LHD experiments relevant to Tokamak MHD control
- Effect of Stochastic Field and Resonant Magnetic Perturbation on Global MHD Fluctuation -

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LHD (Large Helical Device)
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rotational transform
Structure and plasma achievement of LHD

Continuous helical coils of 
\( l=2/m=10 \) field period
All superconducting coil system
Plasma major radius \(~3.7\) m
Plasma minor radius \(~0.6\) m
Plasma volume \(~30\) m³
Toroidal field strength \(3\) T

High beta
\(<\beta> = 5.1\%\) at B = 0.425 T
High density
\(n_e(0) = 1.2 \times 10^{21}\) m⁻³ at B = 2.5 T
High ion temperature
\(T_i = 5.6\) keV at \(n_e = 1.6 \times 10^{19}\) m⁻³
accompanied by impurity hole
Long pulse : 0.6 MW for 1 hour
\(n \tau E T = 5 \times 10^{19}\) m⁻³ s keV
Introduction

Recently MHD stabilities in tokamaks related with RMP, stochastic fields and the islands are strongly concerned.

RWM control;
   Interaction between MHD instability and Resonant Magnetic Perturbations

ELM control;
   Suppression/Mitigation of ELM activities due stochasticization of edge magnetic fields

NTM;
   Island dynamics through interaction among seed island, NC current, flow and so on.

Mag. Perturb., Stochastic region of Mag. Field and Islands are induced even in Vac. Config. in Stell./Heliotrons
=> Responses of MHD instabilities on them are observed.
Today's talk
Outline

0. Characteristics of MHD insta. in LHD
1. Effect of Mag. Perturb. Field on Global MHD Fluc
   (1) Resonant MP
   (2) Non-resonant MP
2. Effect of Stochastic on Global MHD Fluc
3. Discussion
Characteristics of MHD instability in LHD

Amp. mag. fluc. low-mn

Volume ave. tor. $\beta$ upto 5%
Mag, Reynolds # $10^6$-$10^9$

Whole region; Hill

# Mag. fluc. of global MHD insta. resonated with peripheral low-oder rational surf. are observed in high $\beta$ regime.
Characteristics of m/n=1/1 mode structure

# 92000, $R_{ax} = 3.75m, 0.9T$

1.8s

Radial profile of SXR fluctuation amplitude

t=1.8s

Line-integrated

Sight lines of SX

No phase inversion (No mag. island structure?)

$\Rightarrow$ Similar structure to linear theory prediction of resistive interchange MHD instability
Effect of Magnetic Perturbation on Global MHD Fluctuation

1. Resonant MP
2. Non-resonant MP

Magnetic Perturbation by LID coils in LHD

10 pairs LID (for Local Island Divertor config.) coils produce m/n=1/1 RMP.

m/n=1/1 MP of $I_{LID}/B_0 \sim 1\text{kA/T}$ => $w_{is}/r \sim 20\%$ island in vac.
Suppression of $m/n = 1/1$ mode by resonant mag. field

$R_{ax} = 3.6 \text{ m}, B_t = 2.75 \text{ T}, A_p = 5.7, \text{ NBI, } <\beta> \sim 1\%, D_1 < 0.2, D_R > 0, S \sim 10^7$

At $I_{LID} = 220 \text{ A/T (W/a_p \sim 0.20)}$, Fluc. disappears despite finite grad.$T_e$ remains near $\imath=1$ surf.

Amp. of Fluc. decreases with reduction of the gradient. Then the mode frequency slowed down.

Radial Profiles of MHD Modes with Low Mag. Perturb. \((I_{\text{LID}}/B_t=0.57\text{kA/T})\)

- **O-point of \(m/n=1/1\) static island**
- **Vertically elongated section (6.5-U port section)**
- **Vertically elongated section (3.5-U port section)**
- **Horizontally elongated section (4-O port section)**

**Low MP (0.57kA/T)**

Mode has Interchange like structure.

- \(m/n=2/3\)
- \(m/n=2/3\)

\(m/n=1/1\) static island isn’t Clear n Te prof.

