§24. Study on the Confinement Optimization and Stability Control of an Advanced Helical System

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The main purpose of this NIFS bidirectional collaboration research in Heliotron J during the 2nd six-year (FY2010 ~ FY2015) research plan is "Study on the confinement optimization and stability control for an advanced helical system. Since FY 2011, as the cooperation project among the research centers under the NIFS bidirectional collaboration research, two subjects have been also promoted; (a) "Study of ECH/EBW heating and current drive" and (b) "Study of heat/particle control (edge plasma control)".

The research is categorized to six groups; (1) confinement improvement through controlling magnetic configuration and related plasma self-organization mechanisms, (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 suppression by controlling magnetic configuration, 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. Some results are briefly reviewed below.

Study of plasma parallel flow in NBI heating [1]

The parallel flow dynamics is investigated in the tangential NBI plasmas of Heliotron J. Two configurations with different magnetic ripple strength γ, was adopted to clarify the effect of the magnetic ripple on the parallel flow. Hear, γ is an average of the field ripple strength along the field line; $\gamma^2 = \left\langle \left(\partial B/\partial s\right)^2 / B^2 \right\rangle$. In the core region, where the plasma is in the plateau regime, the parallel flow velocity of carbon impurity (C^{6+}) under the high γ configuration is 2-3 times smaller than that in the low γ case. The observed flow velocity is generally consistent with the neoclassical (NC) prediction, indicating that the damping force by the NC parallel viscosity is much higher under the high γ configuration. On the other hand, in the region of $r/a > 0.6$, the flow velocity was not so sensitive to γ and measured to be around 2-4 km/s for both the co- and counter-NBI plasmas

Study of E_r-fluctuations in the boundary region [2]

A toroidally symmetric radial electric field, E_r, fluctuation is found inside the last closed flux surface (LCFS) in low density ECH plasmas of Heliotron J for the first time. The fluctuation has dominant frequency components of < 4 kHz, and shows electrostatic characteristics. The fluctuation has quite similar characteristics to zonal flows observed in other devices, except for its radially elongated structure. The E_r fluctuation can generate the velocity shear synchronized with the fluctuation around LCFS since the fluctuation amplitude sharply increases inside LCFS. Nonlinear coupling between the radial and poloidal electric field fluctuations exists in the low frequency range. Cross-correlation analysis indicates that turbulence structure drastically changes at the boundary of LCFS, which results in the steep increase of Reynolds stress inside LCFS. Consequently, radial shape of the Reynolds stress is similar to that of the symmetric fluctuation amplitude. These observations imply that the generation of the symmetric fluctuation is coupled with the Reynolds stress.

Stabilization of EPMs by ECH/ECCD [3]

Energetic-ion-driven MHD instabilities such as energetic particle modes (EPMs) have been studied. We clarified the characteristics of the observed EPMs in NBI-heated plasmas with a low magnetic shear configuration of Heliotron J. The observed EPM has a low mode number such as $m/n = 2/1$ or 4/2 with a single helicity. Here, m and n are poloidal and toroidal mode number, respectively. The observed EPM localizes at the plasma edge ρ ~ 0.8 (ρ: normalized minor radius) where frequency of passing particles in toroidal direction intersects with shear Alfven continua of $m/n = 2/1$ or 4/2. Since the magnetic shear is a key parameter for continuum damping rate of EPMs, we scanned plasma current by adding local ECCD to the target plasma through the parallel refractive-index control. We demonstrated that EPMs could be controlled by means of both positive and negative magnetic shear induced by EC driven plasma current.

Study for high-density plasma operation in Heliotron J [4]

A short pulse high-intensity gas fueling (HIGP) opens a door to a higher density and stored-energy operation regime for NBI plasma at the low-ε_t configuration in Heliotron J. A high density state in the whole confinement region with its steep gradient in the peripheral is realized after HIGP, while the electron and ion temperature keep almost the same level before HIGP, resulting the enhancement of the stored energy. With a carful control of HIGP scenario, high-density NBI-only plasma (~ 10^{20}m^{-3}) with T_{e0} and $T_{i0} \approx$ 0.2-0.3 keV is realized. Here, the enhancement of the peak plasma stored energy is accompanied by the drop of $H\alpha/D\alpha$ emission intensity and the reduction in the edge density fluctuation, indicating a transition to an improved confinement mode after HIGP.

[1] S. Kobayashi, et al., "Parallel Flow Dynamics and Comparison with Neoclassical Transport Analysis in NBI Plasmas of Heliotron J", 25th Fusion Energy Conf. (FEC 2014), Saint Petersburg, Russia, 13-18 Oct., EX/P4-28.
[2] S. Ohshima, et al., "Observation of a Toroidally Symmetrical Electric Field Fluctuation with Radially Elongated Structure in Heliotron J", ditto, EX/P4-26.
[3] S. Yamamoto, et al., "External Control of Energetic ion driven MHD Instabilities by ECH/ECCD in Heliotron J Plasmas", ditto, EX/P4-27.
[4] T. Mizuuchi, et al., "A New Operation Regime for High-Density Plasma in Heliotron J", ditto, EX/P4-29.