Electron temperature measurement using backward and forward Thomson scatterings in the LHD Thomson scattering system

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INTRODUCTION

The large helical device (LHD) Thomson scattering system measures electron temperature and density profiles of LHD plasmas along the LHD major radius. In the original design, an oblique backward scattering configuration with a typical scattering angle of 167-degree was adopted, and the laser pulses are simply absorbed by a beam dump after traveling through LHD plasma. [1-3] Recently we removed the beam dump and installed a beam-returning mirror, a relay lens and an optical delay path of 30 m to observe forward Thomson scatting signals as shown in Fig.1. In the forward scattering configuration, typical scattering angle is 13-degree. By combining the backward and forward scattering measurements, some applications will be possible. In this paper, extension of measurable temperature range and search of temperature anistoropy are discussed.

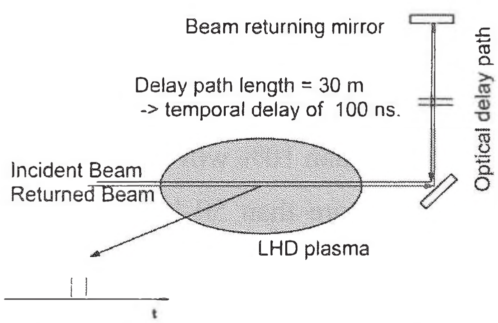

Fig. 1. Schematic diagram of the backward and forward scattering configurations.

EXTENSION OF MEAUREBALE TEMPERATURE RANGE

In the original design of the LHD Thomson scattering system, the optimized electron temperature (T_e) range was set to be T_e = 50 eV – 10 keV. In recent LHD experiments, high-T_e plasmas with the $T_e \geq 20$ keV were generated. So, extending measurable T_e range is one of

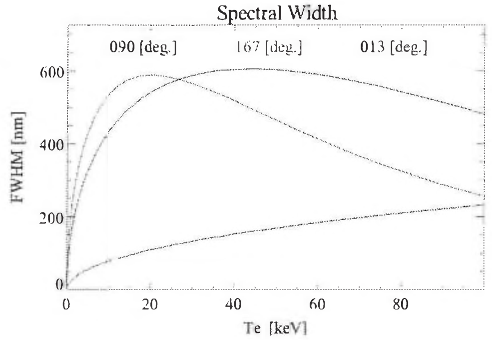

Fig. 2 a) Thomson scattering width as a function of electron temperature for the scattering angles of 90-, 167- and 13-degree.

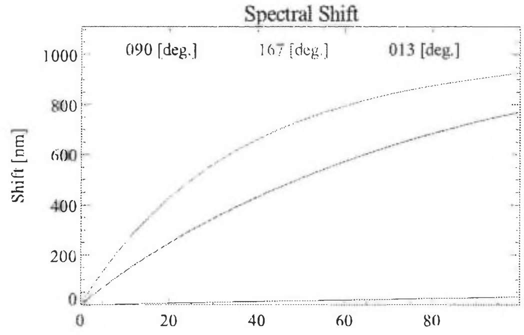

Fig. 2 b) Wavelength shift at which the Thomson scattering spectrum reaches maximum for the scattering angles of 90-, 167- and 13-degree.

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the important issues in the LHD Thomson scattering system. Figures 2 a) and b) show the spectral width and the relativistic peak position shift as a function of electron temperature respectively for 90-, 167- and 13-degree scattering configurations. The two Thomson scattering spectrum are quite different. By using the differences of the Thomson scattering spectrum of the backward and forward scatterings, measurable T_e range will be extended without any modification of light collection optics and polychromators because. The experimental T_e error estimated by using mock data is shown in Fig. 3. In the backward scattering configuration, the T_e error is less than 10 % at $T_e \leq 10$ keV. However, it rapidly increases above 3 keV and exceeds 10 % at $T_e \geq 10$ keV. On contrast, the T_e error in forward scattering measurement is larger then 10 % at $T_e \leq 1$ keV, and becomes smaller above 1 keV. So, the electron temperature range where the T_e error is less than 10% will be extended as T_e = 1 eV – more than 50 keV by using the two scattering configurations complementarily.

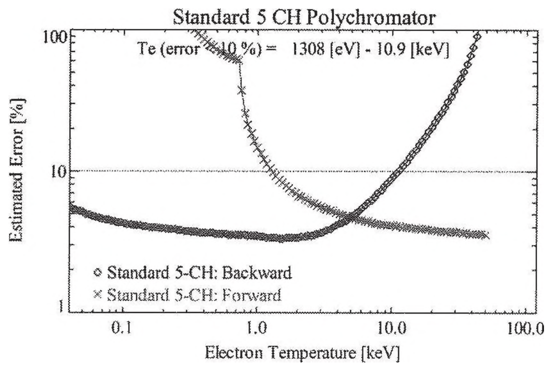

Fig.3. Estimated experimental error in T_e for the backward and forward scattering configurations.

