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ACCESSIBILITY OF LOWER HYBRID WAVE IN TOKAMAK AND STUDY OF FREQUENCY AND MAGNETIC FIELD EFFECTS ON ACCESSIBILITY

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Abstract. With due consideration to dispersion relation of cold plasma and applying resonance condition to a desired root of dispersion relation for lower hybrid heating, lower hybrid frequency is achieved. Then accessibility condition is resulted from confluence of tow roots. Effects of frequency and magnetic field parameters of applied wave on the accessibility are presented in this paper.

A scheme for producing a steady state toroidal current using intermediate frequency lower hybrid waves (f ~1GHz) was first proposed by Fisch in 1978. The idea was to lunch waves with high phase velocities which travelled preferentially in one direction around the torus.

Upon Landau damping on a population of super thermal electrons, these waves would then transfer momentum and energy to the particles generating a net current. In lower hybrid current drive, energy and parallel momentum are transferred from externally-excited waves in the plasma to resonant electrons via Landau damping.

Controlled thermonuclear fusion in a Tokamak may be attained by heating the plasma with Radio Frequency (RF) waves of neutral beams to temperatures above those achieved by Ohmic Heating; RF heating of the plasma in the lower hybrid range of frequencies (0.5-5 GHz) is a possible method for a practical and efficient heating scheme. Lower hybrid waves are predicted to damp on the ion population at the location near the lower hybrid resonance in the plasma.

Direct heating of the ions is considered desirable because it is the ion that undergoes fusion and in most present Tokamaks the ion temperature is lower than the electron temperature by a factor of 1.5 to 3. Furthermore, in present day devices, the ion energy confinement time is generally longer than that for electrons. Increment of plasma energy by ion heating will be more efficient than by electron heating if the absorption efficiencies on the two populations are comparable. Electron heating via electron landau damping of lower hybrid waves is also possible (Krlin et al. 1983).

In order to use of lower hybrid waves for heating or current drive, wave have to be accessible that means it does not cutoff and also doesn't reflect. Accessibility and propagation of lower hybrid waves are defined by considering plasma as a cold region and consequently, as a system without pressure.

Accessibility dispersion relation of the electromagnetic wave in cold plasma is resulted by:

$$D(\omega,\bar{k}) = An_\perp^4 + Bn_\perp^2 + C \tag{1}$$

$$B = (n_\parallel^2 - \varepsilon_\perp)(\varepsilon_\parallel + \varepsilon_\perp) + \varepsilon_\times^2 \quad \text{and} \quad C = \varepsilon_\parallel((n_\parallel^2 - \varepsilon_\perp)^2 - \varepsilon_\times^2)$$

That to consider approximation of lower hybrid frequency, dielectric tensor elements is given by:

$$\varepsilon_\perp = 1 + \frac{\omega_{pe}^2}{\omega_{ce}^2} - \frac{\omega_{pi}^2}{\omega^2}\ ,\ \ \varepsilon_\times = \frac{\omega_{pe}^2}{\omega\omega_{ce}} \ \text{and}\ \ \varepsilon_\parallel = 1 - \frac{\omega_{pe}^2}{\omega^2}$$

Two modes of wave propagation are indicated by two solutions of cold dispersion relation. Here, $n_\parallel$ is assumed a constant which is fixed by the antenna. Consequently, roots of dispersion relation can be achieved (Porkolab 1981, Freidberg 2007):

The lower hybrid frequency is defined as follow (Knowlton 1975):

$$\omega_{lh} = \frac{\omega_{pi}}{(1 + \omega_{pe}^2 / \omega_{ce}^2)^{\frac{1}{2}}} \tag{2}$$

Large values of the slow waves near the resonance are expected to increase ion heating. The solutions are corresponding to the fast and slow converge if $b^2 - 4ac = 0$. Using this condition, we find that (Golant 1972):

$$\text{if}\ \ n_\parallel^2 > \left(1 - \frac{\omega^2}{\omega_{ce}\omega_{ci}}\right)^{-1} = n_{\parallel\, crit}^2 \tag{3}$$

The juncture of two roots is avoided and the resonance is accessible to lower hybrid waves in the vicinity of lower densities. This is so-called accessibility condition.

