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Development of a multi-layer and multi-dish model for the multi-dish solar energy concentrator system

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Abstract

In this paper, a multi-layer and multi-dish model was proposed for a multi-dish concentrator system. Based on the model, the flux distribution of focal plane was calculated by Monte Carlo ray tracing method (MCRTM). The results show that the multi-dish concentrator system is composed of three different focal length parabolic surfaces. The design parameters calculated from the model have a good concentration ratio, and pointing error has a significant effect on the flux distribution. The concentration ratio obtained from the proposed model results in an optimal flux distribution for the design concentration distance, and an increase or decrease in the concentration distance decreases the peak flux distribution of the focal plane.

Keywords: Multi-dish concentrator; Parabolic surface; Flux distribution; MCRTM

1. Introduction

There is an urgent need to develop new energy sources to replace common fossil fuel resources because the amount of fossil fuels is rapidly decreasing and the combustion products are not environment friendly (Anand et al., 2011). Among the possible new energy sources, solar energy has attracted considerable interests because of it is free, abundant, inexhaustible, widely spread and environment friendly. Solar energy has extensive application prospects in many medium–high temperature fields, such as: H_2 production by solar thermochemical reactions (Gokon et al., 2009; Chueh et al., 2010; Pitz-Paal et al., 2011; Säck et al., 2012; Houaijia et al., 2013; Jang et al., 2014), solar cooker (Harmima et al., 2012), solar dynamic space power systems (Tarlecki et al., 2007) and thermal electric power systems (Rene, 2012; Ahlbrink et al., 2013). Solar concentrators are commonly used in the above medium–high temperature utilization fields to collect the sunlight as heat source and provide heat source to the receivers (Abanades and Flamant, 2006; Wang et al., 2014; Dai et al., 2014).

Solar concentrators can be divided into three types: trough concentrators, tower concentrators and parabolic dish concentrators. The parabolic dish concentrator is advantageous over the other concentrating concentrators because of the absence of cosine losses (Kalogirou, 2004), high geometric concentration ratio (Ummadisingua and Soni, 2011), and high temperature. For the convenience of manufacturing, installing and mending, a parabolic dish concentrator is usually composed of several discrete small dishes. Manufacturing factors or assembly error, and unideal sunlight with an increased angular diameter can bring some poor phenomena such as a bigger energy spot in the focal plane, concentrated energy spot nonuniformity of heat flux distribution in the cavity receiver. The radiation

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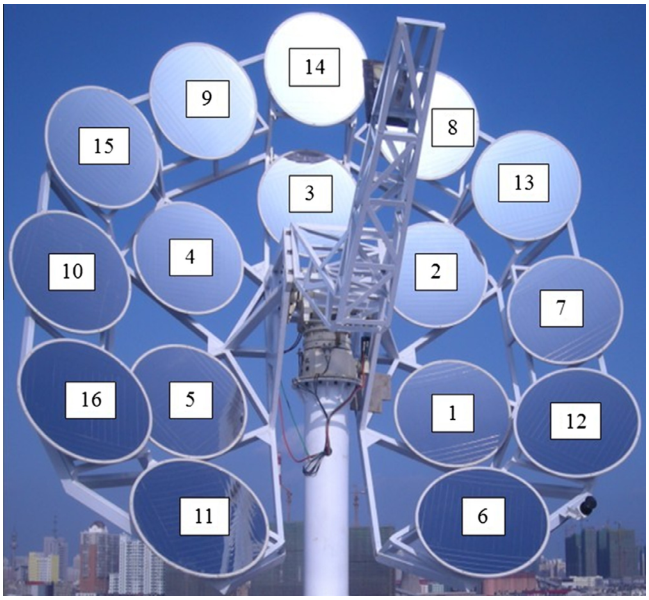

Fig. 1. Schematic diagram of the multi-dish solar concentrator system.

flux distribution in the cavity receiver is depended on the directional distribution and quantity of concentrated energy.

