§23. Development of the Real Time Monitoring Method for the Divertor Heat Load

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The concept of thermal probe method has been proposed in the reactive plasma and divertor plasma[1, 2, 3]. Heat flux received by thermal probes is determined as the solution of the inverse-heat conduction problem in their probe tips. In case of discharge plasma with the longer duration than heat diffusion time of the probe tip, steady state heat balance relation can be applied to obtain the solution[2]. On the other hand, for sufficiently short heat pulse, temperature increment is approximated with the analytical response to delta function like heat load[3]. There exists, however, no applicable method to the plasma discharge with the same order characteristic time as the heat diffusion time.

In present analysis, as shown in Fig.1, plasma heat flux is modeled as the summation of step-like heat flux with both positive and negative amplitude($q(t) \sim \sum_{i=1}^{n_p} q_0 C_i H(t-t_i)$). The size of each step C_i is determined so as that the summation of their temperature response reproduces the observed temperature variation data($T(t) - T_\infty \sim \sum_{i=1}^{n_p} C_i S_i(t)$). The response function $S_i(t)$ is determined from heat conduction equation.

$$S_i(t) = \begin{cases} 0 & (t < t_i) \\ \frac{q_0}{\kappa}\sqrt{4\alpha(t-t_i)}\mathrm{ierfc}(\frac{x}{4\alpha(t-t_i)}) & (t > t_i) \end{cases} . \quad (1)$$

where $\mathrm{ierfc}(x) = -x\mathrm{erfc}(x) + \frac{1}{\sqrt{\pi}}\exp(-x^2)$ and the simplest analytical formula is applied. If a usual mathematical method such as singular value decomposition or Marquart method is applied to this fitting procedure, reconstructed heat flux shows unreasonable large positive and negative value. We consider the casualities of the heat conduction problem and develop a new iterative optimization method to determine each component step-like flux amplitude. By using n_s experimental data($T(t_j) - T_0 = T_j, j = 1, \ldots, n_s$), coefficients $C_i (i = 1, \ldots, n_p)$ is determined so as that $D_i = \sum_j (C_i S_i(t_j) + F_{i-1}(t_j) - T_j)^2$ becomes minimum, where the summation over j is limited only for $t_i - \Delta t < t_j < t_i + \Delta t$, and $F_i(t) = \sum_{k=1}^{i} C_k S_k(t)$. By setting $\frac{\partial D_i}{\partial C_i} = 0$,

$$C_i = \sum_j S_i(t_j)(T_j - F_{i-1}(t_j)) / \sum_j (S_i(t_j))^2 \quad (2)$$

This analyzing method is applied to the thermocouple(TC) data of Hybrid Directional Langmuir Probe(HDLP) used in Large Helical Device(LHD)[4]. Four probe tips of HDLP with 6mm (two), 2mm, and 1mm in diameter and 25mm in length is made of carbon. TC is connected on the opposite side of plasma irradiation surface. Figure 2 shows the HDLP TC data of the calibration experiment with Nd:YAG laser and analysed results with the present model. YAG laser is irradiated for 2 s and TC data shows small fluctuation, which might produce unreasonable solution with conventional analyzing models. By using present modeling, however, reasonable heat flux variation could be reproduced. Of course, if analytical TC data with no noise is analysed, more sharp pulse can be reproduced. Plasma heat flux analysis for many discharges is also done successfully.

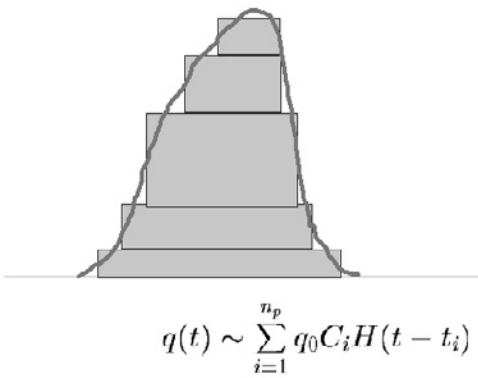

Fig. 1: Basic concept of present step model.

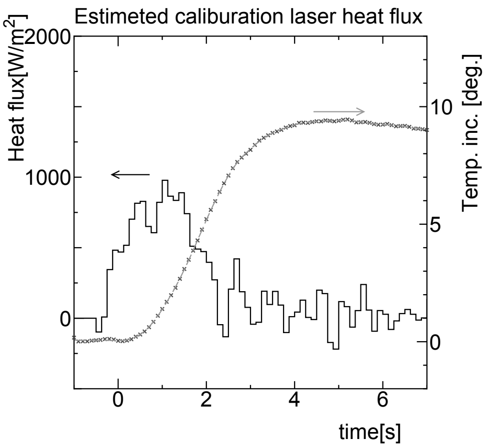

Fig. 2: Estimated heat flux in the laser calibration experiment.

1) E.Stamate et al., Appl. Phys. Lett., 80, 3066 (2002).

2) H.Matsuura and T. Jida, Conrtib. Plasma Phys., 46, 406 (2006).

3) H.Matsuura et al., Plasma Fus. Res., 5, S1045(2010).

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