§12. Possibility of Electron Cyclotron Current Drive at $\omega \approx \omega_c$ with X-mode Launched from the Low Field Side in LHD

Leuterer, F. (Max Planck Inst. for Plasma Phys., Germany), Kubo, S.

Electron cyclotron current drive (ECCD) scenarios for tokamaks use the fundamental ordinary mode (O1-mode) or the second harmonic extraordinary mode (X2-mode) launched from the low field side. O1-mode and X2-mode launched from the low field side are chosen mainly because of their large optical thickness, and simplicity in the design of the launcher. Recently, a scenario of ECCD near the fundamental cyclotron frequency with an fundamental extraordinary mode (X1-mode) launched from the low field side is proposed[1]. In the case of oblique injection of X1-mode, we do not need to access the resonance region that is screened by cutoff region existing in the low field side for an efficient damping and current drive. Accessibility and feasibility of this mode to LHD are studied using the actual magnetic launcher configurations.

A top view of the LHD constant magnetic field contours, flux surface contours and the available ECRH antennas in the horizontal port is shown in Fig. 1. The thick lines are the contours for |B| = 3 T and the outermost closed flux contour (ρ = 1) respectively. The lower frequency among operating frequencies of 84 and 168GHz can be used for fundamental X-mode current drive. In order to achieve effective currrent drive, we need a high $N_\parallel$ in the absorption region. The best conditions in this respect are given for the toroidal launching positions – 0.7 m to –0.9 m. We take here as a representative case the position – 0.8 m. The accessibility condition can be expressed in the functional form of

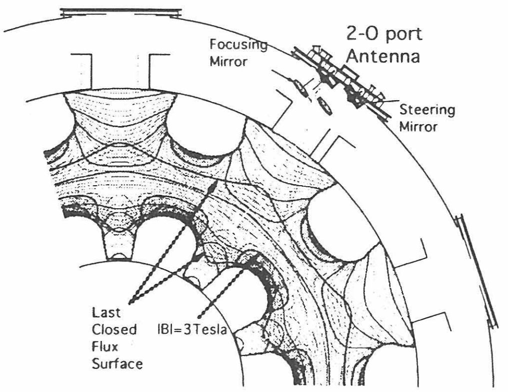

Fig.1 Horizontal cross-section of LHD available launching mirrors. The ray is shown with the toroidal deflection of –0.8m.

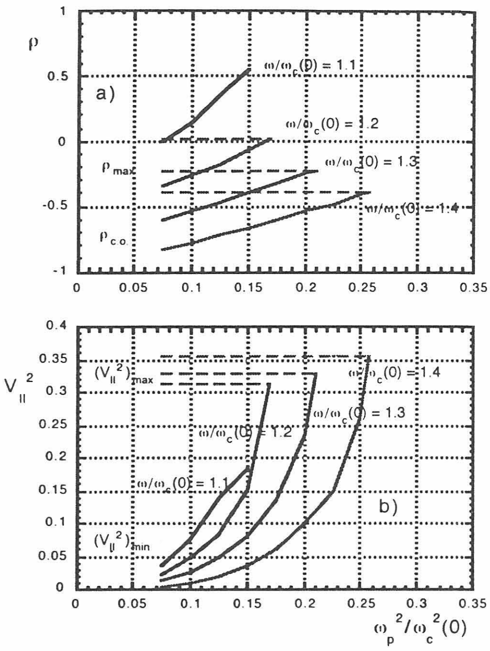

Fig.2. a) locations of ρ_{max} and $\rho_{c.o.}$, and b) associated maximum and minimum energies as function of the central density in LHD at constant toroidal ray deflection of – 0.8 m and various values of $\omega/\omega_c(0)$.

frequency normalized by local cyclotron frequency ω/ω_c, as

$$(\omega/\omega_c)_{c.o.} = \frac{1}{2}\left(1 + \sqrt{1 + 4\left(\omega_p^2/\omega_c^2\right)/\left(1 - N_\parallel^2\right)}\right),$$

and

$$(\omega/\omega_c)_{max} = \frac{1}{\sqrt{1 - N_\parallel^2}}.$$

Here, $(\omega/\omega_c)_{c.o.}$ and $(\omega/\omega_c)_{max}$ correspond to local X-mode cutoff frequency and maximum frequency up to which resonant electron exist in velocity space. A summary of accessibility condition for different magnetic fields and densities, but fixed launch angle, is shown in Fig. 2. Here, cutoff and maximum frequency is expressed by corresponding locations $\rho_{c.o.}$ and ρ_{max}. $V_\parallel$ is the electron parallel velocity normalized by light speed. The density profile is assumed to be $n_e(\rho) = n_e(0)\cdot[1-(\rho)^4]$. Taking $(V_\parallel^2)_{min}$ = 0.05 as a limit for the availability of a sufficient number of resonant electrons, we find for the accessible range of central electron densities $n_e(0) \le 7\cdot10^{18}$ m^{-3}. This density range will expand with a higher local temperature and an increasing number of electrons at higher parallel velocities. However, there remains a limit, independent of temperature, of $\omega_p^2/\omega_c^2 = 0.2$ for an assumed $N_\parallel(\rho) \approx 0.6$, corresponding to $n_e(\rho) \le 1\cdot10^{13}$ m^{-3} for $\omega/\omega_c(0) = 1.3$ and the given frequency of 84 GHz.

References:

1) Leuterer,F. and Kubo,S. NIFS Report NIFS-624 Feb.2000.