Absorption of X-Wave at the Second Harmonic in HSX


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Abstract

Second harmonic extraordinary mode ECH is used in the HSX stellarator at 0.5 T to break down and heat the plasma. To measure the absorbed power a set of absolutely calibrated microwave diodes have been installed inside the machine. In the QHS and Mirror configurations, the absorption efficiency is high (about 0.9) and drops (0.6) in the anti-Mirror mode. A comparison with ray tracing predictions is made.

Perpendicular and Oblique Propagation

Cyclotron absorption shapes

At $\theta = 90$ degs, absorption occurs at $E_B > 0$
- Absorption efficiency drops with $k_{\perp}$
- At large $k_{\perp}$ the absorption is symmetric with respect to resonance point

Temperature effect

The cyclotron absorption shape is broadened with temperature
- At $\theta = 90$ degs, the maximum is moved inward due to relativistic mass increase

Magnetic Field Scan

$E_B = 0.1264 \, \nu = 0.86$
- Shift out of the central resonance reduces the absorption

Absorbed Power Profile

- $P_{\text{abs}} = 100$ kW
- $T_{\text{f0}} = 0.4$ keV
- $B_{\text{B}} = 0.5$ T
- $P_{\text{cold}} = 0.7 \times 10^{6}$ W
- $P_{\text{hot}} = 1.6 \times 10^{6}$ W

Absorption coefficients

- Six diodes are almost identical
- The square law is up to about 30 $\mu$W of input power

Power at each toroidal location

- Power at each toroidal location:
  - $P_{\text{abs}} = 5 \times 10^{5}$ W
  - $W_{\text{abs}} = 22$ J
  - $P_{\text{abs}} = 10^{6}$ W

Ray-Traacing Equations

- Cold plasma dispersion solution: $N^2(k, \omega) = 0$
- After-Appleton-Hartree formula: $N^2(k, \omega) = 0$
- $\Delta \omega = -2 \ln(\zeta); \quad \Delta \phi = \zeta \phi$
  - $\zeta$ - absorption coefficient; $\nu_{\delta}$ - group velocity; $\omega$ - angle between $\nu_{\delta}$ and $k$

Electron Cyclotron Damping

- Resonance condition: $\omega = \nu_{\text{DE}} + k_{\perp} \cdot \nu_{\delta}$
- Extraordinary wave at the second harmonic of $\Omega_e$
- $\Omega_e = 2 \nu_{\delta}$
- $\nu_{\text{DE}} = \omega_{\text{DE}} - \omega / (2 \theta)
- $\nu_{\text{DE}} = \omega_{\text{DE}} - \omega / \theta$
- $\omega_{\text{DE}} = - \omega (1 - \theta / 2)$

Single-pass Absorption

At 1 keV the single-pass absorption is 0.8
- $T_{\text{f0}} = 0.4$ keV
- $B_{\text{B}} = 0.5$ T
- $P_{\text{abs}} = 10^{6}$ W
- Absorbed power profile is not broadened much
- Energy per particle in the center core

Location of Antennas

- Each antenna consists of an open K-band waveguide, attenuator and microwave detector

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