§15. Conditional Averaging Technique Applied for Reconstructing Thomson Scattering Data during Modulated Electron Cyclotron Resonance Heating

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Modulation electron cyclotron resonance heating (MECH) is a useful tool for observing the plasma heat transport, because the deposition can be localized, the deposition profile can be calculated relatively easily, and the modulation power and frequency can be precisely tuned. By observing the response to the MECH, a variety of modern physical issues have been investigated. In order to diagnose the fast response of the electron temperature to the MECH, the electron cyclotron emission (ECE) measurement is routinely used. However, the use can be restricted in a range of experimental conditions such as the electron density and the magnetic field. An alternative way to diagnose the electron temperature profile with a high temporal resolution is desired. A possible alternative can be the Thomson scattering system, but the temporal resolution of the Thomson scattering system is far poorer than that of the ECE measurement in general. Here, we propose a new method to reconstruct the time evolution of Thomson scattering data with a high temporal resolution during a MECH phase applying the sampling scope concept[1)].

The Thomson scattering data is reconstructed using the conditional averaging technique. If one takes the MECH frequency f_{MECH} and the Thomson laser repetition frequency f_{TS} as numbers that are not in the multiple relations, the Thomson scattering system diagnoses various phases in the MECH period as time passes. By taking the measured electron temperature as a function of the measured phase, the time sequence within one period of the MECH can be reconstructed. The time period that is needed to complete a revolution of the measurement phase is given as $T = [\mathrm{G.C.D.}(f_{\mathrm{MECH}}, f_{\mathrm{TS}})]^{-1}$ s, where G.C.D. is the greatest common divisor for frequencies given by integers. As a result, one period of the perturbation is reconstructed with $N \equiv Tf_{\mathrm{TS}}$ points. Note that the number N takes a larger value if one chooses f_{MECH} and f_{TS} as coprime numbers than in the other case. Therefore, the equivalent sampling rate of the reconstructed signal is given as $Nf_{\mathrm{MECH}} = f_{\mathrm{MECH}} f_{\mathrm{TS}}[\mathrm{G.C.D.}(f_{\mathrm{MECH}}, f_{\mathrm{TS}})]^{-1}$ Hz.

Now the method is applied to an LHD discharge, which have a low line averaged density of $\langle n_e \rangle \sim 0.4 \times 10^{19}$ m^{-3} and a high ECH power of $P_{\mathrm{ECH}} = 3$ MW. In this case, the discharge is subject to the non-thermal electrons that provide a serious error to the evaluated temperature. The vacuum magnetic axis position and the magnetic field strength is $R_{\mathrm{ax}} = 3.53$ m and $B_{\mathrm{ax}} = 2.8$ T, respectively. The plasma is sustained with two neutral beams whose total power is $P_{\mathrm{NB}} = 5$ MW, and $P_{\mathrm{ECH}} = 2.3$ MW of the MECH with the frequency of $f_{\mathrm{MECH}} = 19$ Hz is applied. Since $f_{\mathrm{TS}} = 30$ Hz, f_{MECH} and f_{TS} are coprime so that $T = 1$ s and $N = f_{\mathrm{TS}} = 30$. The equivalent sampling rate for one revolution is $Nf_{\mathrm{MECH}} = 570$ Hz, which is 19 times larger than the original Thomson laser repetition frequency. Figure 1 shows the reconstructed Thomson signals at $r_{\mathrm{eff}}/a_{99} \sim 0$ ($-0.05 < r_{\mathrm{eff}}/a_{99} < 0.05$) and $r_{\mathrm{eff}}/a_{99} \sim 0.45$ ($-0.4 < r_{\mathrm{eff}}/a_{99} < 0.5$). Data points outside the center period of the MECH ($|\Delta t| > 26.3$ ms) are repeats of the reconstructed data points in the center period ($|\Delta t| < 26.3$ ms). The points are homogeneously distributed in the center period of the MECH. Comparing two reconstructed signals at the core and the mid-radius, the difference in the waveform is clearly seen. At the plasma core, a rapid response of the electron temperature to the MECH is seen, whereas the response is relatively slow at the mid-radius. In addition, the phase difference between them can also be detected. The reconstructed data set is subject to the Fourier analysis, from which the heat pulse transport can be discussed.

In summary, the time evolution of Thomson scattering data is reconstructed with a high temporal resolution during a MECH phase. The reconstructed data set is subject to the heat pulse propagation analysis.

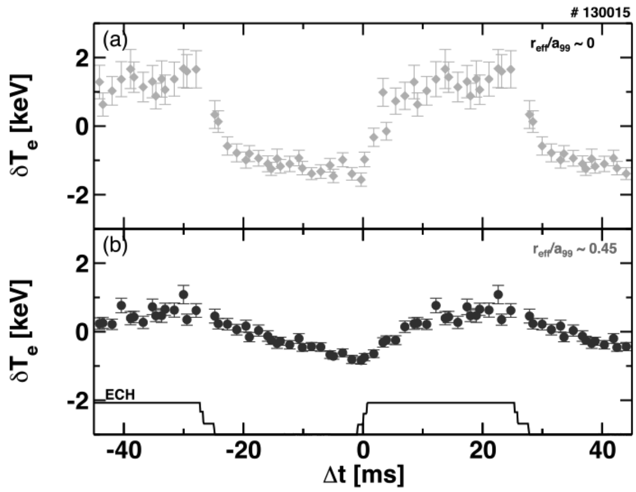

Fig. 1. Time evolutions of the conditional averaged electron temperature measured with the Thomson scattering system at (a) $r_{\mathrm{eff}}/a_{99} \sim 0$ and at (b) $r_{\mathrm{eff}}/a_{99} \sim 0.45$. The Thomson scattering signals are spatially averaged using 5 or 6 points.

1) Kobayashi T, et al.: Rev. Sci. Instrum. **87** (2016) 043505.