Improvement of electron temperature and density evaluation in the 20 kHz Thomson scattering diagnostics on LHD

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Introduction

Operation with a high-repetition-rate Nd:YAG laser started in the recent diagnostics of Thomson scattering system on the Large Helical Device (LHD) [1, 2] in order to study fast changes of electron temperature, T_e, and electron density, n_e, profiles. This laser works in two modes of the repetition rate, one of which is 1 kHz with 30 pulses and the other is 20 kHz with 100 pulses. In the 20 kHz operation, it is possible to measure T_e and n_e with the time interval of 50 μs. This time resolution is suitable for the pellet injection experiments on LHD. In the usulal pellet injection case, since n_e is quite high, the S/N (signal to noise) ratio is sufficiently high enough to evaluate T_e and n_e. However, the temporal change of T_e and n_e in such short time is usually small except for the case of pellet injection. Therefore, more precise evaluation of T_e and n_e is required for this diagnostics.

The data acquisition in such short time interval of 50 μs is made by the multi-channel fast digitizers of the switched-capacitor type, TechnoAP APV85G32L, which has 32 channels in one digitizer board and acquires data with 1 GS/s. The data by this digitizer requires some calibrations and some of large noises can be removed, however, it is difficult to remove some small noises which are caused by the digitizer, especially when they exist near the signal. Figure 1 shows an example of the data of Thomson scattering (green). In order for evaluating the signal intensity, time integration of the signals is needed. The two blue dotted vertical lines show the region of the time integration. The background noises which are caused by the fluctuation of the light from the plasma or the reflection from the wall are observed. Moreover, a spike which is generated by the digitizer is found in the region of the time integration. When the time integration is made simply by summation, this noise component is included in the integration. Then, the errors of the evaluated T_e

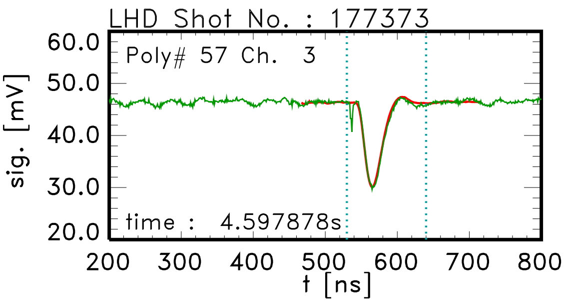

Figure 1: *An example of Thomson scattered signals (green) on LHD and approximation by the "model fitting" method (red).*

and n_e become large. Therefore, some approximation methods of the signals are needed. One method is fitting by a function which represents a Gaussian shape and temporal delay due to the low pass characteristics of the amplifier [3]. However, since the most signals of the LHD Thomson scattering show an overshoot after the main signal, the above function cannot completely reproduce the signals. Then, as one of approximation methods, the "model fitting" method is proposed and it is applied for the data from the central region of the LHD plasmas [4]. This approximation by the "model fitting" is also shown in Fig. 1 with the red curve.

In this study, it is intended to apply "model fitting" in the whole region of the plasmas by making the model signals form the all channels used in the measurement. Improvement of the error and the scattering of the data in T_e and n_e profiles using this method is expected.

Experimental setup

Two types of the digitizers for the data acquisition exist in the Thomson scattering diagnostics system on LHD. One is a charge-integration type digitizers and signals from 144 polychromators are acquired by them. The other is the fast digitizers which acquire the time developing signals with their waveforms. Almost half number of the polychromators are connected to the digitizers of this type and the data in this study are obtained by this. One digitizer board includes four DRS4 chips, which are domino-ring type detectors. The data obtained by them requires some calibrations, one of which is the peak calibration which corrects large spikes at the same timings among 8 channels of the DRS4 chip.

The high-repetition rate laser was developed by the collaboration of NIFS and University of Wisconsin-Madison. This laser works in the "pulse-burst" operation [5]. The repetition rate and the number of pulses are as follows: (1) 1 kHz, 30 pulses and (2) 20 kHz, 100 pulses.

