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Analysis of baffles for stray light reduction in the Thomson scattering diagnostic on EAST

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HIGHLIGHTS

- A stray light analysis model of baffle was built.
- Stray light suppression effect of installed double edged baffle was analyzed.
- A new corrugation baffle with 33.3% less stray light than the old one was designed.
- An EAST TS diagnostic system simulation model was built.
- Stray light suppression effect of the system with the two type baffles was analyzed.

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ABSTRACT

Baffle is a critical technique to suppress stray light. In order to reduce stray light of EAST Thomson scattering (TS) diagnostic system, a 60° cone angle double edged baffle array was installed for the system. Recently the 45° cone angle corrugation baffle was designed based on double edged baffle and simulation results indicate that the new design can reject 33.3% more stray light than the old one. Based on the mechanical structure and surface property of EAST TS diagnostic system, a stray light analysis model has been built, and using the model, stray light of the system was simulated with the two types of baffles added to the system respectively. Results show that the installation of 60° cone angle double edged baffle array in input tube can cut 92.1% of the stray light to the system, while using 45° cone angle corrugation baffle array in input tube and three 45° cone angle corrugation baffles in exit tube, additional 74.1% of the stray light will be removed.

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1. Introduction

Electron temperature and density are both significant parameters in physical research of fusion plasma. Thomson scattering (TS) diagnostic system can precisely measure the profiles of electron temperature T_e and density n_e simultaneously and has been exploited widely in fusion devices [1–7]. For the system, massive stray light is introduced due to optical elements, some mechanical parts of the system, suspended dust and other sources, and the intensity of stray light is very high in comparison with the TS signal. So it leads to some difficulty in system calibration and measurement. Based on the characteristics of different TS diagnostic systems, some stray light analysis and suppression methods have been used. For DIII-D TS diagnostic system, D.G. Nilson used a CCD camera to analyze stray light produced in DIII-D vessel interior, and then reduced stray light to an acceptable level, compared to the Rayleigh signal, through combined methods of image relaying, exit window tilting, entrance and exit baffle modifications, and a beam polarizer [1]. Through simulating ETE TS diagnostic system, L.A. Berni found the main source of stray light generated in the system, and then by changing the design of the beam dump, the stray light was reduced up to 60 times [2]. Additionally, high energy beamlet generated in laser oscillator cavity is a dominant stray light source in HBT-EP TS system. In order to reduce stray light of the system, J.P. Levesque designed a high-power spatial filter which used a focusing lens to focus the laser beam through a pinhole aperture to remove spatial irregularities or high-k components of the laser beam and obtained a good effect [3].

EAST TS diagnostic system is a complex optical system which includes laser, laser propagation path, signal collection system, polychromator, and data acquisition and analysis system [8,9]. Fig. 1 shows the laser propagation path and signal collection sys-

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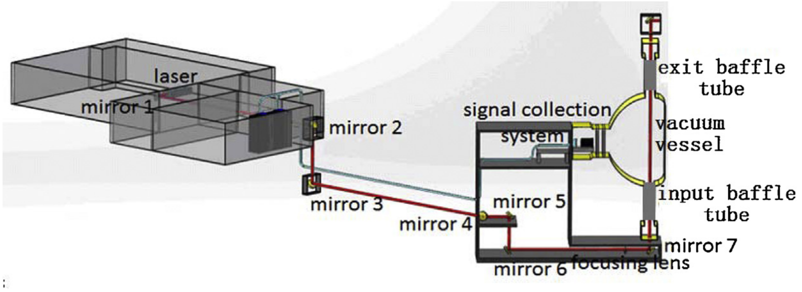

Fig. 1. Diagram of laser propagation path and signal collection system of EAST TS diagnostic system.

