

The Stray Laser Light Simulation of the Beam Dump for Thomson Scattering Systems in HL-2M Tokamak^{*)}

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Two compact beam dumps are needed to install in-vessel in the low field side (LFS) and the divertor region for Thomson scattering (TS) systems of HL-2M tokamak. An upgraded chevron-like beam dump with two dome layers will be installed on the TS systems. According to the ray-tracing simulation results, the upgraded mechanical structure could efficiently reduce stray light level emitting from the beam dump. Half divergence angle of stray laser light from the beam dump would reduce to 23 degrees, with the double dome-like covering over to the chevron beam dump. The upgraded beam dump is able to satisfy both the demands of Thomson scattering systems in the x-point region and the main plasma region.

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1. Introduction

Thomson scattering (TS) systems are being prepared for HL-2M tokamak to measure electron temperature (T_e) and density (n_e) in different plasma regions. Two sets of TS systems, in the central region and the edge region of main plasma, and the x-point region as shown in Fig. 1, are being evaluated and mechanically designed recently. A laser beam path passes through the HL-2M main plasma in the tangential direction on the equatorial plane, which is similar to that on MAST [1], JT60-SA [2], K-STAR [3], and the edge TS system on HL-2A [4]. The port #6 is utilized to transfer the laser beam into the plasma. The other parts of port #6 and port #7 are distributed to collect scattered photons for the edge region and the central region, respectively. A beam dump will be installed in-vessel in the low field side (LFS) of HL-2M to absorb the residual laser beam energy, as shown in Fig. 1 (a). Outside surface of the beam dump should not surpass the limiter in the radius direction. The other laser beam path used for the TS system of x-point region will share the port #6. After passing through the x-point region, the residual laser energy will be absorbed by a beam dump embedded into the target plates of the lower divertor, as shown in Fig. 1 (b). The scattering angle of the x-point TS system is about 150 degrees. If the half divergence angle of stray laser light from the beam dump is not more than 25 degrees, the collection lens would not receive the stray laser light from the beam dump directly. In order to accomplish these systems, design and fabrication of a compact beam dump is a pressing

demand.

The chevron beam dump designed for ITER edge Thomson scattering system [5, 6], has a compact structure. The lifetime of it manufactured by molybdenum materials under the harsh thermal and electromagnetic loads could meet the requirement of TS system in ITER, as well as the TS systems in the main plasma region and x-point region on HL-2M.

In order to better understand the performance of the new type beam dump, and apply it to HL-2M TS systems, distribution and intensity of the stray laser light caused by it are simulated in detail in the paper. Based on the chevron beam dump, upgraded structures are presented, which could decrease effectively the stray laser light emitting from them. In the paper, three parts are included. The first part is the introduction, the second is the upgraded mechanical design and ray-tracing simulation of the beam dumps and the last is the summary and discussion.

2. Upgraded Mechanical Design and Ray-Tracing Simulation of the Beam Dump

Based on the mechanical structure of the chevron beam dump installed on the edge Thomson scattering system of ITER [5, 6], the structure of the chevron beam dump is building-up for the ray-tracing simulation by TracePro[®] [7] software. Meanwhile, a simplified simulation model is established as shown in Fig. 2. Injection laser rays and stray laser rays emitting out from the beam dump are marked with red color and blue color, respectively. Laser rays vertically inject into the beam dump, and a detector is

