Improvement of Aperture Configuration to Reduce the Stray Light for Thomson Scattering Measurement Using a Peripheral Beam Profile Monitor

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The stray light is a major problem in Thomson scattering (TS) measurements. The main cause of stray light is unnecessary divergence of the incident laser beam and an aperture is a standard component to reduce it. In order to improve the aperture configuration (including size, number and position in the laser injection tube), a peripheral beam profile monitor, consisting of a screen with a through hole for the laser beam and a CMOS camera, was developed. Instead of the actual laser injection tube a mock-up tube was used to measure the peripheral beam profiles under various aperture configurations. The configuration with four 15 mm diameter apertures was chosen and installed on the TS system for the TST-2 spherical tokamak. The stray light was reduced to about 4% compared to the smaller diameter injection tube with no apertures. As a result, it became possible to make TS measurements in the electron density range above $1.0 \times 10^{17} \, \text{m}^{-3}$.

1. Introduction

Thomson scattering (TS) is widely used to measure spatial profiles of electron density and electron temperature. Stray light in TS measurements is light entering a detector through unexpected paths, and it has the same wavelength as the injected laser. Usually the light is blocked by an interference filter in front of the detector, but when the blocking is not perfect, it can appear as a (noise) signal which cannot be distinguished from the TS light. When the plasma density is very low, the stray light, which is mainly caused by unnecessary far wings of the incident laser beam hitting structures inside the plasma chamber, becomes the main source of noise. Note that the scattered light at optical parts can be a cause of the stray light and the far wings include such scattered light. Apertures installed in the laser injection tube are standard components to reduce this problem. However, the best configuration (such as the positions and the aperture diameters) has not been established for the TST-2 TS system [1, 2]. On TS systems on other devices, ray tracing calculations with an assumption on the beam divergence are often used to design the apertures [3–5]. In our case, the density of RF driven TST-2 plasma is much lower than typical densities on other tokamaks [6, 7]. Therefore, it is necessary to reduce the stray light as much as possible by improving the aperture configuration.

2. Aperture Testing System

In order to measure the divergent beam quantitatively, a peripheral beam profile monitor system (aperture testing system), consisting of a screen with a through hole for the laser beam and a CMOS camera, was developed. Various aperture configurations were investigated systematically. A camera was used for the DIII-D TS system to investigate the qualitative beam divergence inside the chamber [8]. In the present case, emphasis is placed on the peripheral part of the divergent beam, because that part is considered to be the main cause of stray light. Figure 1 shows the arrangement of the aperture testing system. Instead of the actual laser injection tube, a mock-up tube which can hold apertures with various diameters at five positions was used. Since the vacuum window holds the vacuum of the TST-2 main chamber, we use the mock-up tube to avoid breaking the TST-2 vacuum for a long time. The mirror can be rotated to change the direction of the laser beam axis, and the beam is injected to the mock-up tube when we test the apertures.

A white screen (400 mm × 400 mm) with a central through hole (40 mm diameter) is placed 2600 mm from the mirror, at the distance corresponding to the inboard vacuum vessel wall of TST-2. The inboard wall is considered to be the main cause of stray light, by scattering the far wings of the divergent beam. The role of apertures is to reduce the peripheral intensity that can be scattered by the inboard wall. Improvement of the configuration is

performed by measuring the peripheral beam intensity profile on the screen. The central through hole of the screen is necessary to avoid the intense region of the laser beam. A CMOS camera (FLIR, CM3-36-075) is used to measure the 2-dimensional intensity profile of the light scattered by the screen. The entire aperture testing system is covered by a black curtain to cut unnecessary light. Confirmation that the light from the laser flash lamp does not affect the measurement was obtained using a fast response photo diode (Hamamatsu, S5973-01). In order to improve the signal to noise ratio, 50 images were accumulated in the analysis. Figure 2 shows an example of the image captured by the camera. The intensity of each pixel on a concentric area is averaged to yield the radial profile of the intensity per unit area shown in Fig. 2 (d). In the calculation, the geometrical

distortion of the camera image was corrected. The sensitivity on the screen is uniform, and the radial variation of the sensitivity on the screen is less than 2%.