tem of EAST TS diagnostic system. Laser beam propagates through seven reflection mirrors with total optical path over 40 m. A 6 m focal length lens was inserted in the beam path to focus it down to 3 mm diameter in the middle of the plasma column inside the vacuum vessel. Collecting system, including collecting lens and signal collecting fiber, was installed in the horizontal viewing port (side window) to collect 90° Thomson scattering signals. For the system, the structure and position of the collecting system are easy to introduce stray light into signal collecting fiber if stray light enters vacuum vessel. The scattering light of optical elements and backward scattering light of outgoing laser are two primary sources introducing stray light into vacuum vessel. So, two baffle tubes were installed after the entrance and before the exit window of vacuum vessel used for laser beam propagation to suppress stray light respectively. Raman scattering density calibration result shows that the influence of stray light on Raman scattering density calibration is very small [10]. However, the intensity of stray light isn't yet reduced to a level small enough to realize Rayleigh scattering density calibration, as signal-to-stray ratio is still about 1%–10%. So, it needs to reduce stray light much more for the system to meet Rayleigh scattering density calibration in the future. In the paper, the structure of baffle already installed in the system was analyzed firstly. And then a new corrugation baffle was designed based on the analysis of old baffle. At last, a simulation model of EAST TS diagnostic system was built and stray light of the system was analyzed with the two types of baffles added to the system.

2. Baffle analysis

Referring the baffle installed in DIII-D TS diagnostic system [1], a tube including five circular double edged baffles with 60° cone angle has been designed and installed in EAST TS diagnostic system between entrance window and vessel bottom. It is called input tube with total length 3.37 m and tube aperture diameter 119 mm. It provides a maximum aperture 32 mm diameter baffle near entrance window, three baffles with aperture 25 mm diameter distributed in the middle and a minimum aperture 12 mm diameter baffle in the end of the tube for laser beam to enter vacuum vessel. Fig. 2 shows the structure of 60° cone angle double edged baffle. The other tube including eight rectangle baffles with aperture 32 mm × 182 mm was installed between the vessel top and exit window, which is called exit tube. The total length of the tube is 2.98 m.

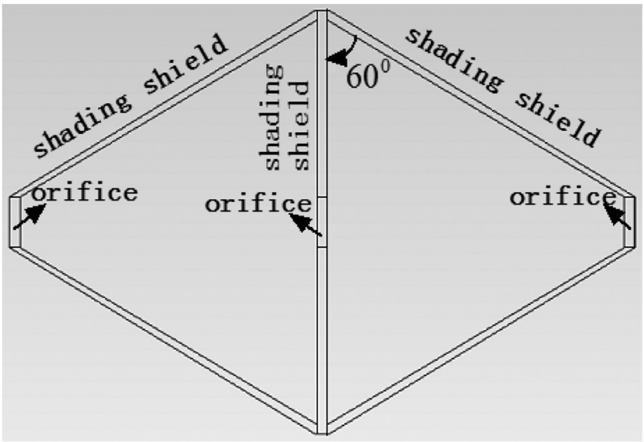

Fig. 2. Structure of the double edged baffle.

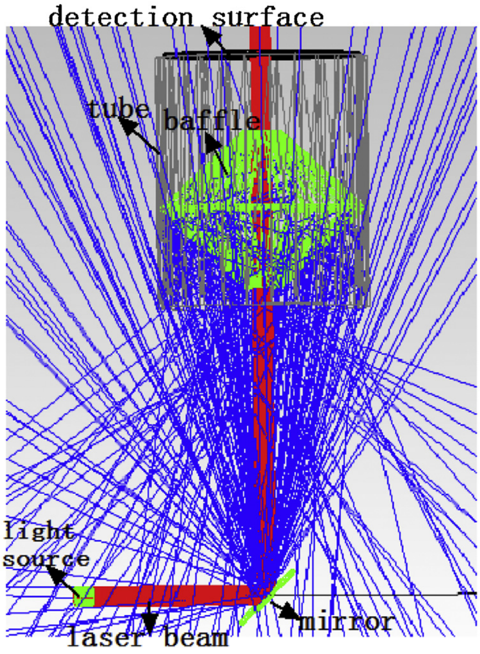

Fig. 3. Simulation model for comparing stray light suppression effects of double edged baffles under different cone angles.

