

7. PROJECTS WITH OTHER UNIVERSITIES AND ORGANIZATIONS

NIFS Fundamental Facility Type Collaboration Research on Heliotron J

The Heliotron J group has been participating in the Fundamental Facility Type Collaboration Research Program, managed by the National Institute for Fusion Science (NIFS), since FY2025. This unique collaboration program promotes bilateral research between NIFS and research institutes or university research centers with facilities for nuclear fusion research. Within the new collaborative research framework, the goal for the 2025-2027 period is research into "limit-free" plasma.

Designing magnetic confinement fusion reactors imposes various constraints. Core plasma faces limits on density, beta, and aspect ratio. Eliminating these limitations would dramatically increase design freedom, enabling the realization of optimized, cost-effective reactors. Therefore, this research aims to achieve "limit-free plasma" by (i) identifying the limits, (ii) understanding the mechanisms, (iii) predicting the limits, and (iv) controlling the limits. This report highlights two achievements from this fiscal year.

Dynamic Profile Reconfiguration by Pellet Injection: We have experimentally investigated plasma dynamics by solid hydrogen pellets in Heliotron J. The physical processes from pellet melting to density increase are categorized as: (i) ablation, (ii) magnetic surface homogenization, and (iii) plasma profile reconfiguration. A two-dimensional visible high-speed spectroscopic diagnostic for the pellet ablation cloud has been developed. From the intensity distribution of the H_{β} line emitted by the ablation cloud, it has become possible to measure the trajectory and penetration length of the neutral cloud, and from the Stark broadening, the electron density of the plasma attempting to spread along the magnetic field lines.

When the plasma reaches a non-equilibrium steady state, it undergoes significant reconfiguration. The plasma does not exhibit an adiabatic response to pellet injection, and confinement performance improved during the reconfiguration process. Plasma contraction and expansion occurred, and the magnetic field structure in the divertor region also changed. As a result of injecting pellets into the high-temperature, low-density target plasma, the temperature decreased, and the density increased to approximately 10 times higher, reaching approximately $3 \times 10^{19} \text{ m}^{-3}$.

Measurements using an AXUV detector array and other diagnostics revealed that this cold plasma initially penetrated the plasma center. Subsequently, it was reheated and expanded. The plasma temperature and density profiles after the expansion ended were completely different from before pellet injection, with the plasma after pellet injection possessing higher stored energy. Such a state cannot be achieved by

slowly increasing the density through hydrogen gas injection, indicating that pellet injection transformed the plasma into a new state. Furthermore, this process revealed abrupt changes in the peripheral structure of the magnetic field that confines the plasma. The increased density led to more collisions. This, in turn, enabled rapid changes in temperature, density, and magnetic structure, facilitating the transition to the new state.

Response of Energetic Particle Driven Modes to ECH: We have conducted experimental research on energetic-particle (EP) driven MHD modes from the perspective of controlling the plasma "limit." EPs generated by D-T fusion reactions and neutral beam injection (NBI) excite Alfvén eigenmodes (AE) and energetic particle modes (EPM) through the gradient of the EP distribution function in the resonance region. These MHD waves can cause reduced heating efficiency and confinement performance. Furthermore, these lost EPs can cause severe damage to the wall. Therefore, understanding and controlling the interaction between EPs and MHD waves in magnetically confined fusion plasmas is critically important. This study investigated the effect of electron cyclotron heating (ECH) on EP waves across multiple magnetic configurations.

Varying the ECH power across different magnetic configurations can cause the excitation and suppression of giant Alfvén eigenwaves (GAE) and EPM to depend on the magnetic configuration. Furthermore, an optimal ECH power exists for certain modes. The radial mode profile measured by beam emission spectroscopy (BES) showed a multi-peak structure, and the mode intensity varied with ECH power.

For a low-bumpiness configuration, the mode intensity decreases with increasing ECH power. In contrast, for high- and medium-bumpiness configurations, an optimum ECH power exists that provides the mode suppression. The 60 kHz and 140 kHz EP modes decay as ECH power increases. On the other hand, the EP mode at 90 kHz and 115 kHz decreases with increasing ECH power below 240 kW but increases again at 305 kW. ECH can alter Landau damping, radiative damping, and continuous-spectrum damping by changing T_e . Conversely, the variations affect the deceleration time via electron drag. According to a linear theory, increasing T_e enhances the growth rate due to energetic ion pressure. Further detailed studies are required to determine the dominant influence on the mode excitation/damping.