The mock-up tube with the inner diameter of 89.1 mm has the same dimensions and aperture positions (from A to E) as the actual laser injection tube. Aperture diameters of 10, 15, 20, 25 and 30 mm were tested. Each aperture is wedged with a thickness of 0.1 mm. The effect of the aperture is stronger when the aperture position is closer to the plasma. Therefore, apertures were added in the order from position A to position E.

3. Result of Aperture Testing

Figure 3 shows the setup of each configuration we tested. Figure 4 shows the radial profiles when we tested three aperture sizes at position A (Case #1 - #4). The intensity becomes smaller as the aperture diameter is reduced. The smallest diameter (10 mm) is the best. However, 15 mm was selected because of easier alignment on the actual system. Figure 5 shows the radial profiles for various apertures located at positions A to E (Case #5 - #10). It should be noted that the vertical scales in Figs. 4 and 5 cannot be compared directly because of different sensitivities. The intensity decreases as the number of apertures increases. Considering these results four apertures with 15 mm diameter were installed at positions A, B, C and D. When the stray light signals are summed up over 10 spatial channels and 6 wavelength channels for each spatial channel, the total signal is reduced to about 4% of that for the previous injection tube with smaller diameter and
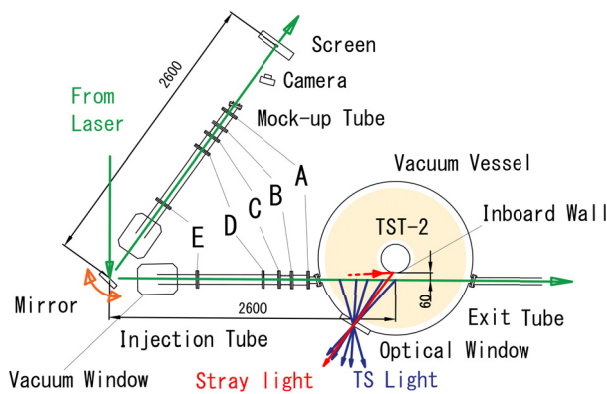
Fig. 1　Arrangement of the aperture testing system. The laser passes through the mock-up tube and the central through hole on the screen. The mirror can be rotated to change the direction of the laser beam axis.
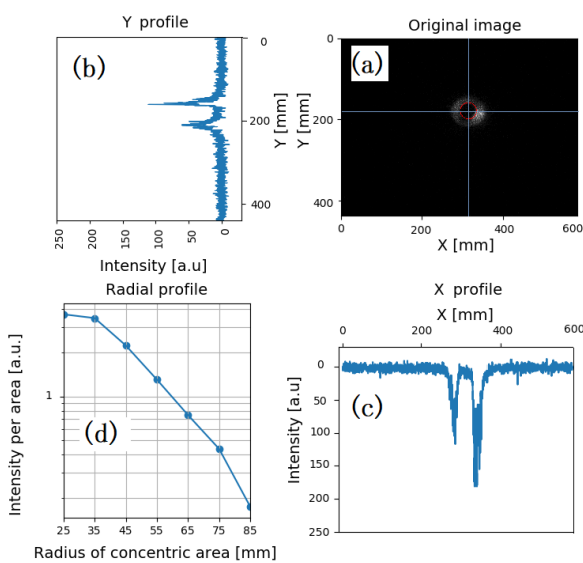
Fig. 2　(a) Example of the camera image. (b) and (c) 1-dimensional distribution through the center in the *Y* and *X* directions. (d) Radial profile.
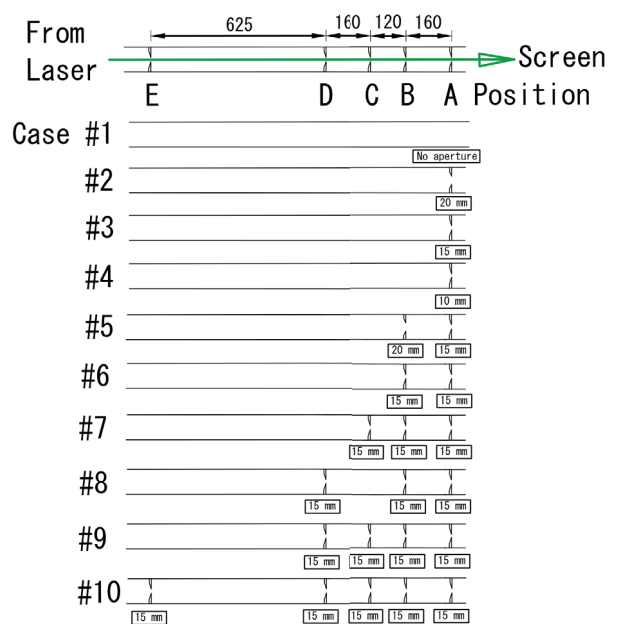
Fig. 3　The setup of each configuration. The results for Case #1 - #4 are shown in Fig. 4 and those for Case #5 - #10 are shown in Fig. 5.
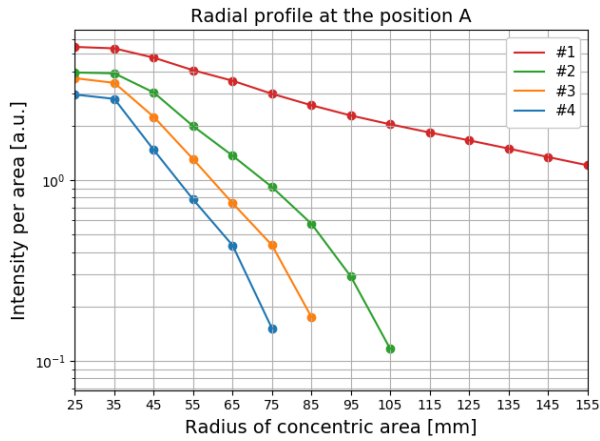
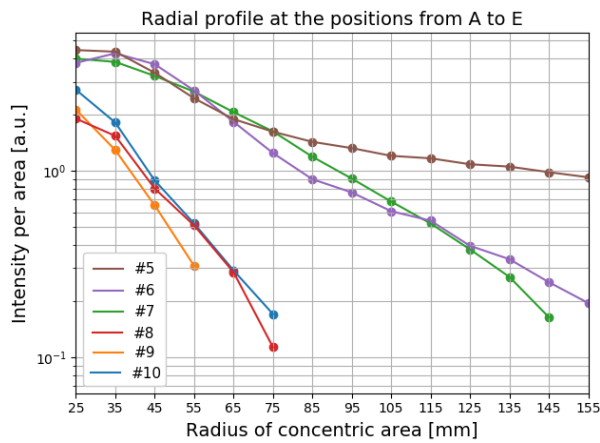Fig. 4 Radial intensity profiles for apertures with various diameters located at position A.