The soft Extensive research has focused on the flux distribution and the application of solar parabolic dish concentrators. Johnston et al. (2003) predicted the flux mapping of a 400 m^2 "Big Dish" by developing the COMPREC compound receiver. Imenes et al. (2006) investigated the flux distribution in the case of a surface error of 3.5 mrad and an ideal tracking regime using the ray-trace program. Jaramillo et al. (2008) evaluated the energy arrived at the focus of a small paraboloidal mirror by an analytical method. Buie and Monger (2004) analyzed the optical error of the flux distribution of concentrators. Shuai et al. (2008a,b, 2011) used numerical methods to investigate the characteristics of the concentration and radiation of a dish concentrator. Xia et al. (2012) numerically investigated the concentrating characteristics of a multi-dish concentrator in tandem with a three-dimensional compound parabolic concentrator. Lovegrove et al. (2011) investigated the concentrating characteristic of a 500 m^2 paraboloidal dish concentrator with an average surface slope error experimentally. Wang et al. (2013a,b) combined MCRTM and finite volume methods to study the heat transfer process of a porous absorber, and the receiver was heated by a parabolic dish concentrator. Villafan-Vidales et al. (2012) analyzed the concentration of a dish concentrator, and then the dish concentrator was used to provide the heat source for a thermochemical reactor.

Much work was conducted to investigate the flux distribution of single solar parabolic dish concentrator, but little work was focused on the multi-dish parabolic concentrator. Considering the convenience of manufacturing, installing and mending, it is necessary to investigate and predict the performance of multi-dish parabolic concentrator. In this Study, the multi-dish parabolic solar concentrator located in Harbin Institute of Technology, Harbin, China was introduced. The design parameters were revised and a multi-layer and multi-focal concentrator model was developed. The radiation characteristics including flux quantity and directional distribution at different concentration distances obtained through using the MCRTM were studied.

2. Multi-dish solar contractor system and MCRTM

The multi-dish solar concentrator system is shown in Fig. 1 and it consists of 16 identical and discrete small parabolic dishes. The equivalent aperture diameter of the multi-dish concentrator system is 5200 mm and the given concentration distance (h) is 3250 mm. The diameter and

Table 1
Original design parameters of the concentrator system (Mao, 2013).

No.	Center coordinate	Angle of $o'x'$ with global coordinate system (ox, oy, oz) (°)	Angle of $o'y'$ with global coordinate system (ox, oy, oz) (°)	Angle of $o'z'$ with global coordinate system (ox, oy, oz) (°)
1	1196, −690.7, 302	10.67, 90, 79.33	90, 6.21, 96.21	100.67, 83.79, 12.51
2	1196, 690.7, 302	10.67, 90, 79.33	90, 6.21, 83.79	100.67, 96.21, 12.51
3	0, 1381.45, 302	0, 90, 90	90, 12.27, 77.73	90, 102.27, 12.27
4	−1196, 690.7, 302	10.67, 90, 100.67	90, 6.21, 83.79	79.33, 96.21, 12.51
5	−1196, 690.7, 302	10.67, 90, 79.33	90, 6.21, 83.79	100.67, 96.21, 12.51
6	1087, −1883, 874	10.67, 90, 79.33	90, 6.21, 83.79	100.67, 96.21, 12.51
7	2174.5, 0, 784	19.54, 90, 70.46	90, 0, 90	109.54, 90, 19.54
8	1087, 1883, 784	10.07, 90, 100.07	90, 17.09, 72.91	100.07, 107.09, 19.65
9	−1087, 1883, 784	10.07, 90, 100.07	90, 17.09, 72.91	79.93, 107.09, 91.65
10	−2174.5, 0, 784	19.54, 90, 109.54	90, 0, 90	70.46, 90, 19.54
11	−1087, −1883, 784	10.07, 90, 100.07	90, 17.09, 107.09	79.93, 72.91, 19.65
12	2117.4, −1222.5, 1013	19.37, 90, 70.63	90, 11.48, 101.48	109.37, 78.52, 21.85
13	2117.4, 1222.5, 1013	19.37, 90, 70.63	90, 11.48, 78.52	109.37, 101.48, 21.85
14	0, −2445, 1013	0, 90, 90	90, 22.09, 67.91	90, 112.09, 22.09
15	−2117.4, 1222.5, 1013	19.37, 90, 109.37	90, 11.48, 78.52	70.63, 101.48, 21.85
16	−2117.4, −1222.5, 1013	19.37, 90, 70.63	90, 11.48, 101.48	70.63, 78.52, 21.85