§25. Evaluation of Energy Confinement Time and Heating Efficiency in ICRF Heated Plasma

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The energy confinement time of the LHD plasma has been observed to be 1.5 times larger than the International Stellarator Scaling (ISS95)[1)]. In the third cycle, ICRF modulation experiment was carried out to evaluate the energy confinement time, τ_E, in the diffrent method.

In this experiment, the radiated RF power from antenna, P_{ant}, was modulated in the following way,

$$P_{\mathrm{ant}} = P_{0\mathrm{ant}} + |P_{1\mathrm{ant}}| \sin \omega t$$

where ω, $P_{0\mathrm{ant}}$ and $P_{1\mathrm{ant}}$ are modulation angular frequency, an average and a modulated RF power from antenna, respectively. Then the modulated plasma stored energy W_p is

$$W_p = W_{p0} + |W_{p1}| \sin(\omega t + \delta)$$

where δ, W_{p0} and W_{p1} are the phase difference in the wave forms between the $P_{1\mathrm{ant}}$ and the W_{p1}, an average and a modulated plasma stored energy, respectively. The absorbed power by the plasma, P_{abs}, is calculated to be ηP_{ant} by introducing the heating efficiency η. The τ_E is a function of the modulated frequency and δ etc. The heating efficiency η is calculated with W_{p1}, $P_{1\mathrm{ant}}$, ω and δ etc.

We considered three models to analyze τ_E asssuming different dependence of the energy confinement time on the various parameters such as the RF heating power and the plasma temperature, T; i.e. (a)τ_E = const.[2)], (b)$\tau_E = A{P_{\mathrm{abs}}}^{\alpha}$ and (c)$\tau_E = BT^{\beta}$. Assuming $W_{p1} \ll W_{p0}$ and $P_{1\mathrm{abs}} \ll P_{0\mathrm{abs}}$, we substitute three types of τ_E, $P_{1\mathrm{ant}} = |P_{1\mathrm{ant}}| \sin \omega t$ and $W_{p1} = |W_{p1}| \sin(\omega t + \delta)$ to the following equation,

$$\frac{dW_{p1}}{dt} = \eta P_{1\mathrm{ant}} - \frac{W_{p1}}{\tau_E}$$

using of Fourier transformation and linear approximation, τ_E is calculated as shown on Table I, which shows calculation results of τ_Es and ηs. Hereafter, τ_E and η calculated by modulation method are written with superscript M:i.e. ${\tau_E}^M$ and η^M.

To evaluate α, β in the case of model (b) and (c), we use the ISS95 scaling law[1)],

$${\tau_E}^{\mathrm{ISS95}} = 0.079 a^{2.21} R^{0.65} P^{-0.59} \bar{n}_e^{0.51} {B_t}^{0.83} {(\iota/2\pi)_{2/3}}^{0.4}$$

Then we assume $\alpha = -0.59$ and $\beta = -1.44$.

From experimental result (Fig.1), we calculated ${\tau_E}^M$ and η^M, and compared them with ${\tau_E}^P$ and η^P calucu-lated with usual method,

$$\eta^P = \frac{(dW_p/dt)_{t_{\mathrm{off}}-0} - (dW_p/dt)_{t_{\mathrm{off}}+0}}{P_{\mathrm{ant}}}$$

$${\tau_E}^P = \frac{W_p}{\eta^P P_{\mathrm{ant}}} \quad \text{(at steady state, } dW_p/dt = 0)$$

Table II shows ${\tau_E}^M/{\tau_E}^P$s and η^M/η^Ps of each three models. It is found that ${\tau_E}^M$s of any model (a)-(c) didn't have an agreement with ${\tau_E}^P$ but that η^Ms of model (a) and (c) shows good agreement with η^P.

To have a good agreement with ${\tau_E}^P$, changing β, ${\tau_E}^M$ of model (c) can be fixed. In this experiment, if we assume $\beta = -0.75$, ${\tau_E}^M$ has a good agreement with ${\tau_E}^P$. In ISS95 the dependence of P on τ_E corresponds to $\tau_E \propto P^{-0.45}$.

In this shot, it turned out to be an effective method of τ_E to calculate it from the phase difference between W_p and P on power modulation experiment. And we also calculate η for another method. The model (c) shows a good agreement with actual τ_E and η. So τ_E should be explained as a function of temperature.

Table I: Three models of ${\tau_E}^M$s and η^Ms

model	${\tau_E}^M$	η^M
(a)	$\dfrac{\tan\delta}{\omega}$	$\omega\sqrt{1+\dfrac{1}{\tan^2\delta}}\dfrac{\lvert W_{p1}\rvert}{\lvert P_{1\mathrm{ant}}\rvert}$
(b)	$\dfrac{\tan\delta}{\omega}$	$\dfrac{1}{\alpha+1}\omega\sqrt{1+\dfrac{1}{\tan^2\delta}}\dfrac{\lvert W_{p1}\rvert}{\lvert P_{1\mathrm{ant}}\rvert}$
(c)	$(1-\beta)\dfrac{\tan\delta}{\omega}$	$\omega\sqrt{1+\dfrac{1}{\tan^2\delta}}\dfrac{\lvert W_{p1}\rvert}{\lvert P_{1\mathrm{ant}}\rvert}$

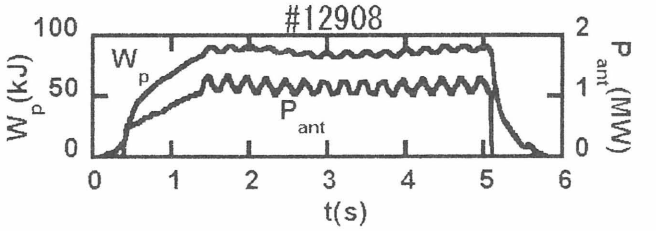

Fig.1: Time evolutions of W_p and P_{ant}. Modulation frequency is 4Hz. ($B = 2.75$T, RF frequency= 38.47MHz)

Table II: Three models of ${\tau_E}^M/{\tau_E}^P$s and η^M/η^Ps in the case of $\alpha = -0.59$ and $\beta = -1.44$

model	${\tau_E}^M/{\tau_E}^P$	η^M/η^P
(a)	~ 0.5	~ 1.0(good)
(b)	~ 0.5	~ 2.0
(c)	~ 1.4	~ 1.0(good)

Reference

1) U.Stroth, et al., Nucl. Fusion **36**, 1063(1996)

2) T.Shoji, et al., Institute of Plasma Physics Reserch Report, Nagoya, IPPJ-795(1986)