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Line-concentrating flux analysis of 42kWe high-flux solar simulator

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Abstract

High-flux solar simulators can provide controlled conditions and allow conducting high-temperature solar-driven thermal and thermochemical research without perturbations due to solar resource intermittency. A 42-kWe high-flux solar simulator, KIRAN-42, with seven hexagonal symmetry reflectors has been built at IMDEA Energy Institute, Spain. The reflectors layout of KIRAN-42 provides sufficient separation of units and it is conceived flexible enough to adjust the flux distribution onto the focal plane, which has expanded the application field of the high-flux solar simulator significantly. A model was built with *Tracepro*© to analyze the optical characterization of line-concentrating flux distribution of KIRAN-42, and the results show that , in spite of the spreading of lamps foci onto a line, the peak flux is still reaching 1.4 MW/m^2. Experimental characterizations were also conducted to study the real flux distribution of KIRAN-42 with line-concentrating, of which the peak flux is about 1 MW/m^2. Divergence between experimental results and *Tracepro*© model should still be improved though the optical characterization of KIRAN-42 confirms the potential use of the solar simulator in a flexible way for different aiming strategies.

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Keywords: high-flux solar simulator; *Tracepro* model; line-concentrating; optical characterization

1. Introduction

Compared with real solar concentrators, a High-Flux Solar Simulator (HFSS) provides controlled conditions and allows conducting high-temperature thermal and thermochemical research without perturbations due to solar resource intermittency. Several high-flux solar simulators have been built all over the word for solar thermal

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research. A high-flux solar simulator for the study of high temperature and flux measurements was established at Lawrence Berkeley Laboratory, with peak fluxes up to 16 MW/m^2 [1]. A high-power linear Ar arc (200 kW electrical input) enclosed by an elliptical trough mirror, designed by ETH-Zurich, is capable of delivering up to 75 kW of continuous radiative power at peak fluxes exceeding 4250 kW/m^2 [2]. A high-flux solar simulator facility comprising an array of ten Xe arcs, built by Paul Scherrer Institute, can deliver over 50 kW of radiative power at peak fluxes exceeding 11 MW/m^2 [3]. DLR has a facility composed of ten 6 kW xenon short-arc lamps with elliptical reflectors. Codd etal. in Massachusetts Institute of Technology used seven 1.5 kW metal halide outdoor stadium lights to simulate concentrating solar power heliostat output for studying optical melting and light absorption behavior of molten salts [4]. University of Minnesota designed a high-flux solar simulator consisting of seven 6.5 kWe xenon arc lamps. It can deliver radiative power of approximately 9.2 kW over a circular area of 60-mm-diameter located in the focal plane [5, 6]. University of Florida built a 56 kWe facility providing peak flux levels in excess of 5000 kW/m^2. A 42-kWe high-flux solar simulator (KIRAN-42) with seven hexagonal symmetry reflectors has been built at IMDEA Energy Institute, Spain [7]. The 7 kW xenon short arc lamp in Taxas A&M University at Qatar delivers a peak flux of 3583 kW/m^2 with an input current of 153 A [8]. A high-flux solar simulator with an array of 23 × 6 kW metal halide lamps was designed in the University of Adelaide, with calculated average heat flux of 1.447 MW/m^2 [9]. Generally, HFSS may be used to help during the scaling up of solar-driven processes to simulate them in a central receiver system or a solar furnace. However, the high-flux solar simulator of IMDEA Energy is flexibly designed having ability to adjust the flux distribution on the focal plane by realigning the reflectors, and also able to simulate the line-concentrating solar system or other aiming strategies, which widens the application field of the High-Flux Solar Simulator significantly. Thus, it is necessary and important to demonstrate the optical characterization of the line-concentrating flux of HFSS.

In this manuscript, based on the design and structure of HFSS in IMDEA Energy, the optical model of the HFSS was built by using *TracePro®*, which was used to simulate the line-concentrating flux distribution on the focal plane of KIRAN-42. Then, according to the optical model of *TracePro®*, the reflector-lamp units of KIRAN-42 were rotated, and the line-concentrating flux of the HFSS on the focal plane was characterized by means of a water-cooled Lambertian target and a calibrated Gardon gauge.

