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Development of Large Helical Device Project
大型ヘリカル装置実験計画の研究展開

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The Large Helical Device Project has been playing a unique alternative and complementary role to tokamaks and advancing fusion science by a virtuous circle of extension of operational regimes, discovery and systematic understanding based on accurate analyses. The highlighted achievements in plasma parameters are 5.1% of β, $1.2\times10^{21}m^{-3}$ of density, steady-state operation beyond 1keV for 1 hour, and 20 keV and 6.4 keV of electron and ion temperatures, respectively, etc. Developed diagnostics and numerical codes, which can manage multi-dimensional geometry with high space and time resolutions, enable us to challenge 3 N's (Non-linear, Non-diagonal, Non-local) and 3-D plasma physics. Achievements and scopes in terms of both extrapolating capability towards a helical DEMO reactor and comprehensive understanding of toroidal plasmas are discussed. The targeted goal of the Large Helical Device Project is integration of high-performance plasma and steady-state operation, which leads to academic creation as well as fusion energy development.

1. Introduction

The Large Helical Device (LHD) has produced more than 110,000 plasma discharges to date since the initial operation in 1998. Amongst large-scale fusion experimental devices, this very high availability is attributed to intrinsic physics advantage of a net-current-free helical plasma and the superconducting coil system [1].

Figure 1 shows a bird's-eye view of the coils in LHD. LHD employs a pair of helical coils and three sets of poloidal coils with top-down symmetry, all which are superconducting and generate confinement magnetic surfaces without any help of net toroidal currents. In addition, LHD has ten pairs of perturbation coils on the top and the bottom, which are used for error field cancellation and generation of *Resonant Magnetic Perturbations.*

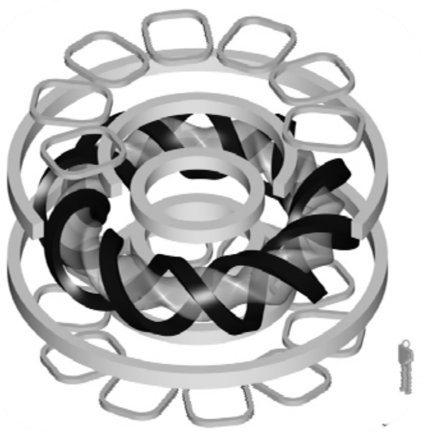

Fig.l　A bird's-eye view of coil systems in LHD.

The mission of the LHD project is establishment of scientific basis for a helical DEMO reactor and comprehensive understanding of toroidal plasmas. The key issue to accomplish the mission emphasized in these days is demonstration of high performance plasma which convinces us that a helical plasma can be ignited and clarification of 3-D plasma physics which is inevitable and critical for tokamaks as well.

2. Status of Machine Capability

The superconducting coil system provides the magnetic field up to 3T in steady-state. A heliotron configuration generated by a pair of helical coils accommodates a built-in divertor, which looks like a double-null divertor in tokamaks but rotates poloidally along the toroidal excursion.

LHD employs three heating schemes; NBI (180 and 40keV), ECH(77GHz) and ICH(25-100MHz). Figure 2 shows their capability. The primary heating source is provided by NBI with up to 29 MW. ECH and ICH play important complementary roles in the experiment. In particular, ECH (up to 4

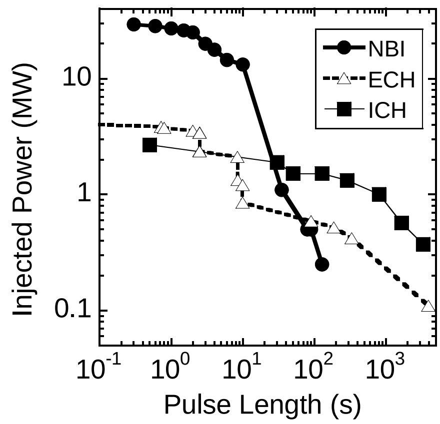

Fig.2 Heating capability as a function of pulse length

MW) is remarkable in well-focused local heating and power modulation to generate heat pulse. ICH (up to 2.7MW) plays the leading part in steady-state operation.

