§25. Heat Flux Measurement in Heliotron J with the Hybrid Directional Probe

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In order to estimate divertor heat load, a simple formula $q = \gamma T_e I_{is}$ has been used. However, relationship between the heat flux and the plasma parameters is very complicated. For example, ion temperature contribution could not be ignored as usual text books, since ion temperature is often larger than electron temperature in divertor plasma. Thus, to check proposed methods to reduce the divertor heat load, the direct measurement of the heat flux is indispensable.

The hybrid directional probe (HDP), which was composed of thermal probes and directional Langmuir probes, was used in Compact Helical System for the first time[1]), then moved to Heliotron J under collaboration with National Institute for Fusion Science (NIFS). HDP is composed of one magnetic probe sensor (Pin 6) and seven Langmuir probe tips (Pins 1-5, 7-8), five of which are equipped with type-K thermocouples (TC) and available also as thermal probes. Two unsteady heat conduction model are constructed and the heat flux is estimated from these thermal probe data[2]).

In the infinite heat pulse model (model1), a probe pin is treated as a semi-infinite plane and the plasma heat flux is treated as a delta-function type short pulse. Then temperature in a probe pin is a function of time t and distance x from the pin surface and is given by

$$T(x,t) - T_\infty = \frac{q\Delta t}{k}\sqrt{\frac{a}{\pi(t-t_0)}}\exp\left(-\frac{x^2}{4a(t-t_0)}\right), \quad (1)$$

where k is the heat conductivity, a is the thermal diffusivity, q is the averaged heat flux density, T_∞ is the initial temperature, and t_0 is the time when heat pulse reaches the pin surface.

In a finite length heat pulse model (model2), a probe pin is treated as a slab with effective thickness L. The plasma heat flux is treated as a box-type pulse,

$$q(t) = \begin{cases} 0 & (t < t_0 = 0, t > t_1) \\ q_\infty & (0 < t < t_1) \end{cases} . \quad (2)$$

By selecting q_∞, L, and pulse length $t_1 - t_0$, obtained temperature in a probe pin is also a function of time t and distance x, which is given in detail on reference 2).

Figure 1 shows the example of thermocouple data for neutral beam injection (NBI) plasma. Temperature increases almost after the end of main discharge, and reaches a maximum value about at $t = 0.5$ [s]. Both model1 (solid line) and model2(dotted line) can reproduce of temperature evolution of Pin 4 very well and their estimated heat fluxs agree each other. So simpler model1 can be applied to Heliotron J normal experiment.

In the low field experiment, plasma is produced by the electron cyclotron heating (ECH) of 2.45 GHz and the pulse length is extended to a few second. Figure 2 shows the example of Pin 4 thermocouple data. Temperature begins to increase about $t = 0.5$ [s] after discharge start and shows no saturation until at $t = 4.0$ [s]. Fitting data with model2 and Pin 4 TC data show a discrepancy after $t \sim 1.8$[s]. This is due to density increase triggered by a LaB_6 hot cathode biasing. The biasing voltage is changed linearly with time. Although this transition occurs at $t \sim 1.1$ [s], thermal probe signal response has a large delay of 0.7 [s].

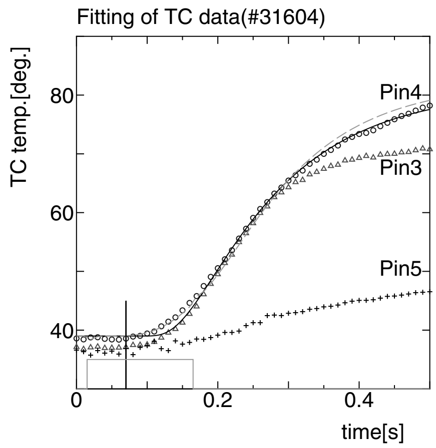

Fig. 1: Fitting results of a normal discharge.

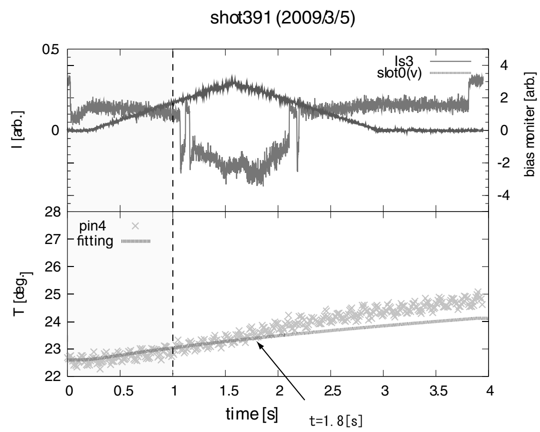

Fig. 2: Fitting results of a long discharge.

1) K.Nagaoka et al.: Plasma Fusion Res.**2**, S1092 (2007).

2) H.Matsuura et al.: Plasma Fusion Res.**5**, S1045 (2010).