First Results of Electron Temperature Measurements with a Multi-Pass Thomson Scattering System in the Tandem Mirror GAMMA 10

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A multi-pass Thomson scattering (TS) system has the advantage of enhancing scattered signals. We constructed a multi-pass TS system modeled on the GAMMA 10 TS system; the new system has a polarization-based configuration with an image relaying system. For the first time, we used the new system to measure electron temperatures in the GAMMA 10 plasma. By using the multi-pass TS system with four passes, the integrated scattering signal was magnified by approximately a factor of three.

Keywords: Thomson scattering, multi-pass, polarization-controlled, tandem mirror GAMMA 10

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The Thomson scattering (TS) diagnostic is one of the most useful methods for measuring electron temperatures and radial density profiles in plasmas. For low-electron-density plasmas, such as the GAMMA 10 plasma and peripheral plasmas in fusion devices, an effective TS system must be developed [1, 2]. The GAMMA 10 TS system can measure the radial profiles of electron density and temperature in the electron-density range above 5×10^{17} m^{-3}. However, in the lower electron-density region, measurement accuracy is low. Moreover, higher time resolutions of TS measurements are required for future turbulence studies. In many devices, multi-pass TS systems have been proposed for improving the accuracy of electron temperature measurements [3–10]. At the Tokamak Experiment for Technology Oriented Research (TEXTOR), the signal-to-noise ratio has been improved by using a multi-pass TS system in which a pair of concave mirrors recycle photons [9]. In the TST-2 spherical tokamak, a confocal spherical mirror system is used [8, 10]. In the JT-60U, a double-pass system was constructed using a phase-conjugate mirror for reflection [3]. Although these approaches have increased the reliability of TS systems, they are limited by their optical systems. Each laser beam pass is different in the concave-mirror-type TS system in TEXTOR and TST-2. The scattering volume must be set near the focal point of the concave mirror, and the system must be calibrated for each beam pass. Moreover, the phase-conjugate-mirror system in JT-60U requires a high-purity laser bandwidth.

A new multi-pass TS system has been developed in the tandem mirror GAMMA 10. This multi-pass TS scheme effectively increases the scattering signal intensity from plasmas. The scheme can be implemented by modifying a basic single-pass TS system with the addition of a polarization device, a high-reflection mirror, and lenses for relaying images of the laser beam. This allows a laser pulse to be focused multiple times onto the scattering volume. In GAMMA 10, a double-pass TS system was constructed, doubling the TS signal and improving the resolution of electron temperatures [4, 6]. In the LHD, a double-pass TS system, which is the same design as the GAMMA 10 double-pass TS system, was installed and operated [5]. The configuration of the multi-pass TS system in GAMMA 10 can be used to realize perfect coaxial multi-passing on each pass. By adding a polarization control device, a polarizer, and a high-reflection mirror to the double-pass TS system, we have successfully constructed a multi-pass TS system [7].

In this paper, we present the first result from an electron temperature measurement using the new multi-pass TS system. The planed specifications for the new multi-pass Thomson scattering system are as follows: the obtained TS signal will be about three times larger than that from a single pass and the accuracy of electron temperature measurements in the multi-pass configuration will be more than twice that in the single-pass configuration.

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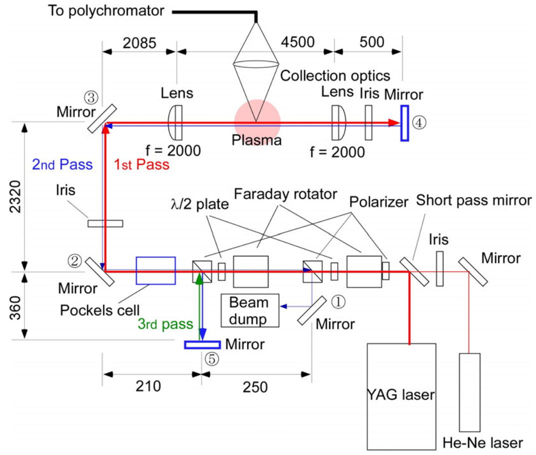

Fig. 1 Schematic of the multi-pass TS system.