For double edged baffle, the cone angle is an important factor to suppress stray light. In order to compare stray light suppression effects of double edged baffles under different cone angles, 60° cone angle was modified to other cone angles to form corresponding cone angle double edged baffles, and a simulation model was built by using TracePro® software to analyze stray light suppression effects of the baffles. Fig. 3 shows the simulation model, which includes a light source, a mirror, a baffle installed in a tube and a detection surface. In the simulation model, the light source generated a 1 mm radius laser beam (red light rays) that was composed of 10,000 rays with each ray of 1 W flux first, and then the laser beam was reflected by a mirror with surface specular reflection coefficient 0.995 and scattering coefficient 0.0011 to generate stray light (blue light rays). Different cone angle edged baffles with the same aperture and surface property were added to the tube for the simulation respectively, and the detection surface was placed

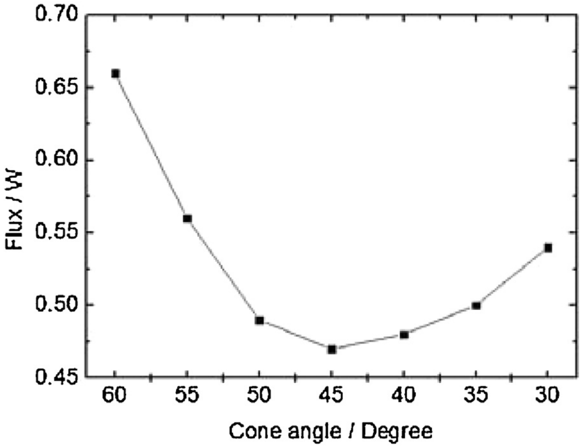

Fig. 4. Variation trend of stray light flux with cone angle of double edged baffle.

after the baffle to record the flux of stray light. In order to avoid laser beam to be detected as stray light, the detection surface was set to ring surface with inner radius 1 mm and outer radius 3 mm. Simulation results show that the flux of stray light is weakest when using 45° cone angle, and it can reject 28.8% stray light more than 60° cone angle. Fig. 4 shows the variation trend of the detected stray light flux with the cone angle of double edged baffle from 60° to 30° with increment −5°. The flux of stray light at 60° cone is 0.66 W and it becomes weaker with the decrease of cone angle to the minimal value 0.47 W at 45° cone angle, and then it becomes stronger. It indicates that 45° cone has best effect for edged structure to suppress stray light. Fig. 5 shows the irradiance maps of stray light detected by the detection surface after laser passing through the 45° and 60° cone angle double edged baffles, where “Min”, “Max”, “Ave”, “Total flux”, “Flux/Emitted Flux” and “incident Rays” represent the minimum irradiance (W/m^2), maximum irradiance (W/m^2), average irradiance (W/m^2), total flux (W), relative flux and number of incident rays, respectively.

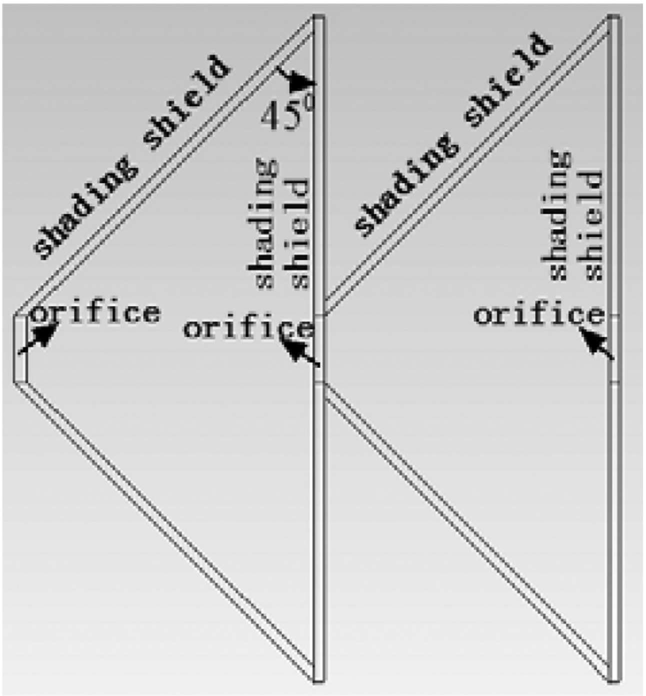

Fig. 6. Structure of the corrugation baffle.

