§2. Coaxial Laser Beam Combine for LHD TS System

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Thomson scattering (TS) diagnostics is one of the most reliable methods for measuring the electron temperature (Te) and density (ne) profiles in fusion plasmas. A TS system installed in a large helical device (LHD) put into operation in 1998 has obtained a large amount of data consisting of Te and ne values from LHD experimental cycles [1]. The LHD TS system measures the Te and ne profiles of plasmas along the major radius horizontally. The system uses three commercially based Nd:YAG lasers for the probe light source, which consists of a 1.6 J laser at 30 Hz and two sets of 2 J lasers at 10 Hz. The multi-laser configuration for enhancing the scattering signal is operated by firing the three lasers simultaneously, whereas the time resolution is enhanced by using pulse trains for the three laser systems. A partially high-reflectance coated mirror is adapted to form the bundle beam emitted from the multiple lasers. The laser beams are packed along a common beam axis at a regular interval of 1 cm by the packing mirror and a partial overlap in the far field where they are focused on a common point inside the LHD vessel at the major radius of 3.65 m. However, each laser beam path out of the focus that passes through the vessel is different. The direction of a laser beam independently affects certain fluctuating parameters such as the mechanical vibration. Electron density profiles measured by each laser have different errors due to the misalignment of the beam and corrective optics. These differences make it difficult to compare ne profiles in a time series.

Minimizing the multiple-laser error requires a special arrangement of the laser optical system. One of the candidate arrangements involves combining coaxial beams using a polarizer (PL) and a Faraday rotator. This arrangement was demonstrated in the JT60 Thomson scattering system based on a ruby laser. The limitation of this system is the approximately 1-ms rise time of optical switching. This is a problem for sub-millisecond time-resolved measurements in burst-mode laser operation. The MAST group overcomes this disadvantage by use of a Pockels cell (PC) instead of a Faraday rotator. A PC can switch the polarization by with a rise time of 10 ns.

In this report we present the two-beam combining system that uses a PL. This scheme employs a PL with a high laser-damage threshold to combine each pair of orthogonally polarized laser beams. There is no limitation of time resolution in this method. The LHD TS system adopts an oblique backscattering configuration. The TS of light into collective optics is not sensitive to the polarization of a probe laser beam. Orthogonally polarized coaxial laser beams can be used in the LHD TS system.

Two laser beams enter the beam combiner with horizontal polarization. The horizontal polarization of the laser pulse from laser 2 (Input 2) is rotated to the vertical polarization by using a Half-wave plate (QR) for reflection at the PL. In contrast, the polarization state of input 1 from laser 1 is horizontal at the PL. Thus, input 1 passes though the PL. After the PL reflects the beam from laser 2, the transmitted beam from laser 1 propagates in a manner that is coaxial to the LHD plasma [2].

Figure 1 shows normalized ne profiles measured by the coaxial lasers 1 and 2 and the off-axial laser 3, which uses a packed mirror for beam bundling. These ne profiles are calibrated by the Rayleigh scattering method. The line integrated electron density measured by TS is in good agreement with that measured by the millimeter (MM)-wave interferometer within 10%. The electron temperature is 2 keV at the center of the plasma. There is no variation in the electron temperature in the time range shown in Fig. 3. This figure shows good agreement between the ne profiles measured by lasers 1 and 2. In contrast, the ne profile measured by laser 3 is different from that measured by the coaxial lasers.

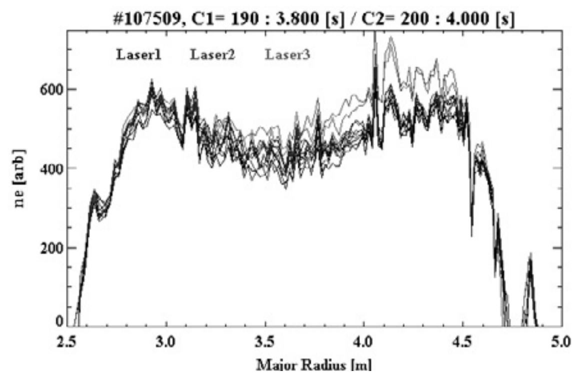

Fig. 1. Normalized ne profiles measured by coaxial lasers 1 and 2 and off-axial laser 3.

A polarization-based method of combining beams from multiple lasers is developed to improve the time resolution and accuracy of the LHD TS system. Two or more beams from different apertures of the laser heads are combined into a coaxial beam line in a time series by the optical components of this beam-combining scheme. We implemented this type of beam-combining method in the LHD TS system in the 15th experimental campaign and confirmed the advantages offered by this beam-combining system. The obtained asymmetry and symmetry profiles are qualitatively consistent with the results of the previous work. Furthermore, we proposed a method of combining three or more laser beams by using PCs with thermal birefringence compensation.

[1]. K. Narihara, I. Yamada, H. Hayashi, K. Yamauchi. Rev. Sci. Instrum. 72 (2001) 1122.

[2]. R. Yasuhara, I. Yamada, K. Narihara, H. Funaba, H. Hayashi. Plasma and Fusion Research 7 (2012) 2402030.