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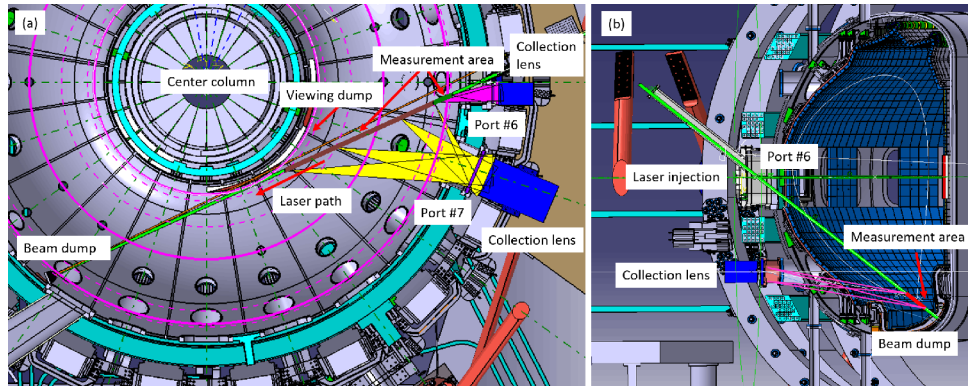


Fig. 1 Layouts of Thomson scattering systems on HL-2M. (a) In the main plasma region, and (b) in the x-point region.

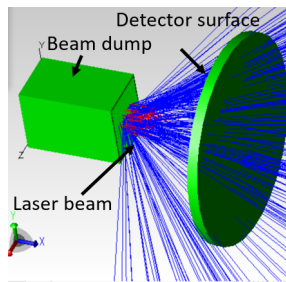


Fig. 2 The simplified model for the ray tracing simulation of the chevron beam dump.

placed in front of the output of the beam dump to receive rays emitting from the beam dump and analyze the irradiance distribution. Besides, surfaces of the slides inside the beam dump are processed to diffuse reflecting surface, so that one ray maybe split into several rays in the ray-tracing process.

In the TracePro® software, the light source parameters are set similarly to the parameters of the actual laser beam used on the TS system of HL-2M. The beam diameter is fixed at 30 mm with a half divergence angle of 5 degrees to ensure rays entering into the beam dump not parallel to each other. The beam contains 1141 rays, and flux of each ray is 1 W. Ray distribution is Gaussian in the beam cross section. Raytracing threshold value is set to 10^{-10} , which means the ray is no longer tracked if its relative flux is less than 10^{-10} W, or after it is absorbed by the beam dump.

In order to simulate accurately, the bi-directional reflection distribution function (BRDF) of molybdenum material with roughness $0.3\mu\text{m}$ is measured by a scatterometer (MWS5) [8] in 532 nm with *s*-polarized light which means that the electric field of laser beam is normal to the plane of incidence. *ABg* scattering property model [9] is used to fit the BRDF measurement results. The model could be expressed as: $\text{BRDF}(\vec{x}) = A/(B+|\vec{x}|^g)$ [9, 10], in which, $\vec{x} = \vec{\beta} - \vec{\beta}_0$, β and β_0 are the projection of the specular and scattered ray vectors down to the surface, respectively. The coefficients *A*, *B*, and *g* are determined

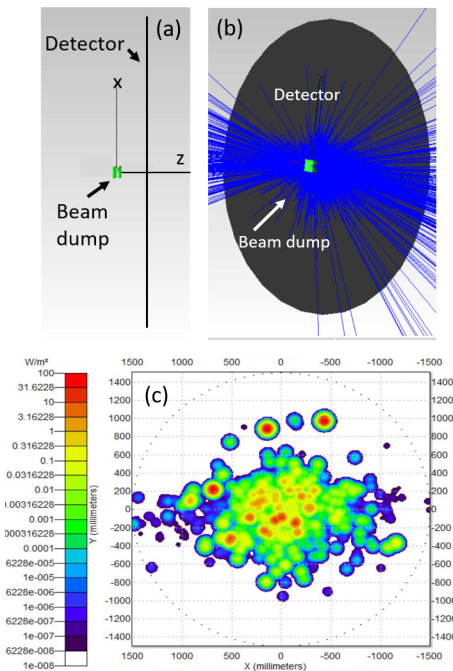


Fig. 3 Stray laser rays simulation model and results of the beam dump (type I). (a) Side view of the beam dump and the detector, (b) stray laser light distribution, and (c) the irradiance map on detector.

by fitting the *ABg* curve to the measured points and transferred to TracePro® in appropriate table form.