SEARCH OF ELECTRON TEMPERATURE ANISTOROPY

In general, the electron velocity along the vector difference of the incident laser direction and observation direction is observed in Thomson scattering measurements. Following the principle, the temperature component is nearly parallel to the incident laser beam direction in the backward scattering measurement and that is almost perpendicular to the incident laser beam in the backward scattering measurement as shown in Fig. 4. By using the feature, we can search electron temperature anisotropy in high-temperature fusion plasmas. [4-5]

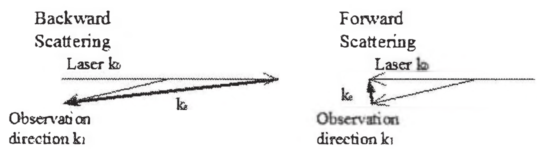

Fig. 4. Temperature component directions obtained from the backward and forward scattering configurations.

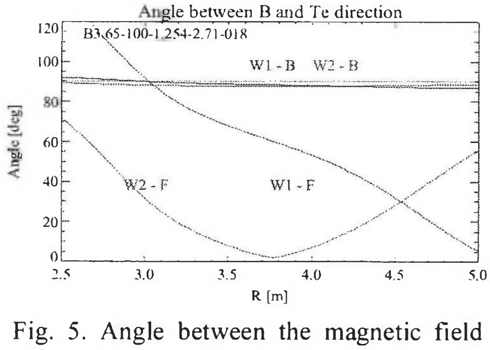

Fig. 5. Angle between the magnetic field line and observed temperature direction as a function of the LHD major radius.

The LHD Thomson scattering system has two observation windows, W1 and W2, on the LHD. Then, total four electron temperature components can be measured. Figure 5 shows the angle between the magnetic field line and observed temperature direction as a function of the measurement point along the LHD major radius. In the backward scattering measurement, the angles between the magnetic field line and measured temperature direction are about 90-degree for both W1 and W2, in the whole observation region. On the other hand, the angles are about 0-degree at R = 4.6 m and 5 m for the forward scattering measurements using the W1 and W2, respectively. Forward scattering measurements using the W1 and W2 are suitable for the observation of the component parallel to the magnetic field line near the plasma edge and center regions, respectively.

FIRST RESULTS OF FORWARD SCATTERING MEASUREMENTS IN LHD

In the 2012 LHD experiment campaign, the forward scattering signals were been clearly observed as well as the backward scattering signals as shown in Fig. 6. The preceding and trailing pulses are backward and forward Thomson scattering signals respectively. The rectangle pulse shows an ADC gate pulse. The temporal difference between the backward and forward scatterings is ~100 nsec, which is caused by the optical delay path of ~30 m as shown in Fig. 1.

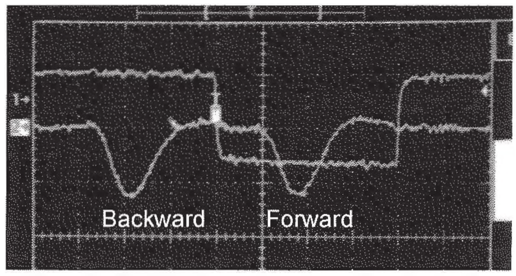

Fig. 6. Thomson scattering signals and ADC gate pulse. The preceding and trailing pulses are the backward and forward scattering signals respectively.

A comparison of electron temperatures obtained from the backward and forward scattering measurements in a plasma discharge is shown in Fig. 7 a). In this case, they show good agreements from the beginning of the discharge to the end. Figure 7 b) shows a

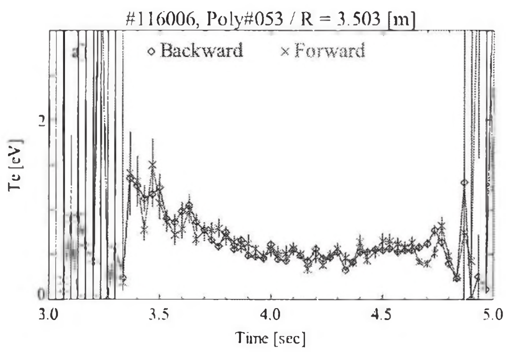

Fig. 7 a) Comparison of T_es obtained from the backward and forward scattering measurements in a plasma discharge.

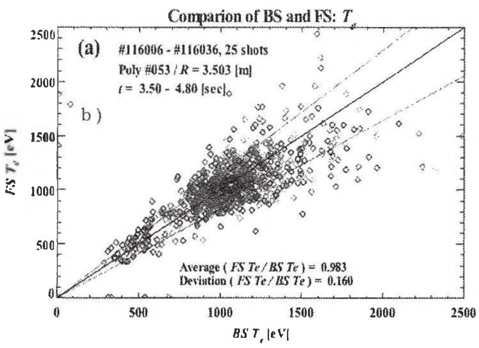

Fig. 7 b) Summary of comparisons of T_es obtained from the backward and forward scattering measurements.

summary of comparisons of electron temperatures for 30 plasma discharges. The data show good agreements within the standard deviation of 16 %.

SUMMARY

The LHD Thomson scattering system has been upgraded as a multipass Thomson scattering system with the aims of extension of measurable temperature range and study of electron temperature isotropy in fusion plasmas. The first results were successfully obtained in the 2012 LHD experiment campaign. Further improvements, such as development of 10 wavelength polychromator, are now in progress.

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