3. Experimental Achievements

The mission to extend plasma parameters and physics study in depth and breadth are synergetically related to each other [2]. Integration of high performances has progressed in recent experiments. For example, high β plasmas of about 5 % have been maintained in steady-state for more than 100 times the energy confinement time.

Robustness of a helical plasma is pronounced in extremely high density operation beyond $1\times10^{21}m^{-3}$ at the moderate magnetic field up to 3T. This demonstration develops an innovative scenario to mitigate physics as well as engineering demands

Figure 3 shows the radial profiles of ion and electron temperatures and electron density in a typical high-ion-temperature plasma. It should be noted that these fine measured profiles are projected on the 3-D MHD equilibrium. The ion thermal transport is improved close to the neoclassical level. It has been found that enhanced ion temperature gradient drives the outward convection of impurities and toroidal rotation [3]. These *Non-diagonal* contributions cannot be explained by the neoclassical theory and have been quantified in terms of impurity mass, 3-D geometrical effect (helical ripples), etc.

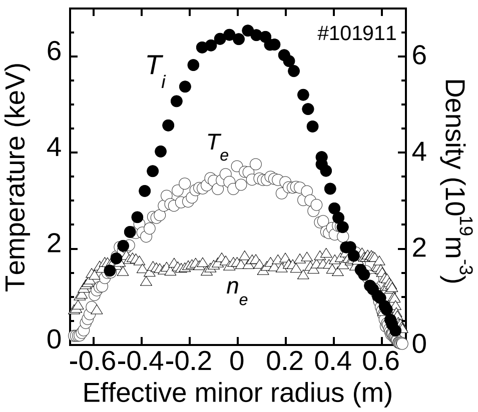

Fig.3 Radial profiles of ion (closed circles) and electron (open circles) temperatures and electron density (open triangles) in a typical high-ion-temperature plasma

Other two N's, i.e., *Non-linear* and *Non-local* are also highlighted research subjects. Experimental observations of turbulence and MHD instability have been compared with large scale non-linear simulations, which lead to validation of the numerical analyses and description of consistent physics pictures. Non-local transport is an unresolved issue which is important to control plasmas. Long-distance correlation [4], which would be a major player in non-local transport, has been identified in electron temperature fluctuations (see Fig.4).

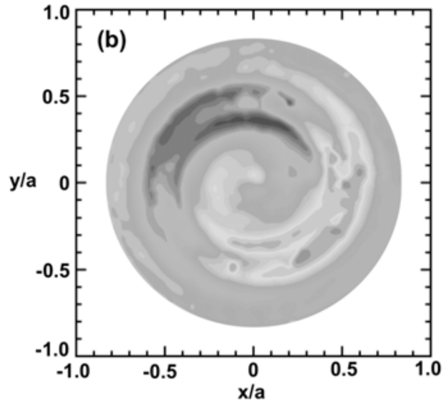

Fig.4 Contour of correlation amplitude of electron temperature fluctuation on the plasma cross-section

Characterization of *3-D effect* has been developed in transport and MHD in the LHD experiment. 3-D geometry affects viscosity and radial electric field which regulate mean flows and zonal flows, and consequently change neoclassical and turbulent transports. 3-D effect is also remarkable in topological change due to magnetic islands and stochastization of magnetic fields.

4. Future Scope

The upgrade of LHD is planned to bring out its maximum performance. Closed divertor with cryo-pump will start to work in 2012. Neutral compression by the modified configuration with baffles and a dome has been demonstrated in the provisional experiment on LHD [5]. Heating capability and the deuterium experiment are also planned

Acknowledgments

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References

[1] A.Komori et al.: Fusion Sci. Technol. **58** (2010) 1.
[2] H.Yamada et al.: Nucl. Fusion **51** (2011) 094021.
[3] K.Ida et al.: Nucl. Fusion **50** (2010) 064007.
[4] S.Inagaki et al.: Phys. Rev. Lett. **107** (2011) 115001.
[5] S.Masuzaki et al.: Plasma Fusion Res. **6** (2011) 1202007.