In addition, the baffle structure is also a critical technique to suppress stray light. By analyzing stray light source after using 45° cone angle double edged baffle to suppress stray light, the structure of double edged baffle was modified, and a new corrugation baffle was designed, as shown in Fig. 6. Stray light suppression effect of the baffle with the same aperture and surface property as double edged baffle was analyzed also by placing it into the above simulation model. Fig. 7 shows the flux of detected stray light when using 45° cone angle corrugation baffle, which is 0.44 W. Simulation result indicates that the corrugation baffle has better effect to suppress stray light than double edged baffle, and it can reject 6.4% stray light more than 45° cone angle double edged baffle and 33.3% stray light more than 60° cone angle.

3. Stray light simulation of Thomson scattering diagnostic system

Except for mechanical structure of the baffle, the surface properties of the mechanical and optical components are critical technique to suppress stray light. In EAST TS diagnostic system, in order to enhance energy of laser propagation, the mirrors were

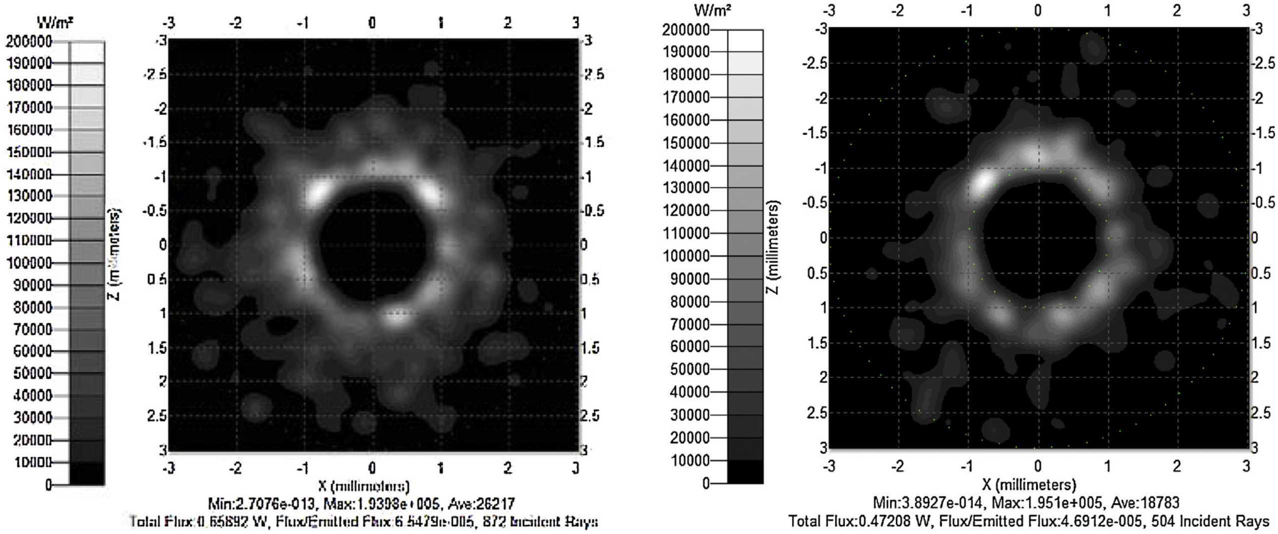

Fig. 5. Irradiance maps of stray light with total fluxes 0.66 W and 0.47 W detected by detection surface after laser passing through 60° (left) and 45° (right) cone angle double edged baffles.