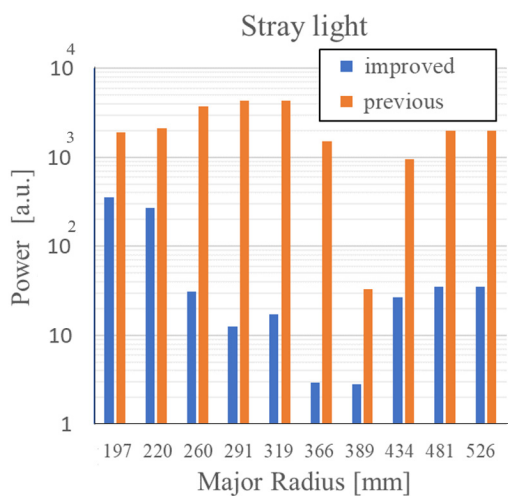Fig. 5 Radial intensity profiles for various apertures located at positions A to E.

Fig. 6 Comparison of the stray light at each spatial channel between the previous injection tube and the improved injection tube.

no aperture.

Figure 6 shows the comparison of stray light for each spatial channel between the previous injection tube and the improved injection tube (note the logarithmic scale). Note that the range of measurement positions from major radius $R = 200$ to $350\,\mathrm{mm}$ corresponds to the range where the inboard vessel wall can be seen from the center of the optical window for collecting scattered light (see Fig. 1). This range corresponds to the region of highest stray light for the previous injection tube. Thus, the apertures are quite
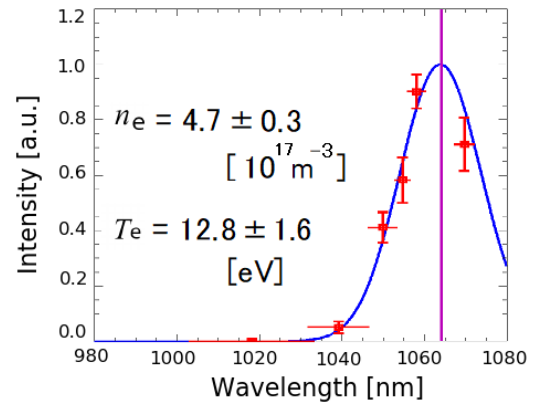

Fig. 7 Example of wavelength spectrum at $R = 260\,\mathrm{mm}$. Red crosses indicate the intensity at each wavelength channel divided by the bandwidth of the interference filter, and the blue curve indicates Gaussian fitting.
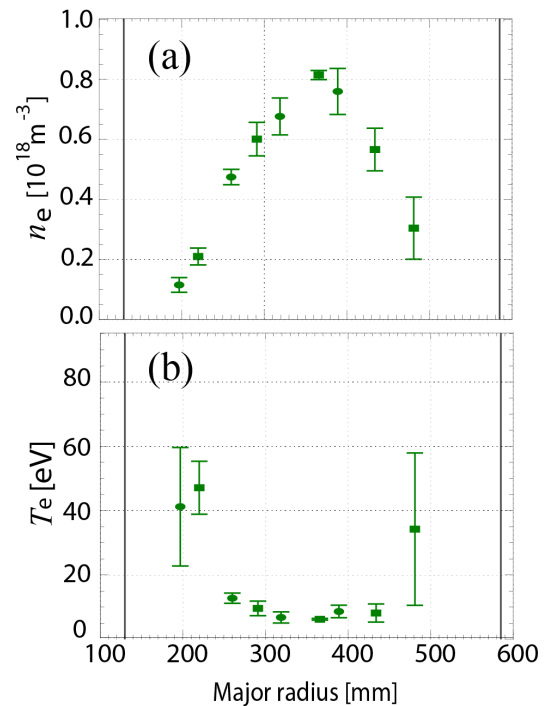

Fig. 8 Profiles of electron density (a) and electron temperature (b) measured using the improved injection tube.

effective for reducing the stray light in this range.

4. Thomson Scattering Measurement

Electron density and electron temperature profiles were measured in a typical RF driven plasma on TST-2 [9]. Figure 7 shows the wavelength spectrum measured at $R = 260$ mm. The plasma current was about 15 kA. Signals from 4 nearly identical plasma discharges (4 laser shots) were accumulated. Figure 8 shows the profiles of electron density and electron temperature measured using the improved injection tube. Electron densities above 1.0×10^{17} m^{-3} can be measured reliably.

5. Conclusions

In order to improve the aperture configuration in a laser injection tube, a peripheral beam profile monitor, consisting of a screen with a through hole for the laser beam and a CMOS camera, was developed. We selected the good configuration from the ones tested, and installed four 15 mm diameter apertures in the injection tube of the TST-2 TS system. The stray light was reduced dramat-ically to about 4% of that for the previous laser injection tube. With this improved laser injection tube, reliable TS measurements became possible for electron densities above 1.0×10^{17} m^{-3}.

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