Effect of Magnetic Configuration on Energy Confinement and Energetic-Particle-Driven MHD Modes in Heliotron J

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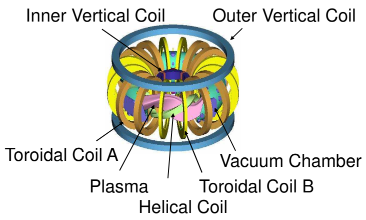
Introduction

- Magnetic configuration has an important role in reduction of neoclassical and turbulent transport, good energetic particle confinement and good MHD stability in stellarator/heliotron devices for attractive fusion reactors
- The energy confinement depends on the magnetic configuration such as bumpiness and rotational transform
- Excitation and damping of energetic-particle (EP)-driven MHD modes can also be affected by magnetic field configuration, and they can be stabilized by electron cyclotron heating (ECH) and current drive (ECCD)
- Study on the magnetic configuration effect on EP-driven MHD modes will provide knowledge about ECH effect which is not clear in tokamaks and stellarator/heliotron device.
- The Heliotron J device, which concept is based on quasi-omgeneity, has a capability to investigate the effect of the magnetic configuration on energy confinement and EP-driven MHD modes

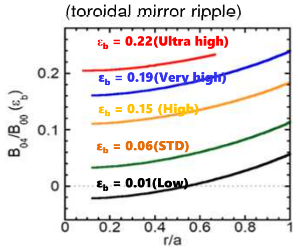
Heliotron J Device



- Typical plasma parameters;
  - n_e<1x10^{20} m^{-3}
  - T_e< 3 keV
  - T_i< 400 eV

Major radius	1.2m
Plasma minor radius	0.15-0.2m
Rotational transform	ι /2π= 0.3-0.8, low shear
Magnetic Field	1.5T
Pulse length	0.5sec

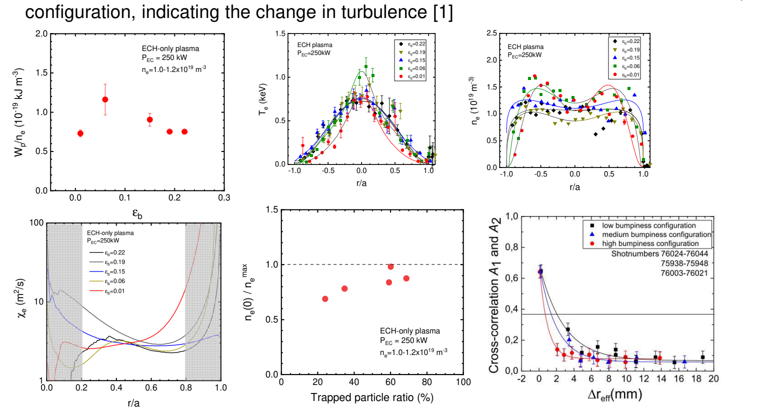
Radial profiles of bumpiness (toroidal mirror ripple)



Effect of Magnetic Configuration on Energy Confinement

Effect of Bumpiness

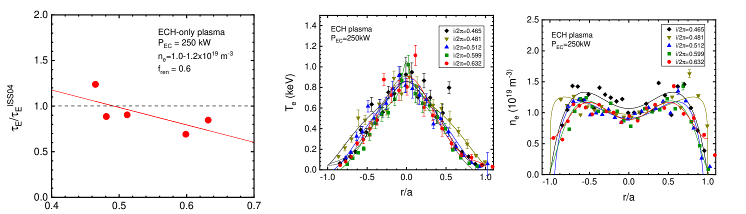
- The stored energy normalized by electron density is maximal in the medium-ϵ_b configuration in which neoclassical transport is reduced
- The thermal conductivity is high at edge region in low-ϵ_b configuration
- The hollowness of n_e profile stronger with a decrease in the trapped particle ratio of ECH
- The radilal correlation length of density fluctuation at the edge region is longest at low-ϵ_b configuration, indicating the change in turbulence [1]



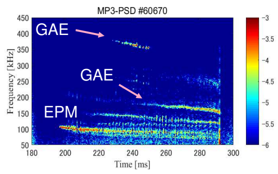
[1] N. Smith, et al., Plasma Fus. Res. 15 (2020) 1202054

Effect of Rotational Transform

- The The energy confinement is degraded as the rotational transform increases This contradicts with the ISS04 scaling, in which the energy confinement time is expected to be longer by scales as $(\iota/2\pi)^{0.41}$ where the energy confinement time is expected to be longer by 20-30%.
- The ne and Te profiles depends on rotational transform. The high edge Te profile is obtained at ι/2π =0.481 where the magnetic islands are formed around LCFS

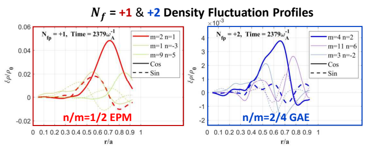


Energetic Particle Driven MHD Modes

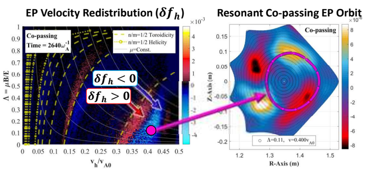


- Energetic particle modes (EPMs) and Global Alfven Eigenmodes (GAE) are observed in Heliotron J NBI plasmas because of its low rotational transform and weak magnetic shear.
- EPMs can be distinguished from AEs by the density dependence of the observed mode frequency.
- Since the EPM is a kinetic mode, the frequency is not proportional to Alfvén velocity, weakly depends on the ion density.