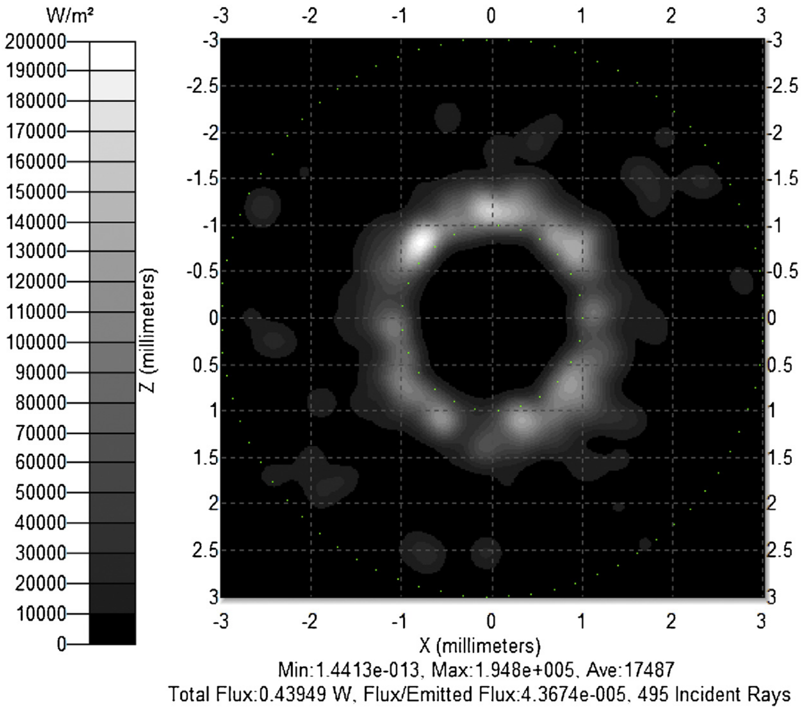

Fig. 7. Irradiance map of stray light with total fluxes 0.44 W detected by detection surface after laser passing through corrugation baffle.

coated high reflection film with reflection coefficient 0.995 and the focusing lens was coated with anti-reflective coating and transmission coefficient is about 0.98. In addition, the materials of the baffle and vacuum vessel inwall facing to the collecting system were processed to Lambertian scattering surface [11], i.e., diffuse reflecting surface, and the surface of the beam dump used to exhaust laser energy after laser beam passes through the exit window of vacuum vessel was blackened.

Based on the mechanical structure and surface property of the system, TS diagnostic system was modeled using TracePro® software to analyze stray light of the system. In the simulation model, firstly a three-dimension mechanical structure of the system was modeled by SolidWorks® software and optical elements were designed by Zemax® software, and then they were transferred to TracePro format using STPE routines. According to the properties of the mechanical and optical components provided by the manufacturers, optical surfaces properties of the mechanical and optical components were modeled by surface property user-defined model with *ABg* scattering property in TracePro® software [11,12]. The specific settings of the principal parameters include specular transmission coefficient, specular reflection coefficient, absorption coefficient and scattering distribution parameters *A*, *B* and *g*. Light source was modeled according to the parameters of laser used in the system, which is a Gaussian beam with diameter 16 mm, divergence angle 0.5 mrad and composed of 10,000 rays with each ray of 1 W flux. The threshold of ray trace was set to 10^{-10}, which means that the ray is no longer tracked after its relative energy is less than 10^{-10} or after it is absorbed by the wall. In the simulation model, three detection surfaces were used. In order to detect the stray light entering signal collecting fiber, detection surface 1 was placed in the side window before the signal collecting fiber and its size was set to $6 \times 1.5\,\text{mm}^2$. The position and size of the detection surface are consistent with the end face of fiber which is used to collect signal in the signal collection system of the diagnostic. The collection system of EAST TS diagnostic system was described in detail in Ref. [9]. Detection surface 2 was placed in the vacuum vessel near the exit of input tube to detect the stray light induced by scattering of input optical elements. While detection surface 3 was placed in the vacuum vessel near the entrance of exit tube to detect the stray light induced by backward scattering of outgoing laser.

