§19. Theoretical Calculation of ICRF Mode Conversion Heating Efficiency

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The efficiency of a mode conversion from a fast wave to an ion Bernstein wave (IBW) was calculated in order to explain the result of the LHD experiment (in the previous section, i.e. Experimental Observation on ICRF Mode Conversion Heating). The theoretical model to calculate the mode conversion efficiency is as follows; a fast wave launched from the antenna located at the lower magnetic field propagates to the L-cutoff layer. Some fraction of the fast wave is reflected toward the antenna by this layer. Some propagates toward the R-cutoff layer through an evanescent region between the L-cutoff layer and the hybrid resonance layer. The rest converts to IBW at the hybrid resonance layer. The fast wave passing though the evanescent region is reflected by the R-cutoff layer located at the higher magnetic field side. Then it approach to the hybrid resonance layer and passes through the evanescent layer again. This wave interferes with the fast wave reflected by the L-cutoff layer. The mode-converted IBW heats electrons via Landau damping. The electron heating efficiency can be considered to be the same as the mode conversion efficiency assuming that there is no absorption at the cyclotron resonance layer, which is located at $\rho = 0.5$.

The wave equation near the hybrid resonance layer is expressed using the Budden form in the following equation[1,2],

$$d^2E(x)/dx^2 + k_{\perp f}^{*2}(1 - w/x)E(x) = 0 \qquad (1)$$

Figure 1 shows a schematic drawing of the propagation of the fast wave. The reflection coefficient r_R and the transmission coefficients t_R and t_L are calculated using Budden form. ϕ is the phase difference between the fast wave reflected by R-cutoff layer and the fast wave which passed though the evanescent region as expressed in the following equation,

$$\phi = -\pi/2 + 2\int_{-c}^{-a} k_\perp dx \qquad (2)$$

The first term $-\pi/2$ is phase difference of the fast wave reflected by the R-cutoff layer at the higher magnetic field. The second term is the phase difference between the point x=-c and the point x=-a. The mode conversion coefficient $A_{mc}(k_{//})$ is given in the following equation,

$$\begin{aligned} A_{mc}(k_{//}) = \; & 1 - \{1 - \exp(-\pi\eta)\}^2 - \exp(-2\pi\eta) \\ & - 2\{1 - \exp(-\pi\eta)\}\exp(-\pi\eta) \qquad (3) \\ & \times\cos\{\phi + 2\psi + \eta\log(2k_{\perp f}^{*}a) + 2k_{\perp f}^{*}a\} \end{aligned}$$

where

$$\eta = k_{\perp f}^{*} w \qquad \psi = \mathrm{Arg}\Gamma(-i\eta/2) \qquad (4)$$

The total mode conversion rate i.e. the electron heating efficiency can be calculated by integrating $A_{mc}(k_{//})$ over the wave number spectrum weighting the antenna loading impedance spectrum and the antenna current spectrum,

$$A_{mc} = \frac{\int_{k//} A_{mc}(k_{//}) Z_R(k_{//}) |I(k_{//})|^2 dk_{//}}{\int_{k//} Z_R(k_{//}) |I(k_{//})|^2 dk_{//}} \qquad (5)$$

where $Z_R(k_{//})$ is real part of the antenna impedance spectrum and $I(k_{//})$ is the antenna current spectrum. The measured radial profile of the electron density was used to get w and $k_{\perp f}^{*2}$ in the equation (1) and to know the position of the layers. The electron density was obtained using a 13 channel HCN laser.

The calculated result is plotted in a solid line as shown in Fig.2 with the dependence of the electron heating efficiency on $n_H/(n_H+n_{He})$ in a dotted line, which was experimentally obtained as described in the previous section. The electron heating efficiency has the maximum near $n_H/(n_H+n_{He})$=0.3, which fairly agrees with the experimental results. The RF power absorbed by electrons can be well explained by this model.

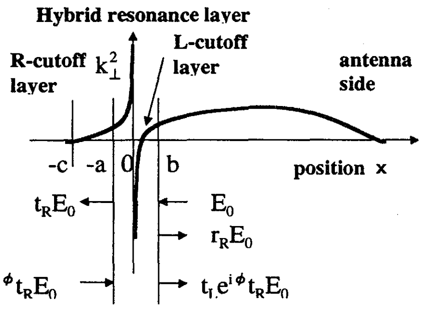

Fig. 1. $k_\perp^2$ calculated using the dispersion relation of the cold plasma in the equatorial plane. Some fraction of a fast wave is converted to IBW at the hybrid resonance layer i.e. $k_\perp^2 = \infty$.

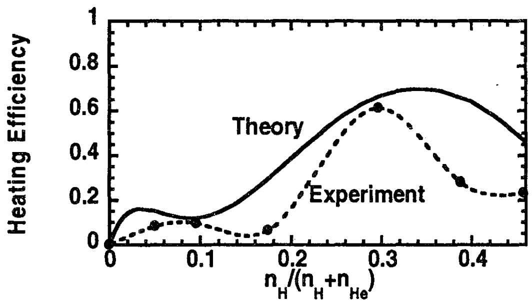

Fig. 2. The dependence of the theoretical calculation of the electron heating efficiency on the hydrogen ratio, $n_H/(n_H+n_{He})$ with the electron heating efficiency experimentally obtained.

Reference

[1] Jacquinot, J., McVey, B. D., Scharer, J. E., Phys. Rev. Lett. 39 (1977) 88.

[2] Perkins, F.W. Nucl. Fusion 17 (1977) 1197.