§24. High Energy Ion Loss Analysis by Fokker-Planck Equation

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In the 4th experimental campaign on LHD the dependence of phase delay of high-energy ion flux (ϕ_{ICRF}-ϕ_{flux}) on energy was investigated with the power modulation of ICRF heating [1]. Here ϕ_{flux} is the phase of high-energy ion flux, ϕ_{ICRF} is the phase of ICRF heating power. Then the plasma major radius was R_{ax}=3.6m. H^{+}+He^{2+} plasma (H^{+}:minority, He^{2+}:majority) was used for minority heating. The time-of-flight neutral particle analyzer (TOF-NPA) was used to measure the high-energy ion (H^{+}) flux produced by ICRF heating. The ICRF heating power was modulated with the frequency of 4 Hz. It was compared with the calculation of Fokker-Planck equation, which does not include the particle loss. In this model energy loss is mainly due to electron drag in a high-energy region. There was small discrepancy between experiment and calculation, but the tendency that the phase delay increase with energy agreed with the calculation.

In the 5th experimental campaign, the dependence of phase delay was studied by using the Silicon-NPA detector not only with the plasma of R_{ax}=3.6m but also with the plasma of R_{ax}=3.75m. In the plasma of R_{ax}=3.75m the loss of high-energy ions produced by ICRF heating is assumed large because the orbit of trapped particle is not aligned with the flux surface. Therefore we made a model of the distribution function f taking the particle loss into consideration.

$$f(v,t,\theta) = A(v,t) + \frac{1}{2}B(v,t)(3\cos^2\theta - 1)$$

$$\frac{\partial A}{\partial t} = \frac{1}{v^2}\frac{\partial}{\partial v}[-\alpha v^2 A + \frac{1}{2}\frac{\partial}{\partial v}(\beta v^2 A) + Kv\frac{\partial}{\partial v}v(A - \frac{B}{5}) - K(A + \frac{2}{5}B)v] - A/\tau_{loss} + \tilde{N}(\frac{m_H}{2\pi T_{He}})^{1.5}\exp(-\frac{m_H v^2}{2T_{He}})$$

$$\frac{\partial B}{\partial t} = -\frac{1}{v^2}\frac{\partial}{\partial v}(\alpha v^2 B) + \frac{1}{2v^2}\frac{\partial^2}{\partial v^2}(\beta v^2 B) - \frac{3}{2}\frac{\gamma}{v^2}B + \frac{K}{v^2}\frac{\partial}{\partial v}v\frac{\partial}{\partial v}v[-A + \frac{5}{7}B] - \frac{K}{v^2}[3A + \frac{30}{7}B] + \frac{K}{v^2}\frac{\partial}{\partial v}v[4A - \frac{5}{7}B] - B/\tau_{loss}$$

where,

$$\tilde{N} = 4\pi\int_0^\infty v^2 A/\tau_{loss}dv \ , \quad K = \frac{\langle P\rangle}{3n_H m_H},$$

$$\alpha = \langle \Delta v_{//}\rangle + \frac{1}{2v}\langle(\Delta v_\perp)^2\rangle, \quad \beta = \langle(\Delta v_{//})^2\rangle,$$

$$\gamma = \langle(\Delta v_\perp)^2\rangle$$

where θ is pitch angle and τ_{loss} is loss time which is a function of energy.

The term $\tilde{N}(\frac{m_H}{2\pi T_{He}})^{1.5}\exp(-\frac{m_H v^2}{2T_{He}})$ is source term that keeps density of hydrogen constant.

$\langle\Delta v_{//}\rangle$, $\langle(\Delta v_{//})^2\rangle$, and $\langle(\Delta v_\perp)^2\rangle$ are Coulomb diffusion coefficients. K is proportional to flux surface averaged power density $\langle P\rangle$. This model coincides with that proposed in ref. [2] when $\tau_{loss} = \infty$. By solving these equations numerically, the phase delay of high-energy ion flux on energy was analyzed.

Figure 1 shows the phase delay of high-energy ion flux with various total loss time from 18msec to ∞. In this calculation T_e=T_{He}=0.75keV, n_e=0.5×10^{13}m^{-3}, and K of 0.5×10^{13} W/kg was adopted. Then the slowing down time by electron was 70msec. As shown in this figure, particle loss makes phase delay small. This tendency qualitatively agrees with the experimental result, i.e. the phase delay is larger in the case of R_{ax}=3.6m than that of R_{ax}=3.75m. This experimental result is described in detail in this annual report April 2001 - March 2002. (High Energy Tail Production and Confinement in ICRF Minority Heating by Mutoh, T.)

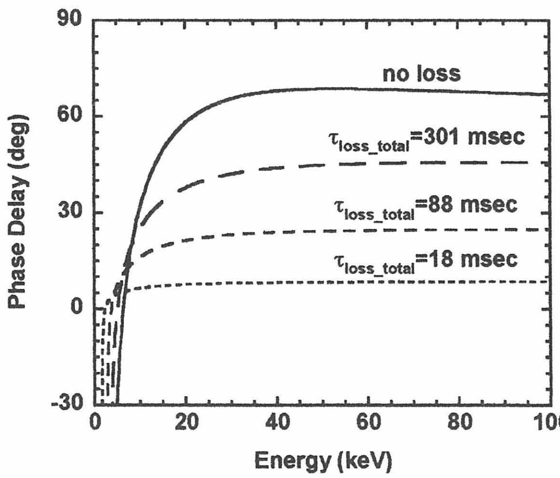

Fig. 1 Phase delay of high-energy ion flux. Phase delay increases with particle loss time. In this calculation loss time is inversely proportional to energy. Total loss time τ_{loss_total} is $N/\tilde{N}$, where N is density of hydrogen.

References

[1] Saito, K., et al., Plasma Phys. Control. Fusion **44** (2002) 103.

[2] Stix, T.H., Nucl. Fusion **15** (1975) 737.