Application of "model fitting" method

In this section, the approximation method of "model fitting" is explained and applied for a polychromator. In this method, an ideal signal shape is derived by averaging of many signals from the same laser and in the same channel assuming that the signal shape doesn't depend on the intensity. At first, the background level is precisely evaluated from just before the signal timing. The stray light components appear in only 2 channels among the whole signals and they are subtracted. Figure 2 shows the process of "model fitting" method for five spectral channels in one polychromator. The figures in the first row of Fig. 2 show an example of one signal in each channel. Overlapping of many signals is shown in the 2nd row. Among them, some small signals are removed and the signals which are used in averaging are shown in the 3rd row. In the 4th row, the signals are normalized but there are some jitters of a few nano-seconds. The timing is determined by averaging the two timings where the signal crosses the horizontal blue line in the figures of the 4th row. The signals are re-arranged to compensate the jitters in the 5th row. The model signal of "model fitting" method is derived by averaging of them (red curve). In the 6th row, signals are well fitted by the model signals (red curve). As an example, when the integration is made for the model signal, a small noise component in the channel 1 is excluded from the time integration.

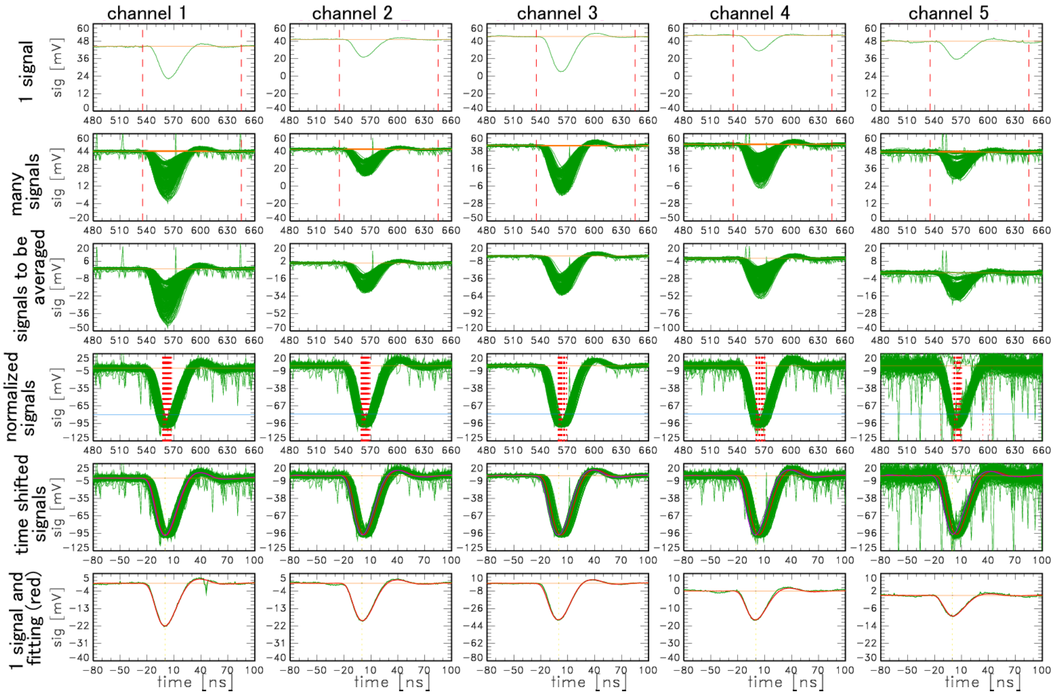

Figure 2: *The cell-size calibration, is needed in order to compensate for the amplitude differences in the capacitors. The process of "model fitting" method for five spectral channels in one polychromator. 1st row : an example of one signal, 2nd row: overlapping of many signals, 3rd row: signals to be used in averaging, 4th row: normalized signals, 5th row: re-arranged signals to compensate the jitters. The model signal of "model fitting" method is derived by averaging of them (red curve). 6th row: a signal is well fitted by the model signals (red curve).*

Results of electron temperature and density profiles

Figure 3 shows the results of T_e (red) and n_e (blue) profiles in the 20 kHz laser operation case, where the time integration methods are compared. The results by the integration by "simple summation" are shown in Fig 3.(a) and (c). In Fig 3.(b) and (d), the results by the "model fitting" method are shown. The timing of Fig. 3(a) and (b) is $t = 5.09936$ s and that of Fig. 3(b) and (d) is $t = 5.09996$ s. This plasma was an ECH plasma and a pellet was injected into this plasma, where the averaged electron density before the pellet injection was about 2×10^{19} m^{-3}.