2. *Tracepro®* model of high-flux solar simulator

The optical simulation software *Tracepro®* was used to build the optical model of high-flux solar simulator KIRAN-42. *Tracepro®*, commercialized by Lambda Research Corporation, is an opto-mechanical design software used for designing and analyzing illumination and optical systems. Its ray tracing engine is fast and accurate, while giving designers complete control over parameters to achieve simulation results quickly with acceptable compromise in accuracy [10].

The high-flux solar simulator KIRAN-42 consists of seven 6 kWe reflector-lamp units arranged in the center and vertices of a regular hexagon. The light sources of KIRAN-42 are the Xenon short arc lamps, which provide the spectral representation of sunlight. The elliptical reflectors made of aluminum and a polymer protective coating reflect the radiation emitted by the lamps located at the first focus of the ellipsoid to the second focal point where the target is located. The spacing between each reflector has been chosen large enough for facilitating different aiming alignments. The semi-major axis of the ellipsoidal reflector is 1374 mm, and the semi-minor axis is 569 mm, which provides a focal length of 2,500 mm. The eccentricity is 0.91. The truncation diameter of the reflector is 750 mm. Fig. 1 shows the high-flux solar simulator KIRAN-42.

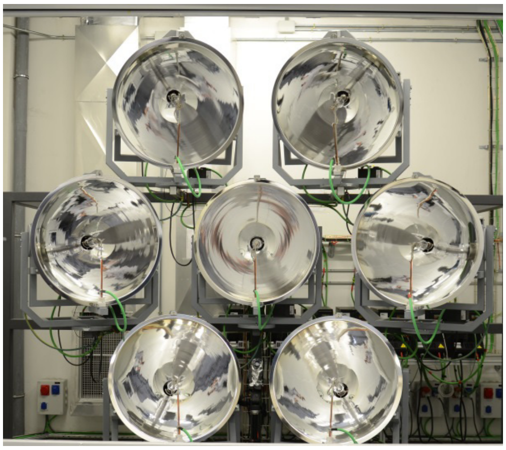

Fig. 1 High-flux solar simulator KIRAN-42

The Xenon short arc lamps are used in KIRAN-42 as light source, and it is therefore very important to build a good arc lamp model to make calculation by *Tracepro®*. The xenon arc lamp is a kind of gas discharge lamp, passing electricity through ionized xenon gas at high pressure. The brilliance distribution in the arc of a typical Xenon short arc lamp is shown in Fig.2 [11]. K.R. Krueger simplified the Xenon short arc source to a cylindrical arc [5]. In this paper, based on the brilliance distribution, the light source of the lamp in *Tracepro®* is designed to be composed by three different shapes of arc, as shown in Fig.3. The inner arc is a plasma ball, which is the primary light source of the lamp, and in the middle there is an arc with ellipsoid shape and the outer arc in the model is represented with hyperboloid shape. In order to make the calculation become more accurate, besides elliptical reflectors, the glass bulb, cathode and anode rods, power cables and support sticks are also built in the model. The *Tracepro®* model of KIRAN-42 is shown in Fig. 4.