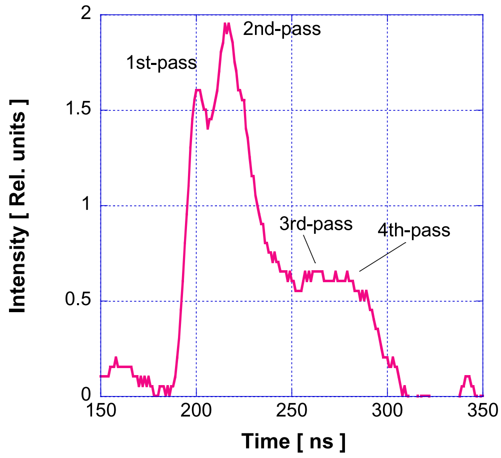

Fig. 2 Multi-pass TS signal of CH. 1.

A schematic diagram of the new multi-pass system is shown in Fig. 1. A more detailed description is given elsewhere [7]. This system is a modification of the GAMMA 10 double-pass TS system [6]. A horizontally polarized laser beam from the yttrium–aluminum–garnet (YAG) laser (Continuum, Powerlite 9010, 2 J/pulse, pulse width of 10 ns, and 10 Hz) is reflected from a short-pass mirror and then passes through two Faraday rotators for isolation, two half-wave plates, three polarizers, a Pockels cell (FastPulse, Q1059P12SG-1064), mirrors ② and ③, and irises before being focused onto the plasma center by the first convex lens (Shigmakoki, $f = 2000$ mm, $\phi = 50$ mm) at the downside port window. After interacting with the plasma, the laser beam is emitted from the upper-side port window and is collimated by the second convex lens (Shigmakoki, $f = 2000$ mm, $\phi = 50$ mm). A pair of lenses forms a key component in this optical system. These lenses maintain the quality of the laser beam during multi-pass propagation through the image-relaying optical system from the iris to the reflection mirror. The laser beam is reflected by reflection mirror ④ for the second pass and is again focused onto the plasma. The Faraday rotator and the Pockels cell are used to control polarization. The Pockels cell switches the polarization of the laser beam from horizontal to vertical for reflected passes during the gate pulse (~ 550 ns). The third laser pass is produced by a Pockels cell for polarization control and reflection mirror ⑤. The laser light is confined between reflection mirrors ④ and ⑤ for multi-pass propagation. For the TS light-collection optics, we used an Al:SiO_2-coated spherical mirror with a curvature radius of 1.2 m and a diameter of 0.6 m. The scattered light is collected and reflected by the spherical mirror, after which it reaches an optical fiber bundle with a cross section of 2×7 mm^2. The scattering angle is 90°. The 6.67-m-long optical fiber bundle is connected to a 5-channel polychromator. The fiber aperture is located at about 0.873 m from the spherical mirror. The polychromator is comprised of five relay and collection lenses, five interference filters, and five silicon avalanche photodiodes (PerkinElmer, C30659-1060-3AH, bandwidth of 50 MHz) with preamplifiers. Measured wavelengths of the polychromator are 1059 ±2 nm (CH. 1), 1055 ±2 nm (CH. 2), 1050 ±3 nm (CH. 3), 1040 ±7 nm (CH. 4), and 1020 ±14 nm (CH. 5). A four-channel high-speed oscilloscope (IWATSU, DS5524) is simultaneously used to measure four wavelength channels with a bandwidth of 200 MHz and a sampling rate of 1.0 GS/s. The measured signals are recorded by a Windows PC using the LabVIEW analyzing software. Electron temperatures are obtained by the chi–square method.

We used this system to measure electron temperatures in the GAMMA 10 plasma. Figure 2 shows the measured TS signal from the multi-pass signal of CH. 1. We can clearly identify TS signals from the first through fourth passes in the multi-pass configuration. The integrated TS signals from passes 1–4 (integration time of $\Delta t = 120$ ns) in the multi-pass configuration were about three times larger than that in the first pass ($\Delta t = 30$ ns). The electron temperatures obtained from the first pass and from passes 1–4 were about 34 ±5 eV and 28 ±2 eV, respectively. The error in the electron temperature obtained from the first pass was ±5 eV, which is more than twice that from passes 1–4 (±2 eV). The resolution of the electron temperature measurement was improved by the multi-pass TS system. We have successfully constructed a multi-pass TS scattering system and, for the first time, have obtained multi-pass TS signals for electron temperature measurements.

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