driven through the large radial electric field formation due to the transition to the "electron root" in the neo-classical transport. This experiment in Heliotron J gives a good chance to understand the three-dimensional magnetic field effects on eITB.

Fast plasma production using neutral beam injection heating with assistance of none-resonant micro waves [2]

The plasma production only with neutral beam injection (NBI) heating has been demonstrated in LHD and W7-AS, where the beam path length of NB is long enough. On the other hand, the pre-ionization is very useful in the case of short beam path length in the plasma or quick production requirement. In Heliotron J, a pre-ionization method with a low-power (< 20 kW) 2.45 GHz μ-wave injection scheme successfully accelerates the sound start-up of NBI plasma for the magnetic field strength from 0.6 T to 1.3 T. The ECE measurement confirms the production of high energy electrons by the μ-waves. Controlling the gas-fueling and NBI timing effectively increases electron density up to $0.45\times10^{19}\ m^{-3}$ in the pre-ionization phase. Further gas puffing in a later timing of NBI pulse easily increases electron density more than $1.0\times10^{19}\ m^{-3}$. This procedure has a critical electron density of $2\text{-}3\times10^{17}\ m^{-3}$ in the pre-ionization plasma produced only by the μ-waves.

Fast ion generation using combination heating of ion cyclotron range of frequencies and NBI [3]

Since "self-heating of plasma" by alpha particles is essential for a fusion reactor, the study on the behavior of high energy ions is important. The fast ion generation and confinement are studied by using ion cyclotron range of frequencies (ICRF) minority heating (H minority and D majority) and NBI heating. The energy range is extended from the injection energy of the NBI beam (25 keV) to 60 eV during the ICRF pulse for a medium density operation ($1\times10^{19}\ m^{-3}$) in the low-ε_t configuration. This configuration is suitable for the fast ion generation and confinement from the viewpoint of the neo-classical theory than that in the high bumpiness configuration, which shows the best performance in the bumpiness scan experiments under the standard ε_t condition in Heliotron J. The observed fast ions in the high bumpiness configuration are limited up to 35 keV for the same heating conditions. The Monte-Carlo calculation also shows that the larger high energy tail in the ion energy distribution is formed in the low-ε_t configuration.

[1] T. Minami, et al., "3D magnetic field effect on electron internal transport barrier in Heliotron J", 20th International Stellarator/Heliotron Workshop (ISHW), Greifswald, Germany, 5-9 Oct., 2015, S1-I4.
[2] S. Kobayashi, et al., "Rapid NBI plasma initiation using pre-ionization method by non-resonant microwave injection in Heliotron J", ibid., S3-O2.
[3] H. Okada, et al., "Magnetic field optimization study for fast ions generated by ICRF heating in Heliotron J", ibid., P2S3-36.