§26. Development of the Realtime Monitoring Method for the Divertor Heat Load

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In order to deal with the change of plasma heat flux, time dependent heat flux is modeled as the summation of step-like heat flux with both positive and negative amplitude. ($q(t) \sim \sum_{i=1}^{n_p} q_0 C_i H(t-t_i)$, where $H(t)$ is Heaviside's step function.). The size of each step C_i is determined so as that the summation of their temperature response reproduces the observed temperature variation data.($T(t) - T_0 \sim \sum_{i=1}^{n_p} C_i S_i(t)$, where T_0 is base temperature before plasma irradiation.) For the response function $S_i(t)$, the simplest analytical formula is applied.[1)]

The rest task to determine heat flux is determine of n_p coefficients $C_i (i = 1, \ldots, n_p)$ by using n_s TC data($T_j = T(t_j) - T_0, j = 1, \ldots, n_s$). We consider the casualties of the heat conduction problem and develop a new iterative optimization method to determine each component step-like flux amplitude. At first, it is assigned that $n_p = n_s$. This means that step like heat fluxes reach at each timing of TC data. Second, the coefficient C_i is determined so as that the residual $T_i - F_{i-1}(t_i)$ can be approximated as $C_i S_i(t_i)$, where

$$F_i(t) = \begin{cases} 0 & (i=1) \\ \sum_{k=1}^{i} C_k S_k(t) & (i = 2, \ldots, n_p) \end{cases} \qquad (1)$$

is temperature response with previously determined $C_1, \ldots, C_{i-1}$. Thus, C_i (that is the heat flux at $t = t_i$) is determined only with the past TC data $T_1, T_2, \ldots, T_i$. So this procedure ensures the rule of causality. This procedure is, however, a little stiff and small fluctuation of TC data might induce unrealistic behaivor of estimated heat flux. So we introduce the smoothing parameter M and define

$$D_i = \sum_{j=-M+i}^{M+i} (C_i S_i(t_j) + F_{i-1}(t_j) - T_j)^2 \qquad (2)$$

with the summation only over $j = -M+i, \ldots, i, \ldots, M+i$. By setting $\frac{\partial D_i}{\partial C_i} = 0$, C_i is determined as

$$C_i = \frac{\sum_{j=-M+i}^{M+i} S_i(t_j)(T_j - F_{i-1}(t_j))}{\sum_{j=-M+i}^{M+i} (S_i(t_j))^2} \qquad (3)$$

Figure 1 shows the effect of parameter M. Left figure is for $M = 10$ and right figure is for $M = 15$. In both cases, measured temperature evolution is well reproduced with estimated C_i and $T(t) = T_0 + \sum_{i=1}^{n_p} C_i S_i(t)$, and agrees each other in spite of the choice of M. But when smoothing parameter M is too small, estimated heat flux shows many noise or non-physical oscilation. On the other hand, detail heat flux change is lost for too large M. In the following, we choose optimum or a little small M value to see heat flux change more clearly.

This analyzing method is applied to the thermocouple(TC) data of Hybrid Directional Langmuir Probe(HDLP) used in Large Helical Device(LHD)[2)]. Plasma heat flux analysis for LHD discharges of the 14th campaign is done successfully. Figure 2 shows the change in heat flux with / without plasma detachment. Although only total heat load reduction can be seen from TC signal, deduced heat flux shows different time evolution. NBI heating pulse lasts 3 [s] (that is $t = 3.3 \sim 6.3$[s]). For Shot number 99252, plasma stay attachment condition and heat flux keeps about half of the peak value till $t = 6$[s]. For Shot number 99252, plasma detachment occurs at $t = 4.3$[s]. Heat flux at divertor leg starts decreasing at this timing and reaches zero level before NBI pulse end.

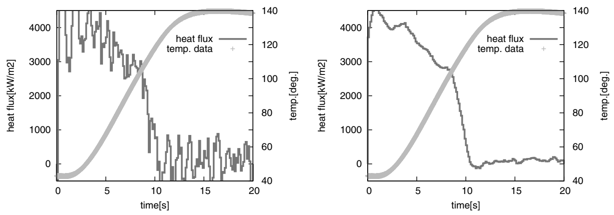

Fig. 1: Effect of smothing parameter M. Left figure is for $M = 10$. Right figure is for $M = 15$.

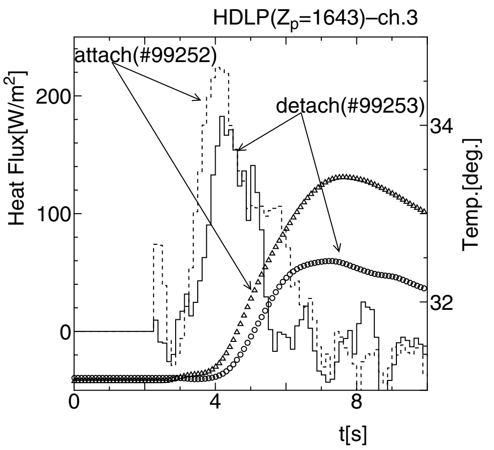

Fig. 2: Heat flux in the detachment experiment. (attach: #99252, detach: #99253)

1) H.Matsuura *et al.*, Ann. Rep. NIFS, Apr.2010-Mar.2011(2011)48.

2) K.Nagaoka et al., Rev. Sci. Instr., 79, 10E523 (2008).