Hybrid Simulation of Energetic Particle Driven MHD Modes with Free Boundary Condition [1][2]



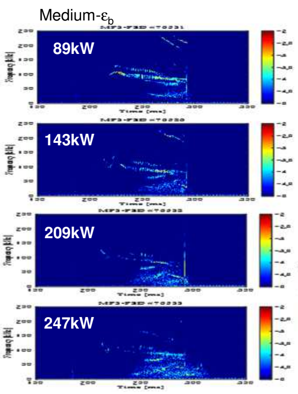
- Heliotron J has a **low magnetic shear**.
  - → The AEs can displace the plasma at the LCFS.
  - → **Free boundary**[3, 4] condition is introduced to account for the edge displacement.
- The n/m=1/2 EPM & n/m=2/4 GAE are successfully reproduced.
  - → **Free boundary** condition is for the low-n MHD instabilities near the plasma edge in Heliotron J.



- The n/m=1/2 EPM is driven by the high velocity co-passing energetic particles (EPs).
  - →Transit the core region (High f_{h0}).
  - →Large orbit width.
  - →Effectively interact with the n/m=1/2 EPM at the plasma edge.

[1] P. Adulsiriswad, et al., 2019 Nucl. Fusion 60 096005
[2] P. Adulsiriswad, et al., to be submitted
[3] Chen E Y et al 2011 *Physics of Plasmas* **18** 052503
[4] Yang S et al 2018 *Nuclear Fusion* **58** 046016

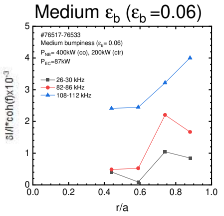
Effect of ECH on Energetic Particle Driven MHD Modes



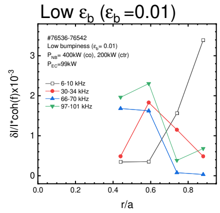
- NBI: BL1 400kW, BL2 250kW
- ECH: $N_{||}$=0.0 (no ECCD)
- n_e~0.6-1.2x10^{19} m^{-3}
- I_{EC}: ~0.0 kA, independent on P_{ECH}

$P(f) = \mathrm{coh}^2(f) * P_{BES}(f)$,
coh(f): coherence between BES and MP signals
$P_{BES}(f)$: PSD of the BES signal

Medium ϵ_b (ϵ_b =0.06)

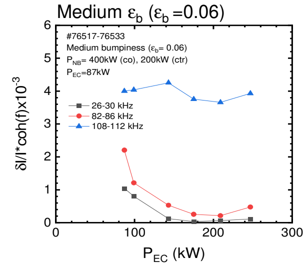


Low ϵ_b (ϵ_b =0.01)

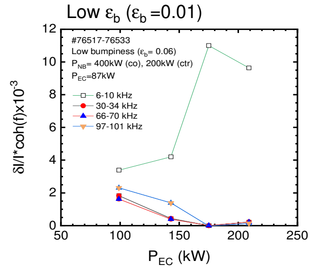


- In the medium-ϵ_b configuration, the EP-driven MHD modes of 20-90 kHz are monotonically mitigated with ECH, and the mode of around 110GHz is weakly dependent on the EC power.
- In the low- ϵ_b configuration, all the EP-driven modes are suppressed with an increase in the EC power from 99 kW to 209 kW.
- ECH effect may be related to the balance between stabilization effect by continuum damping and destabilization effect by energetic particle pressure.

Medium ϵ_b (ϵ_b =0.06)



Low ϵ_b (ϵ_b =0.01)



Summary

- We have studied the effect of magnetic configuration on energy confinement and EP-driven MHD modes in Heliotron J
- The best energy confinement is achieved at the medium-ϵ_b configuration where the neoclassical diffusion is reduced, while it is degraded at too high and low bumpiness.
- The dependence on the rotational transform does not follow the ISS04 scaling. The plasma shape is affected by the magnetic configuration, which may be related to the edge magnetic field structure, in particular, the magnetic island around LCFS
- The free boundary EP-MHD hybrid simulation successfully reproduces the experimental mode excitation, and it indicates that the boundary condition plays a significant role in the modeling of the peripheral low-n MHD mode in the low magnetic shear configuration
- Some EP-driven modes which are excited at the edge region are mitigated with increasing on-axis ECH power, some are weakly dependent on the ECH power