Design and focusing performance simulation of trough solar concentrator

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Abstract

Abstract: In order to minimize the focal plane spot size of trough solar concentrator with fixed opening width, the bus equation of trough solar concentrator is calculated theoretically. According to the Monte Carlo ray tracing method and the law of mirror reflection, the focusing performance of a trough solar concentrator with an opening width of 5.77 m and a length of 0.4 m is simulated. The error between theoretical analysis and simulation results is 2.6% in terms of received energy on focal plane. This will provide a reliable basis for the design and optimization of trough concentrating system.

Keywords: Trough solar condenser, Focusing performance, Simulation

1. Introduction

Trough solar thermal power generation technology is the most mature solar thermal power generation technology at present (Wang, 2006). Therefore, based on the analysis of solar focusing theory, the focusing performance of a trough solar concentrator with an opening width of 5.77 m and a length of 0.4 m is simulated. It provides a reliable basis for the design and optimization of trough concentrating system.

2. Solar focusing analysis theory

In the analysis of solar focusing, 0.533 degrees misalignment of sunlight needs to be considered in the solar concentrating analysis (Xu et al. 2013), and following assumptions are made:

1) In the solar angle, the incident sunlight is considered to have the same irradiance in all directions;

2) Only the mirror reflection of paraboloid is considered;

3) The local sunshine constant is 1000 W m^{-2} (Tao et al. 2011).

After the sunlight is reflected by the parabolic reflector, an optical path is formed on the xoy plane, as shown in Fig. 1. In the figure, "o" is the origin of the coordinate, "F" is the focus of the paraboloid, and "A" and "B" are the endpoints of the projection of the paraboloid on the xoy plane.

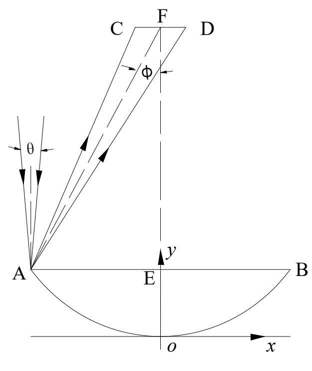

Fig.1: Optical path diagram of concentrator

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3. Design example and result analysis of trough solar concentrator

3.1 Design requirements：

1) The trough type solar concentrator is adopted, and its opening width is 5.77 m;

2) The focal plane spot size is the smallest;

3) The bus equation of trough solar concentrator is determined.

3.2 Calculation process of bus equation

Focal plane spot size CD can be calculated by：

$$CD = \frac{2\times AF\times tan\frac{\theta}{2}}{cos\emptyset} = \frac{4\times f\times tan\frac{\theta}{2}}{cos\emptyset\times(1+cos\emptyset)} = \frac{2\times AE\times tan\frac{\theta}{2}}{sin\emptyset\times cos\emptyset} = \frac{2\times AB\times tan\frac{\theta}{2}}{sin2\emptyset} \quad \text{(eq. 1)}$$

Where, AB is the opening width of trough type solar concentrator, CD is the focal plane spot size, θ is the splitting angle of incident solar rays, ϕ is the angle between the normal incident light and the main optical axis.

When ϕ is 45 degrees, the minimum CD is 0.054 m

That is, $AF = \frac{AB}{2\times sin\emptyset} = 4.08$ (eq. 2)

Then, $f = \frac{AB\times(1+cos\emptyset)}{4\times sin\emptyset} = 3.4825$ (eq. 3)

So, the bus parabolic equation is $x^2 = 13.93y$.

3.3 Focusing performance simulation

A solar concentrator with bus parabolic equation is $x^2 = 13.93y$, opening width and length is 5.77 m and 0.4 m respectively, is established. The solar sunshine constant is 1000 W m^{-2} and the lens reflectivity is 0.92. According to Monte Carlo ray tracing method and mirror reflection law introduced in literature, the energy flow distribution and energy size on the focal surface of the condenser are calculated Simulation. The sunlight perpendicular to the opening surface of the trough condenser is reflected by the condenser, and the energy is gathered on the focal surface and a spot is formed. The light path is shown in Fig. 2. The calculation results of the shape of the spot and the distribution of energy flow on the focal surface are shown in Fig. 3.