Ref: F. WATANABE NF (2008)
Radial Profiles of MHD Modes with Large Mag. Perturb. ($I_{LID}/B_t=1.13kA/T$)

- Vertically elongated section (6.5-U port section)
  - m/n=2/3

- Vertically elongated section (3.5-U port section)
  - m/n=2/3

- Horizontally elongated section (4-O port section)
  - m/n=3/4

- m/n=1/1 Island center

**SX fluc in inboard side; decreased. in outboard; strongly enhanced.**

Ballooning-like Character

Ref. F. Watanabe NF (2008)
Global MHD Fluctuation behavior in Stochastic Region surrounding Nested Flux Surfaces

ref.
According to HINT calc., Stochastic region extends with $\beta$ in LHD configurations.

HINT code;
Full 3D MHD equilibrium analysis code in real coordinates =>
can treat Islands/Stochastic fields
Reconstructed MHD equil. and Mag. surf. in high $\beta$ using HINT

Well defined last closed mag. surf. in vac.

$2* n_{e-FIR} * T_{e-TS}(Normalized)$

Mag. surf. predicted by HINT

$\#46465(1.625s)$, $R_{ax}^V = 3.6m/0.5T$, $<\beta_{dia}> \sim 3\%$

In Region; Stochastic mag. surf is expected by HINT, Finite $p_e$ and $T_e$ are observed
Observ. of Coherent MHD fluc. in Stochastic Region

In Region; Stochastic mag. surf is expected by HINT, Resonated Coherent fluc. are observed
Brief Summary

# Effect of Mag. Perturb. (MP) on global MHD instabilities
1. Global MHD instability are suppressed by resonant MP before $T_e$ is flattened.
2. Interchange like instability is observed in small non-resonant MP and w/o MP. On the contrary, ballooning like global MHD instability appears in large non-resonant MP.

# Observation of coherent global MHD fluctuation in stochastic region in finite $\beta$ plasmas predicted by HINT.
Discussion

Simulation of Interaction between MHD instabilities and Island/Stochastic field should be accelerated.

Accompany with the following experimental study;
(1) Accurate estimation of perturbed mag. Field in plasmas
   Sometimes RMP looks shielded by plasmas.
(2) Confirmation of stochasticity
   In actual plasmas, is mag. field stochastic?
(1) Sometimes RMP looks shielded by plasmas.
   Island does NOT appear as RMP simply superposed in vac. fields (Heals/Enhased)

=>

How does plasma shield RMP?

=>

Accurate estimation of perturbed Mag. Field in plasmas is important

ref.
Y.Narushima, Nuclear Fusion (2008)
S.Sakakibara, 15th ICPP (Santiago de Chili, 2010)
Y.Narushima, 23rd IAEA Conf. (Daejon, 2010) EX/5-2
Island does NOT appear as RMP simply superposed in vac. (Heals/Enhanced)

Response of Perturb. Field from Plasmas

Where perturb. current flows inside/outside/on resonant surf?
Example of Dynamical response of Static island by MP of ex. coils

Time trace of RMP from Coil

Response of RMP from Plasma

Detail time response is under investigation
(2) In actual plasmas, mag. field is NOT stochastic.

=> Confirmation of stochasticity is important

In LHD, **Response of transient electron thermal transport response by Power modulation of ECH**

=>

**Identify mag. island and stochastic structure of mag. field**

ref. K.Ida, 23rd IAEA Conf. (Daejon, 2010) EX/5-2
Modulation ECH

Modulation ECH is applied to study the heat pulse propagation in the Te flat region. The modulation power ($A^2$) drops at $r/a \sim 0$ and increases at $r/a \sim 0.5$. Flattening of modulation power suggests that heat pulse propagates radially faster than the transport time scale determined by thermal diffusivity $\chi_e$. 

![Graph showing modulation ECH results]
Identification of stochastization of magnetic fields

Switch of NBI from co. to ctr. increases the central rotational transform ➔ decreases magnetic shear

Heat pulse propagation by modulated ECH
Future subjects in LHD exp.

# Accurate estimation of perturbed mag. Field in plasmas

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Dynamical response of Static island Response of Heavy Ion Beam trajectory on Perturbed Field induced by external MP coils

# Confirmation of Pred. Stochastic region

By Modulation of ECH (analysis trough transport response)

Welcome to your proposal!!