Recent Topics of the ECRH Experiments in LHD


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Introduction

Background

• 3- 77 GHz, 1 MW Gyrotrons become available
• Total ECH injection power exceeds 3.7 MW
• Importance of the confinement properties in the low collisional regime (low\( n_e \), high\( T_e \))
  • neoclassical confinement in stellarator/heliotron
  • production of high energy electron, relativistic effect
• Long pulse operation

Contents

• 77GHz Gyrotron development
• High\( T_e \) plasma confinement and formation of the transport barrier (e-ITB)
• CW operation
• Summary
ECRH System
Upgrades
ECRH System in LHD (2009)

- 1-168GHz 500 kW 1s  88.9mm Corrugated Waveguide
- 2-84 GHz 800 kW 3s  31.75mm Corrugated Waveguide (Evacuated)
  - Switchable to 84GHz 500 kW 10s/ 200 kW 1000s
- 1-84 GHz 800 kW 3s  88.9mm Corrugated Waveguide (Evacuated)
- 2-82.7GHz 500kW 2s  88.9mm Corrugated Waveguide
- 3-77 GHz 1MW 3s/ 0.3 MW CW 88.9mm Corrugated Waveguide (Evacuated)

Total injection power attained 3.7 MW

77GHz 1-1.5MW,5s/ 0.3MW CW

168GHz 0.5 MW,1s

84GHz 0.8 MW, 3s

82.7GHz 0.5MW, 2 s

84GHz 0.2MW CW
Since July 2007, the installation of 1 MW-77 GHz gyrotrons has progressed in LHD. This is a co-research & development with Tsukuba University and JAEA.

- Increment in central heating source.
  - Improvement of core temperature/ pressure.
- Different frequency from those of existing gyrotrons.
  - Simultaneous-multi-point heating of plasma
  - Local control of radial electric field/ radial transport by local collisionality control.
  - Influence of deposition power/ position on the CERC formation.

### 77 GHz Gyrotron Development

<table>
<thead>
<tr>
<th>Items</th>
<th>Design</th>
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<tbody>
<tr>
<td>Frequency</td>
<td>77 GHz</td>
</tr>
<tr>
<td>Power/ Pulse length</td>
<td>1.0 MW/ 5 s, 300 kW/ CW (#1)</td>
</tr>
<tr>
<td></td>
<td>1.2 MW/ 5 s, 300 kW/ CW (#2)</td>
</tr>
<tr>
<td></td>
<td>1.5 MW/ 5 s, 300kW/ CW (#3)</td>
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<tr>
<td>Cavity mode</td>
<td>TE$_{18,6}$</td>
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<tr>
<td>MIG type</td>
<td>Triode</td>
</tr>
<tr>
<td>Collector type</td>
<td>Collector Potential Depression</td>
</tr>
<tr>
<td>Output window</td>
<td>CVD diamond</td>
</tr>
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</table>
High Te experiments
Thomson data accumulated more than 10 shots at low density
Appreciable high energy electrons generated at low density

High $\text{Te}_0 > 15 \text{ keV}$ Achieved
Dependence of $T_{e0}$ on the normalized power density

- Central electron temperature scales as the power density.
- High energy electron component can play an important role in the low density region.
Dependence of the Electron Temperature Profile on the Magnetic Configuration

- Highest central temperature achieved at
  \[ R_{ax} = 3.53 \text{ m Configuration} \]

- Consistent with neoclassical prediction although the diffusion coefficient seems anomalous.

- Production and the confinement of high energy electrons may play an important role.

DCOM code

Radial Electric Field

- Potential measured by HIBP
- GSRAKE results show more radial electric field formed at Rax=3.53 m
- Diffusion coefficient from GSRAKE show minimum at Rax=3.53 m
Formation of Electron Internal Transport Barrier

- Clear threshold exists in the Power density
- Flat profile near the core grows sharp
- ITB foot point stays at \( \varphi/2\pi = 0.5 \)
- Ambi-polar electric field jumps to positive at the threshold density
ITB foot point and rational surface

- ITB foot point almost stays near rational surface.
- ITB formed only when the absorbed power inside rational surface exceeds threshold.

Power deposition inside low order rational surface play an important role in forming the electron ITB.
Non-local effect further pushes up electron temperature

- Transient change in the electron temperature due to TESPEL injection can push further the maximum.
CW experiments
ECH 110 kW 65 minutes injection

1.48 T, 3.6 m
Second Harmonic

\[ P_{in} \sim 110 \text{ kW}, 65 \text{ minutes} \]

\[ T_{e0} > 1.0 \sim 1.5 \text{ keV} \]

\[ n_e > 1.5 \times 10^{18} \text{ m}^{-3} \]

Gas feed controlled manually by mass flow controller
- Tried to increase density, after 2000s

ECH terminated manually
- Due to the data acquisition setting

Achieved in 2005
Long pulse discharge using 77GHz and 84 GHz CW plasma sustainment is an important issue for LHD

New 77GHz gyrotron can be operated 300 kW/CW

Due to the lack of conditioning time, 275kW, 400 s simultaneous operation was the maximum power and pulse width with 2-77GHz+1-84GHz

some shots are suffered from arcing at the mirror surface contaminated by co-deposition
Summary

Three 1MW, 77GHz Gyrotron are operated successfully

High Te plasma

  • Optimum magnetic axis position exists.
  
  • High energy electrons play important roles in low density region, in the power deposition, electric field structure formation, etc.

  • ITB formation and foot point are closely related to the low order rational surface

CW plasma sustainment

  • needs gyrotron and antenna conditioning