Overview of transport and MHD stability study and impact of magnetic field topology in the Large Helical Device

Katsumi Ida on behalf of LHD experiment group

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OUTLINE

1 Extension of operation regime in LHD
   48 minute long pulse discharge
   Simultaneous achievement of high Te and Ti plasmas

2 Transport analysis beyond power-balance
   Non-diffusive term of momentum and impurity transport
   Heat and momentum transport in modulation ECH experiment

3 MHD–Transport interaction
   Impact of stochastic magnetic field on MHD
   Pellet injection into the magnetic island
   The effect of energetic particle driven MHD to transport

4 Detachment and impurity control
   stabilization of detached plasma by RMP
   impurity behavior in LHD

5 Summary
48 minute long pulse discharge

The ultra-long pulse (τd ~ 48 min):

\[ n_e \tau E T_i \sim 3.5 \times 10^{18} \text{ keV m}^{-3} \text{ s}, \]
\[ n_e \sim 1.2 \times 10^{19} \text{ m}^{-3} \text{ measured with FIR} \]

\[ T_e \sim T_i \sim 2 \text{ keV}, \]

Simultaneous injection of ICH
(T. Seki FIP/P5-3) + ECH
\[ P_{RF} \sim 1.2 \text{ MW} \quad P_{inj} \sim 3.4 \text{ GJ}. \]

Mixed-material (C-Fe) deposition layers increase retention of helium and contributes to the wall pumping

Carbon spikes
Dusts (M. Shoji EX/P6-33) induce frequent spikes of emission of iron and carbon impurities and trigger the termination of discharge
Simultaneous Achievement of High $T_e$ and $T_i$ plasmas

High $T_e$ and $T_i$ plasmas are realized with the simultaneous achievement of electron and ion ITB by applying central focused ECH (T. Shimozuma EX/P6-34) and by reducing neutral density, which is confirmed by $H_\alpha$ measurements (K. Fujii EX/P6-31).

The reduction of turbulence transport is evaluated to be factor more than three by using heat deposition code GNET-TD (S. Murakami TH/P6-38) and transport code TASK-3D (M. Yokoyama EX/P6-27).
Transport analysis beyond power balance

Power balance analysis (database of $\chi_i, \chi_e, D$)

Dynamic transport analysis
Flux-gradient relation

Radial propagation of plasma response to perturbation

M. Yokoyama EX/P6-27

M. Yoshinuma EX/P6-30

S. Inagaki EX/2-1
The reversal of intrinsic torque from counter-direction to co-direction is observed to be associated with the formation of ion ITB, where the ITG mode is expected to be unstable due to the increase of ion temperature gradient and flattening of electron density profile.


ITG mode M. Nunami TH/P7-9.  Analysis tool M. Emoto FIP/P8-28
The reversal of radial flux starts at $r_{\text{eff}}/a_{99} = 0.65$, where the ITB also starts, and propagates toward the edge and center in the time scale of 15 ms which is much shorter than the time scale of change in the mean plasma parameter.
Heat pulse propagation

Bulk propagation (fundamental frequency) $\rightarrow$ slow
Front propagation (higher harmonic frequency) $\rightarrow$ fast

S. Inagaki (Kyushu Univ.) EX/2-1
Intrinsic rotation at LCFS

Modulation ECH is applied near the plasma boundary of $r_{\text{eff}} \sim 0.88$ to make a perturbation of temperature gradient at LCFS in LHD.

The modulation of toroidal rotation $V\phi$ at the LCFS is clearly observed.

The driven rotation is in the counter-direction for positive $E_r$ and it propagates inward from LCFS.

This experiment suggests the existence of strong intrinsic torque at the boundary of plasma.

K. Kamiya (JAEA)
When the stochasticization of the magnetic field is enhanced by the RMP, the pressure driven mode is suppressed even without a change in the pressure gradient itself.

Amplitude of $m/n = 2/3$ mode are reduced by the RMP field when the normalized RMP coil current $I_{RMP}/B$ exceeds 0.7.

S. Ohdachi EX/P6-29

Related Simulations  K. Ichiguchi TH/6-2 and A. Ishizawa TH/P6-40
Pellet injections into magnetic island

Hydrogen pellets are injected into the O-point of the magnetic island. The magnetic island prevent the inward shift of density. The significant peaked pressure profile inside the magnetic island is observed.
Effective Ion heating by energetic particle driven MHD

MHD burst excited by energetic particle driven GAM is observed in the very low density plasma of $5 \times 10^{17} \text{ m}^{-3}$.

The increases of effective ion temperature evaluated from the neutral particle spectra is observed associated with EGAM excitation.

This is a clear evidence for the interaction between MHD instability and heating/transport in the plasma.

M. Osakabe EX/10-3
Stabilization of Detachment Plasma by RMP

The detached plasma can be stabilized by localizing the radiation spot at the X-point of magnetic island produced by the RMP.

The chord-integrated intensity has a reasonable agreement with the experimental results.

Detached plasma without RMP

Carbon radiation distribution by EMC3-EIRENE

Detached plasma with RMP

M. Kobayashi OV/4-4
K. Mukai EX/P6-25
N. Ohno EX/P6-26
G. Kawamura TH/P6-39
Impurity behavior in LHD

Impurity hole (very hollow carbon profile) is observed in the high performance plasma with ion ITB.

Impurity accumulation takes place only in the narrow parameter space in LHD.

Simultaneous achievement of high temperature and low impurity concentration is expected in the future heliotron/stellarator devices.

Tungsten impurity transport: D. Kato MPT/P7-36 I. Murakami EX/P6-28.
Summary

1 Transport analysis beyond power-balance provides new understanding of transport
- The time scale of sign flip of momentum/particle non-diffusive term is shorter than the time scale of profile change.
  \( \Rightarrow \) non-diffusive term is directly connected to turbulence states rather than gradients.
- Heat pulse driven by MECH shows “fast” and “long” front propagation
  \( \Rightarrow \) Diffusive transport model is too simple to explain the front propagations.

2 MHD–Transport interaction
- Stochastic magnetic field ---- stabilizes the MHD instability
- Magnetic island ---- change the transport
  (not just flattening but playing a role of transport barrier)

3 Detachment and impurity control
- RMP --- stabilizing the detached plasma by controlling radiation spot
- Stochastic magnetic field at the plasma edge --- reducing impurity influx
List of LHD presentation

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