With assumption of $\varepsilon_\parallel < 0$, there are two requirements for good accessibility (i.e., $n_\perp > 0$). Firstly, $k_\perp$ must be positive everywhere in the region of interest. In order to achieve this condition, ω must be greater than a critical value. Secondly, the expression under the square root can become negative unless $n_\parallel^2$ is sufficiently large. For too small value of $n_\parallel^2$, a mode conversion layer forms, where the slow wave is converted to a fast wave which then propagates back to the launcher. In other words, there is no accessibility beyond the mode conversion layer. Thus, a combination of high ω and large $n_{\parallel}^2$ is required for appropriate accessibility (Freidberg 2007). The condition of $n_{\perp} > 0$ can be written as:

$$\omega^2 > \omega_{lh}^2(x) = \frac{\omega_{pi}^2(x_r) / \omega_{ce}^2}{1 + \omega_{pe}^2(x_r) / \omega_{ce}^2} \quad (4)$$

Here, $\omega_{lh}(x)$ is the local lower hybrid frequency along the mid plane. The resonant radius x_r can lie anywhere in the range of $-a << x_r << a$. The distance of $a - x_r$ corresponds to the penetration depth of the wave from the lunching structure before reaching the lower hybrid resonance (neglecting the effects of Landau damping). Clearly, $n_{\parallel}$ and ω must be chosen so that there is good accessibility over the entire region of interest, which is assumed to be district between the launcher and the center of the plasma: $a > |x| > 0$ for $n_{\perp}^2 > 0$.

Here, $n_{\parallel}^2 > n_{\parallel crit}^2$ is considered to avoid the mode conversion layer.

This may be imagine that the problem of choosing $n_{\parallel}$ and ω has been solved; but it has shown that when landau damping occurs, assuming similar reactor parameters, waves can not penetrate to center of plasma and little percent of them can reach to middle of plasma. Here, effect of various parameters on wave penetration and accessibility to plasma are shown appropriately.

.Lower hybrid wave penetration is improved by increment of the magnetic field or by decrement of the wave frequency. This is illustrated in following figures where we have plotted $N_{\perp}^2$ from the cold plasma dispersion relation as a function of major radius along the mid plane of the Tokamak. The dispersion curves are plotted for various $n_{\parallel}$ values ranging between 1.5 and 3.5, with $\Delta n_{\parallel} = 0.1$. We have included the toroidal magnetic field gradient, given by $B(R) = \frac{B_0 R_0}{R}$. In addition, we have assumed a Gaussian density profile as: $n_e(r) = n_{e0} \exp\left(\frac{-r^2}{\lambda_n^2}\right)$, where $r = R - R_0$, and $\lambda_n = 10cm$. R is distance from Tokamak axis and R_0 is the major radius (Golant 1972, Mayberry 1986).

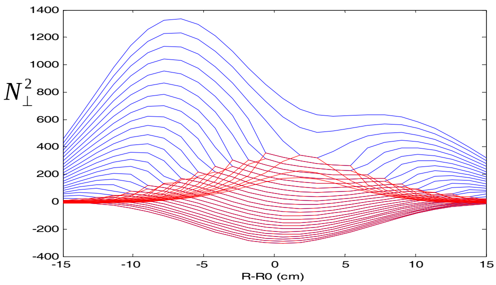

Figure 1: Dispersion curve for $B_0 = 1.2\ T$.

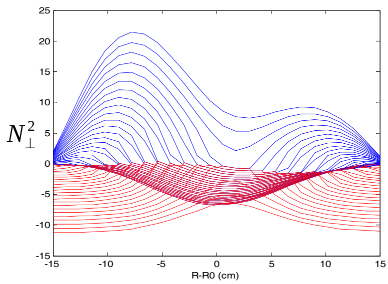

Figure 2: Dispersion curve for $f = 10\ GHz$.

CONCLUSIONS

The calculations, showed that lower hybrid wave can propagate from the edge into the plasma. Toroidal field is stronger on the inside of a tokamak. The wave penetration is more favorable from the inside. As it shown in Figs. 1 and 2, the wave accessibility increases by increasing tokamak magnetic field. The critical $n_{\|}$ decrease that means accessibility and wave penetration is obtained for a lower amount of $n_{\|}$, so above the critical $n_{\|crit}$, the roots of dispersion relation are well separated and are accessible to the center of the plasma without converted mode and for lower amount of $n_{\|crit}$ two waves mode converted. Accessibility is improved by lowering the wave frequency. Therefore raising the toroidal magnetic field and lowering the wave frequency improves accessibility.

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