超高速熱流束測定に及ぼす熱電対回路の時間遅れの効果

Effect of time delay in thermocouple circuit on fast heat flux measurement

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Introduction: Plasma is often in non-equilibrium state and plasma facing materials receives large heat flux from plasma. Although this process is complicated, plasma heat flux measurement is proposed as a diagnostic tool [1]. Precious estimation of heat flux is important for material processing or living cells treatment, since it induces target uncontrollable heating and damage. This problem is more serious for fusion divertor plasma heat flux with fast change of ms order. We have developed the exact heat conduction model to determine it [2] and designed heat flux sensors with good time response. In this work, time delay in the thermocouple (TC) circuit was found to put limitation to detect fast heat flux change [3]. A simple mathematical procedure is proposed to model this mechanism and compensate deformed target temperature data.

Primary delay system model：

If temperature change is faster than 1 s, TC circuit must be considered as a primary delay system, which is described with the following differential equation

$$\tau\frac{dy(t)}{dt} + y(t) = \frac{1}{\kappa}u(t)$$

where $u(t)$ is the system input, that is temperature evolution, and $y(t)$ is the output, stored TC signal data. τ and κ are time delay and conversion factor of the system.

Mathematical solution of this system is

$$y(t) = y(0)e^{\frac{t}{\tau}} + e^{\frac{-t}{\tau}}\int_0^t \frac{1}{\tau}u(t')e^{\frac{t'}{\tau}}dt'$$

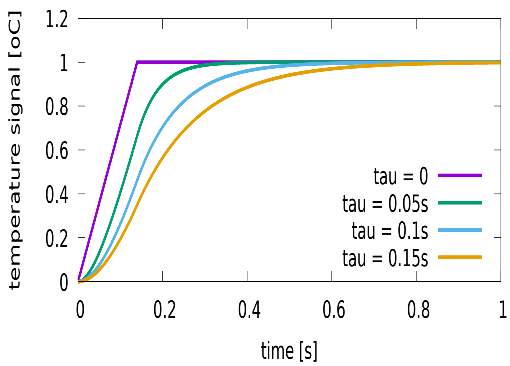

図 1: With the increment of time delay τ, signal deformation becomes more severe. Heat flux pulse duration is set as 0.14s, and simple temperature response is assumed.

If the sensor target is small and thermally insulated, Lumped-Heat-Capacity system approximation ($T \propto \int q(t)dt$) can be applied. So if heat flux is constant, temperature response is expected to be lump function of time (purple line in Fig.1). As shown in the figure, "TC signal" $y(t)$ delays to "real temperature response" $u(t)$, according to τ value. In fact, many experimental data obtained in various group heat flux sensors [4] shows similar behavior with that for large τ. Combining this time delay τ effect with our heat conduction model is under way. It would help us to determine τ value experimentally for each heat flux sensors.

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References：[1] H.Kersten, et al.: J. Appl. Phys. 87 (2000) 3637. [2] 松浦寛人他; 第 71 回応用物理学会学術講演会 31a-ZJ-1(2011). [3] H.Matsuura, et al., PSI24, TP3-080(H) (2021). [4] H.Matsuura, et al.,IEEE Trans.Plasma Sci. 47, 3026-3030 (2019).