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-omgennyality, has a capability to investigate the effect of the magnetic configuration on energy confinement and EP-driven MHD modes.

Heliotron J Device

<table>
<thead>
<tr>
<th>Inner Vertical Coil</th>
<th>Outer Vertical Coil</th>
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</thead>
<tbody>
<tr>
<td>Toroidal Coil A</td>
<td>Vacuum Chamber</td>
</tr>
<tr>
<td>Plasma</td>
<td>Toroidal Coil B</td>
</tr>
<tr>
<td>Helical Coil</td>
<td></td>
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</tbody>
</table>

Major radius: 1.2m
Plasma minor radius: 0.15-0.2m
Rotational transform: 1/2k-0.3-0.8, low shear
Magnetic Field: 1.5T
Pulse length: 0.5sec

Effect of Magnetic Configuration on Energy Confinement

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

Effect of Rotational Transform
- The energy confinement is degraded as the rotational transform increases.
- The ne and Te profiles depends on rotational transform. The high edge Te profile is obtained at ω/2π = -0.481 where the magnetic islands are formed around LCFS.

Energetic Particle Driven MHD Modes

- Energetic particle modes (EPMs) and Global Alfvén Eigenmodes (GAE) are observed in Heliotron J NBI plasma 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 electron density profile in the plasma at the LCFS:
  - Free boundary 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.

Effect of ECH on Energetic Particle Driven MHD Modes

- In the medium-εb 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-εb 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.

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-εb 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, and they can be stabilized by electron cyclotron heating which is not clear in tokamaks.
- 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.