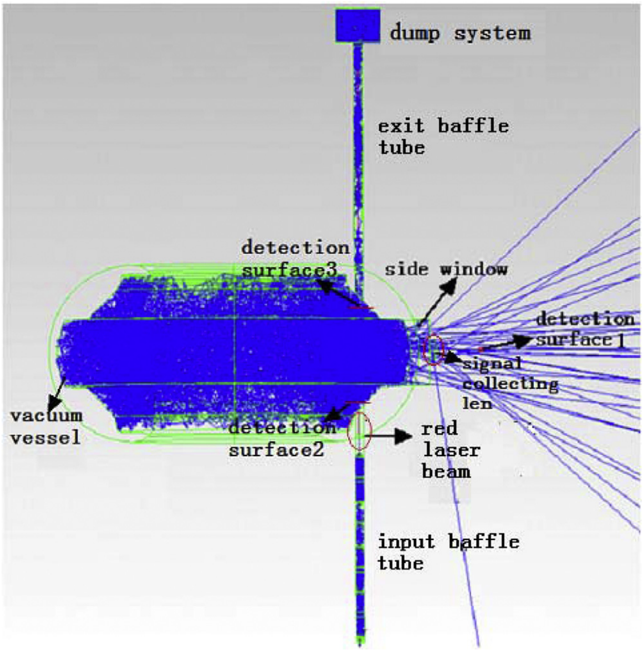

Fig. 8. Stray light simulation model of TS diagnostic system.

Fig. 8 shows the simulation model of TS diagnostic system including stray light. It can be seen that in the tail of the input tube, blue light rays reduces and red laser beam is displayed, which indicates that the stray light was suppressed evidently and double edged baffle array has a good effect to suppress stray light entering vacuum vessel. Simulation results show that when the simulation system is without and with 60° cone angle double edged

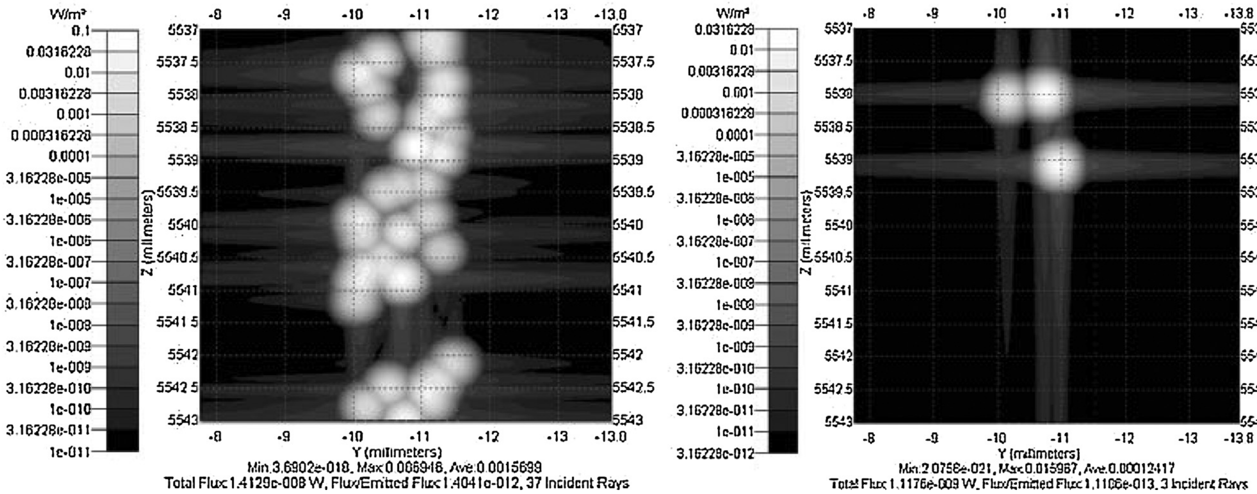

Fig. 9. Irradiance maps of stray light with total fluxes 14.13×10^{-9} W (left) and 1.12×10^{-9} W (right) detected by detection surface 1 when the simulation system without and with 60° cone angle double edged baffle array in input tube, and each blob represents a light ray.

