§16. High Energy Ion Component Measurement by ICRF Power Modulation Method

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As the confinement time of high energy ions is much different between in R_{ax}=3.6m and in R_{ax}=3.75m, a different ratio of the stored energy of the high energy ions to that of the bulk plasma can be experimentally observed. An analysis in the plasma discharge with the RF power modulation gives the tail fraction of high energy ions by measuring phase difference among the total stored energy δW_p, the bulk plasma stored energy δW_b and the ICRF heating power δP_A. The relations between δW_p and δW_b and between δP_A and δW_p are derived from the power balance equation and expressed in the following complex equations,

$$\frac{\delta W_P}{\delta W_b} = 1 + \frac{3}{2}\frac{AR_{tb}}{\eta_{trns}} + i\frac{3}{2}\omega\tau_{se0}/2,$$

$$\frac{\delta W_P}{\delta P_A} = \eta_{trns}\tau_{se0}/2\eta_0 \frac{1+\frac{3}{2}(i\omega\tau_{se0}/2+\frac{AR_{tb}}{\eta_{trns}})}{-BR_{tb}+(i\omega\eta_{trns}\tau_{se0}/2+1)(i\omega\tau_{se0}/2+\frac{AR_{tb}}{\eta_{trns}})},$$

$$R_{tb} = \frac{\tau_E^{tail}}{\tau_E},\quad A = \frac{3}{2}+(1-\beta),\quad B = \frac{\eta' T_0}{\eta_0}+\frac{3}{2}.$$

Here the energy transfer from the high energy ions to helium ions is neglected. R_{tb} is a ratio of the stored energy of the high energy ions to that of the bulk plasma. ω and β are an applied modulation frequency and a numerical factor derived from the dependence of the energy confinement time on the temperature, *i.e.*, $\tau_E \propto \tau_{E0}T^\beta$; β=-1.44 derived from ISS95. η_0 is a heating efficiency and η' is its derivative of temperature[1]. The phase difference θ_{pb} between δW_p and δW_b, and the phase difference θ_{pA} between δW_p and δP_A are given in the following equations;

$$\tan\theta_{pb} = \frac{\frac{3}{2}W}{1+\frac{AR_{tb}}{\eta_{trns}}},$$

$$\tan\theta_{pA} = -W\frac{(A+\frac{3}{2}B)R_{tb}+1+\frac{3}{2}(AR_{tb})^2+\frac{3}{2}W^2}{(\frac{A}{\eta_{trns}}-B)(1+\frac{3}{2}\frac{AR_{tb}}{\eta_{trns}})R_{tb}+(\frac{3}{2}-\eta_{trns})W^2},\quad W=\omega\tau_s/2.$$

A relation between θ_{pA} and θ_{pb} is obtained in the following equation by substituting $\tan\theta_{pb}$ instead of $\omega\tau_s/2$;

$$\tan\theta_{pA} = -\frac{2}{3}\tan\theta_{pb}(1+\frac{AR_{tb}}{\eta_{trns}})$$

$$\times\frac{(A+\frac{3}{2}B)R_{tb}+1+\frac{3}{2}(AR_{tb})^2+\frac{2}{3}(\tan\theta_{pb}(1+\frac{AR_{tb}}{\eta_{trns}}))^2}{(\frac{A}{\eta_{trns}}-B)(1+\frac{3}{2}\frac{AR_{tb}}{\eta_{trns}})R_{tb}+(\frac{3}{2}-\eta_{trns})(\frac{2}{3}\tan\theta_{pb}(1+\frac{AR_{tb}}{\eta_{trns}}))^2}.$$

θ_{pA} was calculated as a function of R_{tb} at five different θ_{pb}, θ_{pb}=10°, 15°, 20°, 25°, and 30° and plotted in Fig.1. θ_{pA} increases with R_{tb} when R_{tb} < 0.2, reaches its maximum at R_{tb} = 0.2 and decreases with R_{tb} at θ_{pb}=10°. θ_{pb} depends on $\omega\tau_s/2$; it increases with T_e and with decrease in n_e. The relation between θ_{pA} and θ_{pb} is calculated as a parameter of R_{tb}. Loci of R_{tb} of 0.01, 0.1, 1.0 and 10.0 are plotted in the plane of θ_{pb} and θ_{pA} as shown in Fig.2. It should be noted that the pressure ratio of R_{tb} can be deduced from the measurement of θ_{pA} and θ_{pb}.

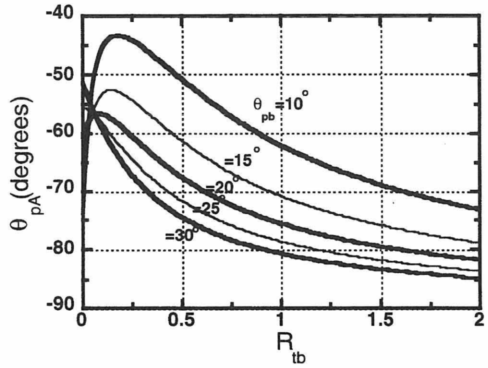

Fig.1 Dependence of a phase difference between W_p and P_A on the pressure ratio of R_{tb} as the parameter of θ_{pb}.

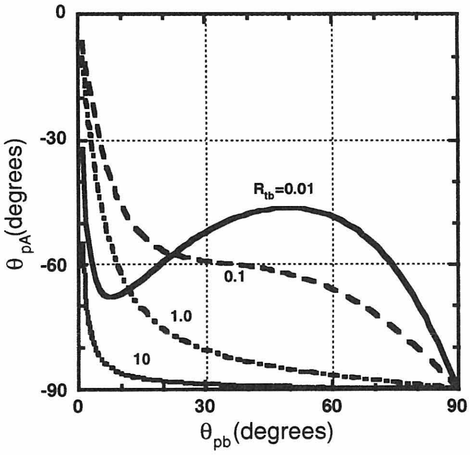

Fig.2 Dependence of a phase difference between W_p and P_A on a phase difference between W_p and W_b as the parameter of the pressure ratio of R_{tb}.

Reference

1) Y. Torii, et. al., Plasma Physics and controlled Fusion, **43** (2001) 1191.