Coaxial Multiple Laser Beam Combiner for the LHD Thomson Scattering System*)

Ryo YASUHARA, Ichihiro YAMADA, Kazumichi NARIHARA, Hisamichi FUNABA and Hiroshi HAYASHI

National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

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We developed a polarization-based beam-combining method for multiple lasers to improve the time resolution and accuracy of a large helical device (LHD) Thomson scattering system. We combined two or more beams from different apertures of the laser heads in series into a coaxial beam line with the use of polarization optics. We have implemented this beam-combining method in an LHD Thomson scattering system from the 15th experimental campaign. We also propose a method of combining three or more laser beams by the use of a Pockels cell.

Keywords: Thomson scattering, multi-laser configuration, beam combining

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1. Introduction

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. Thomson scattered light is collected with a large (1.5 m × 1.8 m) spherical mirror and analyzed by polychromators with five wavelength channels. 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 developed in DIII-D [2] 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 LHD 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 electron density 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 [3]. 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 [4]. A PC can switch the polarization by with a rise time of 10 ns.

In this paper, 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. In addition, we also mention future plans for realizing a three-beam combining method by using a PC.

2. Polarization-based Method of Combining Laser Beams

A schematic diagram of the new beam-combing method of a polarization-based system is shown in Fig. 1. Both lasers 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.

author's e-mail: yasuhara@nifs.ac.jp

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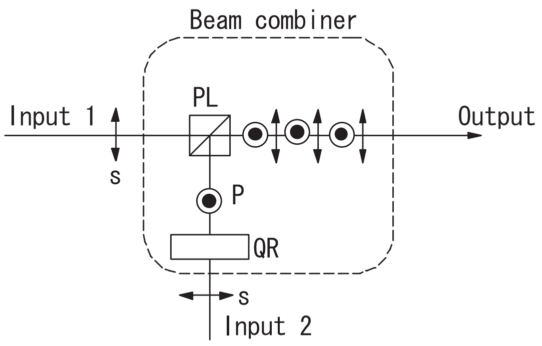

Fig. 1 Schematic diagram of polarization-based beam-combining method. PL: polarizer, QR: Half-wave plate.

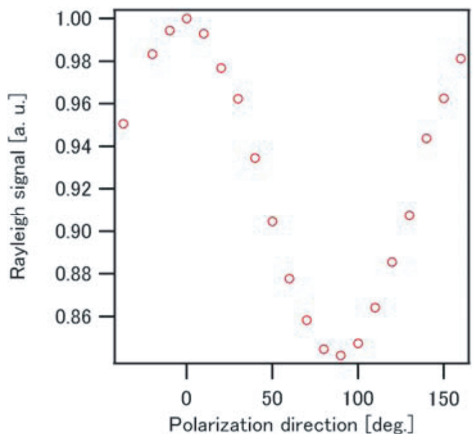

Fig. 2 Sensitivity of Rayleigh scattering signals to polarization direction.

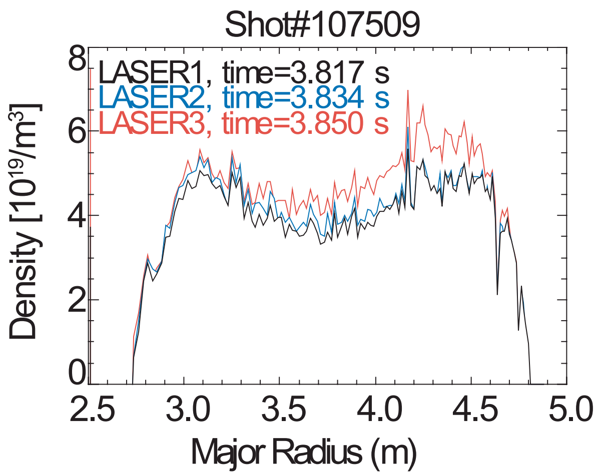

Fig. 3 Normalized ne profiles measured by coaxial lasers 1 and 2 and off-axial laser 3.

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. A polarization beam splitter (PBS) by Showa Optronics Co., Ltd. is adopted as the PL in our system. This PBS has a high laser damage threshold and good transmittance of the Nd:YAG laser pulse.

3. Experimental Results

The orthogonally polarized coaxial laser beam can be used in the LHD TS system owing to an oblique backscattering configuration. To evaluate the effect of polarization on the TS signal, the Rayleigh scattering signal was measured as a function of the polarization angle near the laser amplifier (before transportation to the LHD vacuum vessel). A TS signal shows the same behavior as a Rayleigh scattering signal for the polarization of the probe laser beam. We can assume the response of the TS signal from LHD plasma by this measurement. Figure 2 shows a Rayleigh signal as a function of the polarization direction at the laser output. At the polarization direction of 90°, the Rayleigh scattering signal is reduced to 85% of the maximum value at 0°. This loss can be tolerated for the benefit of the coaxial beam line of the two lasers.

In the 15th experimental campaign of the LHD, we implemented this beam-combining method in the LHD TS system. Figure 3 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. The corresponding asymmetry profile is qualitatively consistent with the result of the previous work [5]. This shows that the coaxial beam-combining method that uses TS is effective for reliable ne profile measurements.

4. Three-beam Combining Method

Presently, the LHD TS system has three lasers. A PC is needed to combine three coaxial beams as shown in Fig. 4. Beyond the PL, the polarization of a reflected laser pulse from input 2 is switched to horizontal polarization by the PC. Horizontally polarized coaxial laser pulses from two lasers are transmitted to the second PL. A vertically polarized laser pulse from laser 3 is reflected by the second PL. Therefore, three beams are combined coaxially after the second PL. This beam-combining system is scalable for three or more sets of lasers. Figure 5 shows an example of a multiple coaxial laser system that makes use of this beam-combining method. One problem with this multi-laser system is the thermally induced birefringence

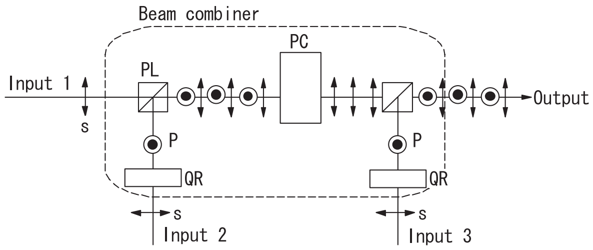

Fig. 4 Schematic diagram of polarization-based three-beam combining system using a PC.

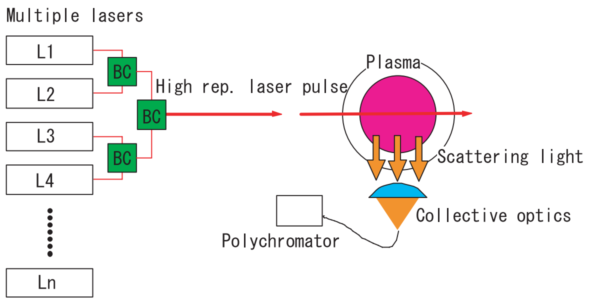

Fig. 5 Example of a multiple coaxial laser system using the polarization-based beam-combining system.

in the EO crystal of PC due to the absorption of laser light at the average laser power of 100 W. To avoid this problem, a compensation technique for thermal birefringence that uses two pieces of EO crystal and a 90° polarization rotator should be employed [6]. This makes it possible to operate the laser at an average power of 1 kW at a PC. Thus, 20 sets of a 1.6 J × 30 Hz laser (average power of 960 W) can be combined by this scheme.

5. Summary

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.

Acknowledgments

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