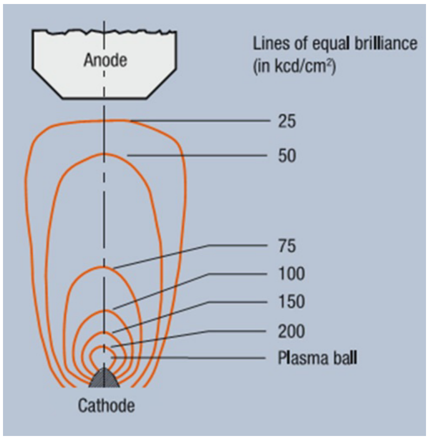

Fig. 2 Brilliance distribution in the arc of an Xenon short arc lamp

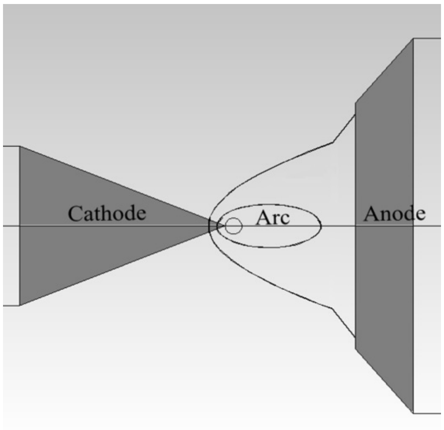

Fig. 3 Schematic of lamp arc model

Based on this geometrical configuration, the optical characterization of line-concentrating flux of KIRAN-42 was analyzed. The optical aiming points of each reflector-lamp unit were adjusted to have the spots focused onto a line. Figure 5 shows the *Tracepro®* calculation results of flux distribution of all the seven lamps with the realignment, of which the axial spacing between flux distributions of each lamp is 40 mm. The total length flux distribution in vertical direction is about 300 mm, and width in horizontal direction is about 100 mm. From the calculation, we obtain that the peak flux is about 1.4 MW/m^2, and total flux is about 16 kW. In this model, all the lamps are assumed with same performance, but the reality is that flux distribution of each lamp is slightly different, and peak flux is also different, which may be caused by different concentrating angles and distance of each lamp. Thus, we should pay attention to refine this when the line-concentrating flux distribution is used to carry out experiments.