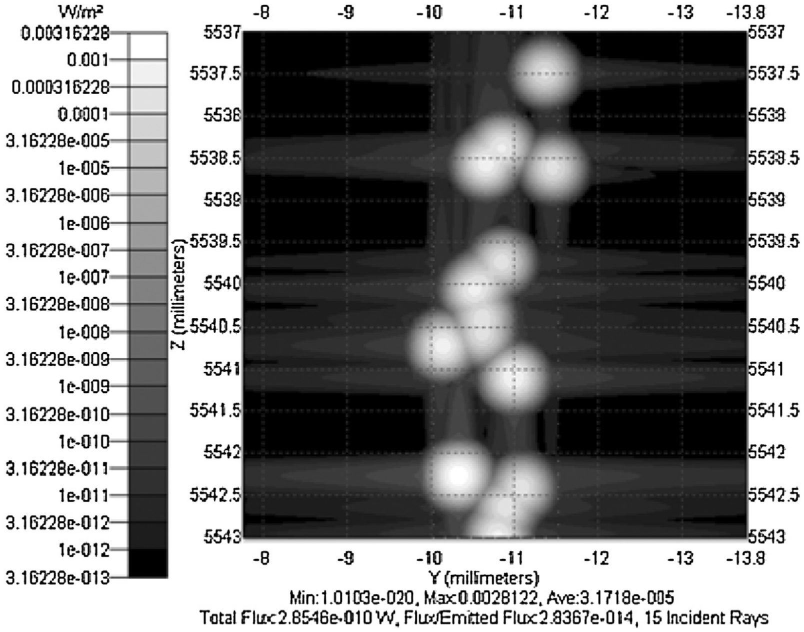

Fig. 10. Irradiance map of stray light with total fluxes 2.9×10^{-10} W detected by detection surface 1 with the input and exit tube modified.

baffle array, the total fluxes of the stray light detected by detection surface 1 are 14.13×10^{-9} W and 1.12×10^{-9} W, respectively. This indicates that the baffle array can cut 92.1% of the stray light entering signal collection system. Fig. 9 shows the irradiance map of stray light detected by detection surface 1 when the simulation system is without and with the baffle array in input tube. In addition, the stray light rays were analyzed by the function of ray sorting in TracePro® which can analyze the ray type (specular, single or multiple scattering) reaching detection surface. The stray light ray with maximum irradiance 0.016 W/m^2 was introduced by backward scatter of outgoing laser by the way of single scattering. Single scattering means that the light is scattered only once by the intersection. So, stray light intensity of the system can be weakened further by modifying exit baffle array. According to the analysis of baffle in section 2, 45° cone corrugation baffle can suppress stray light more than double edged baffle. So, both the input and exit baffle arrays in the system were modified for the simulation. For the input tube, 60° cone angle double edged baffle array was modified to 45° cone angle corrugation baffle array. And for the exit tube, considering the adjustment of optical path system for laser propagation [13,14], the baffle aperture should not be less than 32 mm, so three 45° cone angle corrugation baffles with aperture 32 mm diameter were used to substitute eight rectangle baffles. Simulation results show that the total flux of stray light detected by detection surface 1 is 2.9×10^{-10} W for the modified system, which reduces 74.1% stray light more than the original system (total flux 11.2×10^{-10} W). Fig. 10 shows the irradiance map of stray light detected by detection surface 1. It can be seen that the maximum irradiance is reduced to 0.0028 W/m^2, and the number of incident rays increases. This indicates that the stray light ray with 0.016 W/m^2 irradiance was removed and some stray light rays were introduced maybe because of the lessening of baffle aperture increasing scattered times of the rays.

4. Conclusions

High accuracy measurement is one of the goals of improving EAST TS diagnostic system. Stray light is one of the key problems that have to be solved and baffle is a critical technique to suppress stray light. In order to reduce stray light, 60° double edged baffle array was installed in input tube of the system. A simulation model was built to analyze stray light suppression effects of the baffle under different cone angles. The results indicate that 45° cone angle has best effect for edged structure to suppress stray light. And then by analyzing stray light source after using 45° cone angle double edged baffle to suppress stray light, 45° cone angle corrugation baffle was designed. Simulation results indicate that the 45° cone angle corrugation baffle can reject 33.3% stray light more than 60° double edged baffle. In addition, an EAST TS diagnostic system simulation model was built and two types of baffles were compared in our simulations. The simulation results show that the installation of 60° cone angle double edged baffle array in input tube can cut 92.1% of the stray light to the system, while using the 45° cone angle corrugation baffle array in input tube and three 45° cone angle corrugation baffle in exit tube, additional 74.1% of the stray light will be removed.

Acknowledgments

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