In order to receive as many rays as possible, a larger round detector is set in the actual simulation model. The size comparison of the beam dump and the detector is shown in Fig. 3 (a). Figures 3 (b) and (c) display the simulation results of the distribution of stray laser rays and the irradiance map on detector, respectively. This chevron beam dump is marked as type I to describe conveniently. Total number of rays and total flux on detector are 4582 and 0.79 W, respectively. The ratio of the flux to emitted flux is 6.96×10^{-4} . All the data are listed in Table 1. Actual stray rays number and flux of stray light are larger than these detected data because some of the stray rays are not

Table 1 Simulation results for different structures of the beam dump.

	Type I	Type II	Type III
Total number of ray on detector	4582	3542	1561
Total flux on detector (W)	0.79	0.94	0.56
Flux/Emitted flux	6.96×10^{-4}	8.29×10^{-4}	4.92×10^{-4}

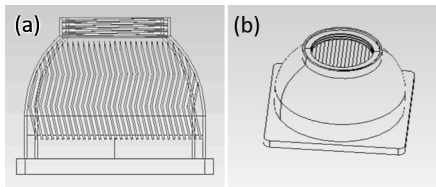


Fig. 4 The mechanical structure of the type II beam dump. (a) Side face, and (b) overall view.

received by detector. In addition, the stray laser ray number is much more in the parallel direction (X-axis) than in vertical direction (Y-axis) as shown in Fig. 3 (c). It is obvious that the half divergence angle of the stray light from the beam dump is much more than 25 degrees. The simulation results demonstrate that the structure cannot meet the demand of the x-point TS system on HL-2M because the half divergence angle of the stray light is so large that the stray laser rays could directly enter into the collection lens to disturb scattered photons measurement.

In order to solve the problem, a dome-like cover with a proper clear aperture is added onto the type I beam dump as shown in Fig. 4. This beam dump is described as type II beam dump. The dome-shape cover is able to limit the stray laser rays emitting out in the direction which is parallel to the slides' direction. The advantage of the type is that the cover is able to reduce the stray rays emitting into the vacuum vessel. The ray-trace simulation results are shown in Fig. 5. The total number of rays detected by the detector is 3542. The total flux on detector is 0.94 W, and the ratio of the flux to the emitted flux is 8.29×10^{-4} . It seems that although the total number of rays reduces from 4582 to 3542, the total flux increases a little. In order to increase the absorption efficiency of the beam dump, an upgraded structure of the beam dump is developed as illustrated in Fig. 6, and it is marked as the type III beam dump. The added second cover could efficiently restrict the divergence angle of stray laser ray as the simulation results shown in Fig. 7 (b) and Fig. 8. The total number of rays detected by the detector is 1561. The total flux on detector is 0.56 W, and the ratio of the flux to the emitted flux is 4.92×10^{-4} . The numbers of rays on detector listed in Table 1 suggest that the type III beam dump could decrease the stray laser rays up to 44% of the type II beam dump. The half divergence angles, in Figs. 7 (a) and (b), α_1 and α_2 are about

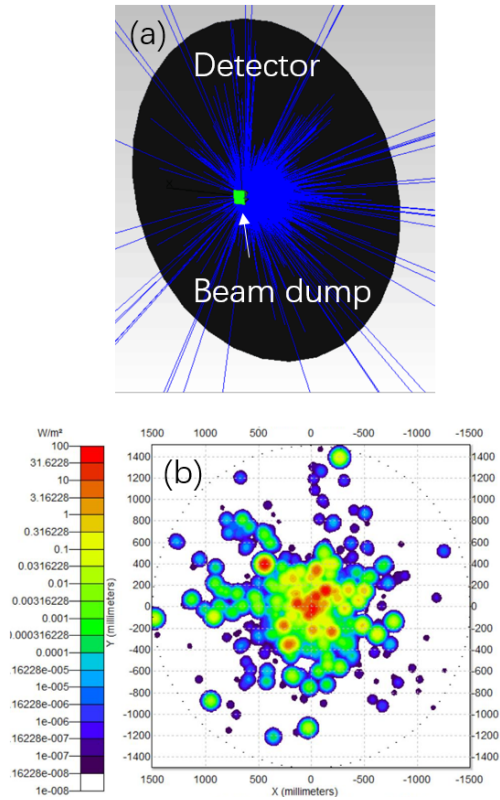


Fig. 5 Simulation results of the type II beam dump. (a) Stray laser light distribution, and (b) irradiance map on detector.

