7. PROJECTS WITH OTHER UNIVERSITIES AND ORGANIZATIONS

NIFS Bilateral Collaboration Research Program on Heliotron J

The Heliotron J group at IAE, Kyoto University has joined the Bilateral Collaboration Research Program managed by National Institute for Fusion Science (NIFS) since FY2004. This unique collaboration program promotes joint research bilaterally between NIFS and research institutes or research centers of universities that have facilities for nuclear fusion research. Under this collaboration scheme, the facilities operated in the different universities are open to all fusion researchers just as joint-use facilities of NIFS.

The main objective of the research in our Heliotron J group under this joint research program is to investigate experimentally/theoretically the transport and stability of fusion plasma in the advanced helical magnetic field and to improve the plasma performance through advanced helical-field control in Heliotron J. Picked up in FY2022 are the following seven key-topics; (1) magnetic configuration control for energy confinement, (2) production and confinement of high-density NBI plasmas and high-beta plasmas with novel fuelling methods, (3) electron thermal turbulent transport with self-criticality, (4) control of MHD and its physical mechanism, (5) edge plasmas in advanced helical systems, (6) production of energetic (MeV) electrons by non-resonant microwaves, and (7) development of new plasma diagnostics and analysis methods.

Two results from this collaboration research in FY2023 are shortly reported below. The annual report for all the collaboration subjects in this program will be published by NIFS.

Role of rational surface on energy confinement: In rotational transform control experiments, no clear dependence of energy confinement on the helical ripple has been observed, therefore the contribution of turbulence transport is anticipated. Generally, no profile stiffness is observed in temperature profiles in helical systems, and the transport may be driven under a critical gradient compared to tokamaks. Since the avalanche transport is generated at the gradient around the critical gradient, comparison between helical systems and tokamaks provides understanding of profile formation. We have analyzed the electron thermal avalanche transport in Heliotron J and JT-60U, comparing their properties.

Electron thermal fluctuations in the low-frequency component (f < 3 kHz) observed by an ECE radiometer have been analyzed in the heating power scan experiments in Heliotron J and JT-60U. The temperature profiles show little variation with heating input for both devices. This indicates the confinement degradability with respect to heating power common to both devices. Since the transfer entropy is a quantity that quantifies the causal relationship between two signals as a quantity of information, the spatio-temporal evolution of the transfer entropy shows the spatial propagation of thermal fluctuations. The electron thermal fluctuation propagates from the center (ECH heating position) to the periphery in about 0.2 ms (about the diamagnetic drift velocity) in Heliotron J and from the vicinity of the maximum temperature gradient to the center and periphery in about 1 ms (about 1/10 of the antimagnetic drift velocity) in JT-60U. In both cases, the time and spatial scales of propagation are non-diffusive, which is characteristic of avalanche transport, but there are differences in the direction and speed of propagation. The Hurst index, a measure of avalanche transport, is also compared. In Heliotron J, it increases with increasing ECH power and is close to unity over the entire radial range, while in JT-60U, no such dependence on heating power is observed and the Hurst exponent tends to depend on the magnitude of the temperature gradient.

Statistical acceleration using non-resonant wave heating: In Heliotron J, energetic electrons exceeding 2 MeV have been observed when non-resonant 2.45 GHz O-mode microwaves are injected at the magnetic field of about 1 T. Relativistic electron production requires multiple accelerations by an electric field. Statistical acceleration is a possible acceleration mechanism. Simulation studies on the diffusion process of the electron energy distribution show that the diffusion coefficient is proportional to the electron energy to the power of 3.6, and that this strong energy dependence is the essence of the power-law spectrum formation.

A model equation shows that the change in kinetic energy due to an electric field is proportional to the product of the electron's initial speed relative to the speed of light and its Lorentz factor, i.e., the larger the initial energy of the electron, the larger the change in kinetic energy. We have performed electron acceleration simulations by changing the initial electron energy in the range of 10 keV to 1 MeV and investigated the amount of change in the kinetic energy of electrons that are accelerated or decelerated in an electric field. The results obtained from the simulations agreed with the experimental ones. On the other hand, to model the diffusion coefficient, it is necessary to evaluate the incremental energy determined by both the initial phase and the final phase when exiting from the electric field region, and the issue is how to incorporate the randomness of the phase considering the electron orbit in the confining magnetic field.