The magnitude of errors and the scattering of the T_e data in the spatial profiles become small in the case of the "model fitting" method. The n_e values are in a.u. since temporary density calibration data are used here. The change in the n_e profiles is not large since n_e is mainly depend on the total intensity of the all spectral channels.

Although "model fitting" is applied for many channels, it cannot be used in some channels. For example, the "model signals" cannot be made in the 5th spectral channel in the region of $R > 4.2$ m since the signals are small due to low T_e in the peripheral region.

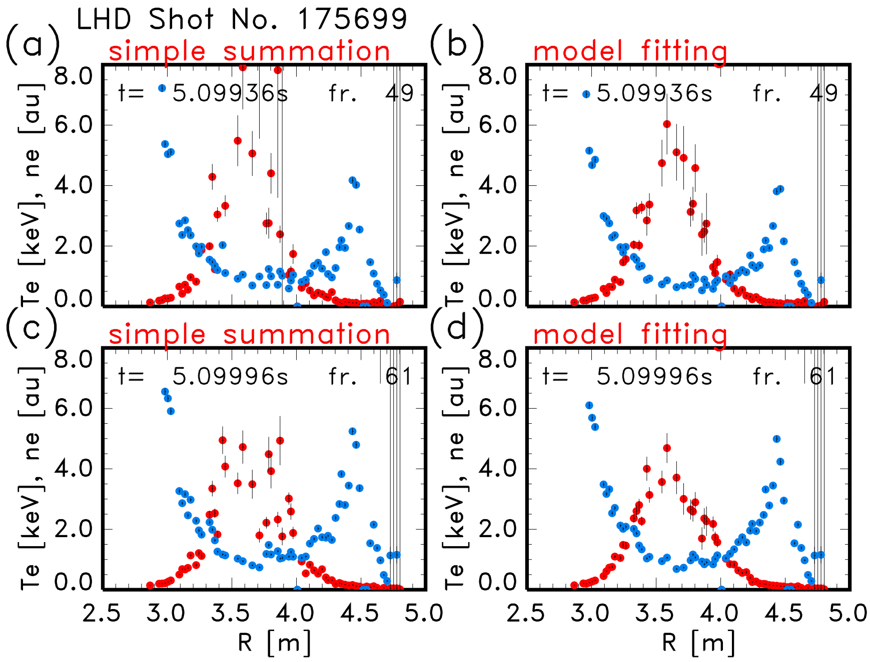

Figure 3: *The results of* T_e *(red) and* n_e *(blue) profiles, where the time integration methods are compared.* *(a)* $t = 5.09936$ *s, "simple summation", (b)* $t = 5.09936$ *s, "model fitting"* *(c)* $t = 5.09996$ *s, "simple summation" (d)* $t = 5.09996$ *s, "model fitting".*

Summary

In order to evaluate T_e and n_e precisely, the "model fitting" method is applied for the data by the Thomson scattering diagnostics with the high repetition rate laser on LHD. The application of this method is extended for the whole spatial region of the plasma. However, some channels are still integrated by "simple summation". The fitting by this method is successful and small noises near the signals are excluded from the time integration. The magnitude of errors and the scattering of the data in T_e and n_e profiles become small in the wide region of the plasmas.

Acknowledgement

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References

[1] K. Narihara, *et al.*, Rev. Sci. Instrum. **72**, 1122 (2001)

[2] I. Yamada, *et al.*, Fusion Sci. Tech. **58**, 345 (2010)

[3] B. Kurzan, *et al.*, Plasma Phys. Control. Fusion **46**, 299 (2004)

[4] H. Funaba, *et al.*, *Plsma Fusion Res.*, **17** (2022) 2402032.

[5] D.J. Den Hartog, *et al.*, Rev. Sci. Instrum. **81**, (2010) 10D513.