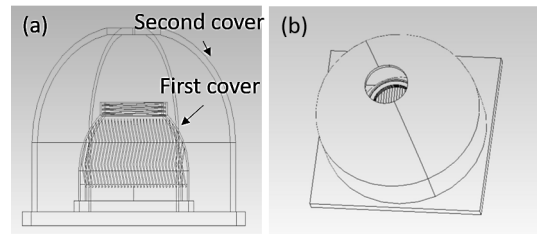


Fig. 6 The mechanical structure of the type III beam dump. (a) Side face, and (b) overall view.

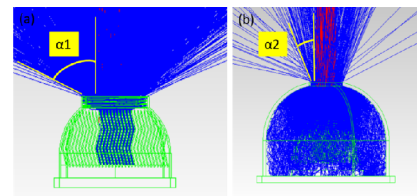


Fig. 7 Ray tracing simulation results of the two upgraded beam dumps. (a) Type II beam dump, and (b) type III beam dump.

65 degrees and 23 degrees, respectively. The latter value is less than the angle between the collecting direction of scattered photons and the laser beam direction for the x-point TS system as shown in Fig. 1 (b). Therefore, the type III

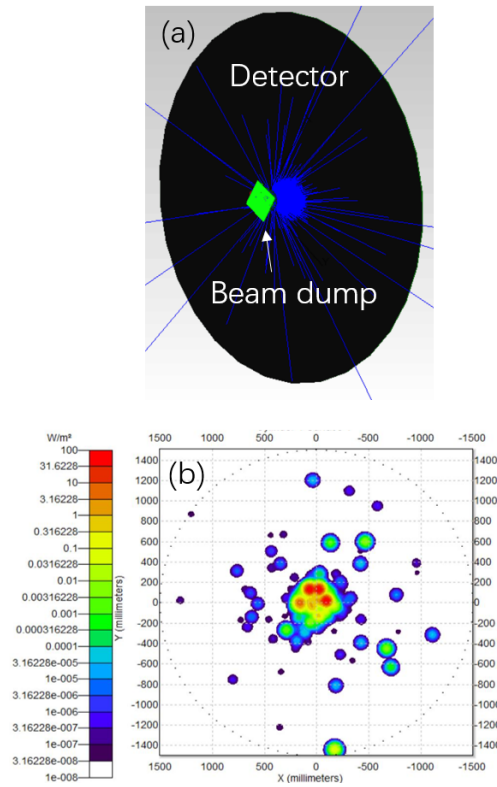


Fig. 8 The simulation results of the type III beam dump. (a) Stray laser light distribution, and (b) irradiance map on detector.

beam dump could decrease more stray laser rays entering into the collection lens directly. So the type III beam dump is more suitable for the x-point TS system.

3. Discussion and Summary

One proper compact beam dump has been obtained by

upgrading the mechanical structure of the chevron beam dump for HL-2M TS systems. The ray-tracing simulations of the beam dumps have been accomplished by TracePro® software. The type III beam dump could effectively decrease the flux and the divergence angle of the stray rays. It is suitable for the main plasma region TS system and the x-point region TS system on HL-2M.

In next step work, BRDFs of molybdenum and tungsten materials with different roughness at 1064 nm are being prepared to measure. Then they will be tried to choose more suitable materials with different roughness values to further reduce the stray light from the beam dump. In addition, the whole TS system model on HL-2M will be built to simulate the stray laser light level detected by the polychromators, and analyse the effects of stray laser level on the ratio of signal to noise in different spatial locations.

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