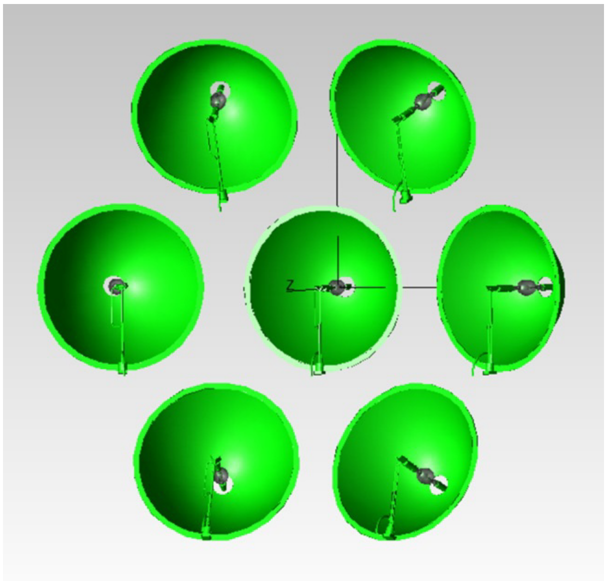

Fig. 4 *Tracepro®* model of KIRAN-42

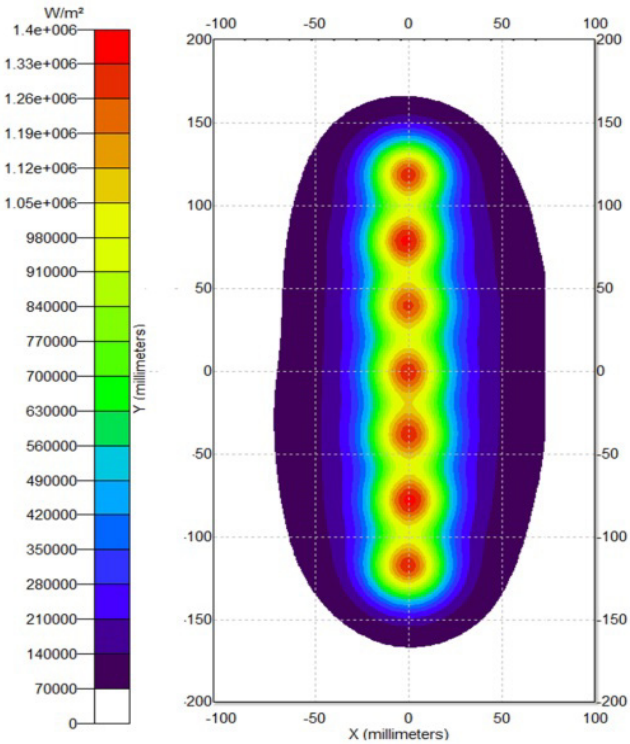

Fig. 5 Flux distribution calculated by *Tracepro®*

3. Characterization experiments

3.1. Method

According to the optical model of *TracePro®*, the reflector-lamp units of the KIRAN-42 were adjusted to make the flux distribution on the focal plane line-concentrated, and it was characterized by means of a water-cooled Lambertian target and a calibrated Gardon gauge [7]. A SiS1-p1010 CCD camera with 16-bit 1024×1024 pixels was used to record the concentrated radiation reflected by the Lambertian target. Absorptive-reflective neutral density filters were used to decrease the intensity of reflected concentrated radiation. A heat flux gauge Gardon TG1000-1with an uncertainty of ±3%, mounted in another plate, was used to calibrate the CCD image, as shown in Fig. 6. After the test, the images taken by the CCD camera were processed in order to get the flux distribution of the solar simulator, including correcting the distortion of the image, transforming the coordinate unit and converting the greyscale of the images to flux intensity.

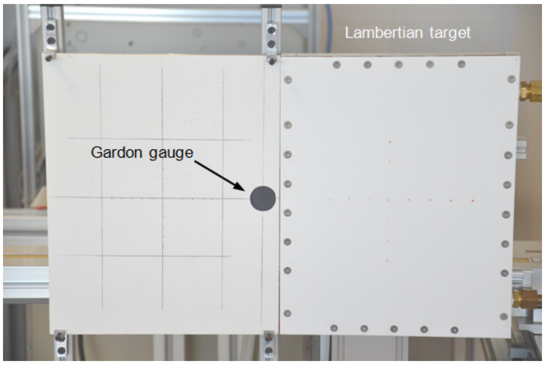

Fig. 6 Gardon gauge and Lambertian target

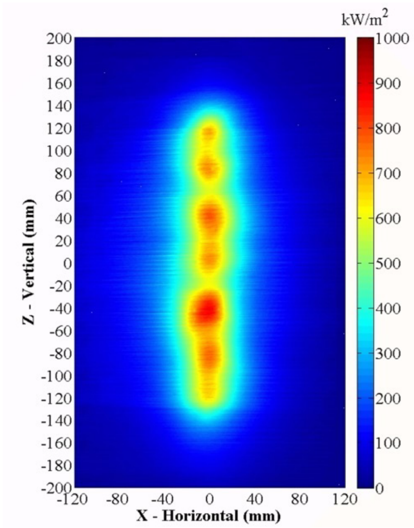

Fig. 7 Experimental results of flux distribution of KIRAN-42 with line-concentrated

Because the height of the Lambertian target is not large enough, the characterization experiments were conducted by moving the Lambertian target step by step. After the experiments, all the characterization images were processed by MATLAB® to produce one complete flux distribution image. Fig. 7 shows the flux distribution of all the seven lamps realigned with central distance between flux distributions of each lamp 40 mm. In the results of characterization experiments, the peak flux is only about 1 MW/m^2, which is less than the calculation results. Comparing the calculation results versus test results, the flux distribution is similar, but there are also some differences. In the simulation results, the flux distribution of each individual lamp is easily distinguished, but in the test results the flux distribution of some lamps is overlapping. The reason may be that the arc model used in the *Tracepro®* is a simplification model, still different from real one; the elliptical reflectors of KIRAN-42 are fabricated from polished aluminum alloy, and the reflectance properties are complex; the lamps are not mounted perfectly because of the mechanical structure; etc.. Thus, compared with characterization test results, the *Tracepro®* model of KIRAN-42 should be improved to make the model closer to the real properties of each component of the high-flux solar simulator.

As a positive result of the modeling and comparison with experiments, it could be demonstrated the potential of realignment of KIRAN-42 optical design and its flexibility to cover fix focus pure concentration as reported elsewhere [7] and the extreme condition of working with a linear focusing aiming strategy herewith reported.

4. Conclusions

In order to study the optical characterization of the line-concentrating flux of high-flux solar simulator KIRAN-42 in IMDEA Energy, the *Tracepro®* model was built to calculate the flux distribution at focal plane according to the design and structure of KIRAN-42. The calculation results show that the peak flux is about 1.4 MW/m^2, but the flux distribution and peak flux of each lamp are different. Characterization experiments were also conducted, and peak flux measured is about 1 MW/m^2, which is less than the simulation results. The flux distribution of calculation results and test results is similar, but there are also some differences. The reason may be that the present *Tracepro®* model is still not considering some real properties and errors of KIRAN-42 perfectly, and therefore the model should be improved.

Acknowledgements

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