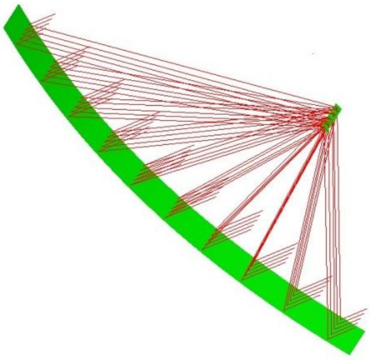
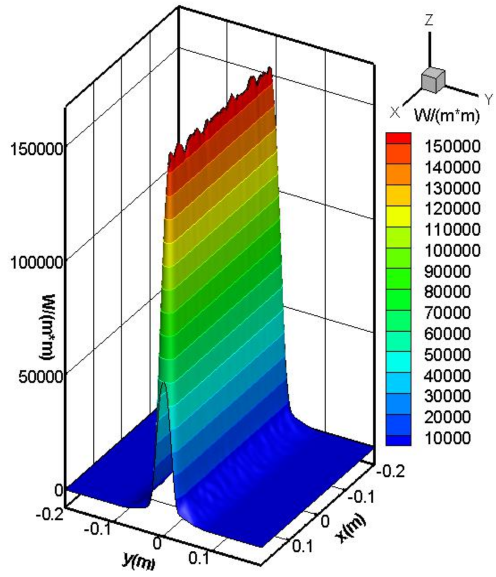
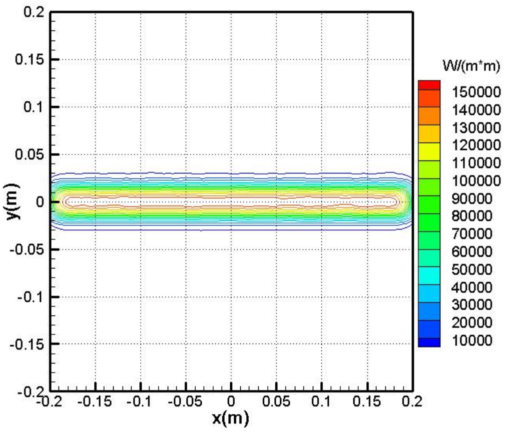


Fig. 2: Light path diagram



a) 3D display



b) 2D display

Fig. 3: distribution and size of energy flow in focal plane

As can be seen from Fig. 3, due to the existence of Fig. 2 light path diagram of the solar angle, the solar rays on the focal plane do not converge into a line, but form a rectangular region, with the peak energy of 1.5×10^5 W m^{-2}. The total energy received by the focal plane is 21233.6 W. When the aperture area of the trough condenser is $5.77 \times 0.4 = 23.08$ m^2, the total incident energy is 23080 W. Therefore, the focusing efficiency of the trough condenser is 21233.6/23080 = 0.974, and the error between the theoretical analysis and the simulation results is 2.6%.

On the other hand, the focusing energy is mainly concentrated in the range of ± 0.03 m on the focal plane, which is basically consistent with the theoretical calculation width of 0.054 m focal spot. This is mainly because the theoretically calculated focal spot width CD consists of CF and FD segments. In the theoretical calculation, it is assumed that CF and FD segments are equal, but in fact FD segment is slightly longer than CF segment, so the actual focal spot width should be slightly longer than CD.

4. Conclusion

4.1 When the opening width is fixed, in order to minimize the focal plane spot size, a reasonable trough solar reflector is designed. According to the Monte Carlo ray tracing method and the mirror reflection law, the focusing performance of a trough solar concentrator with an opening width of 5.77 m and a length of 0.4 m is simulated;

4.2 Due to the existence of the solar angle, the solar light does not converge into a line on the focal plane, but forms a rectangular region. The peak energy is in the center of the rectangular region, decreases outward along the length of the trough condenser, and is basically constant in the width direction of the trough condenser. The error between theoretical analysis and simulation results is 2.6% in terms of received energy on focal plane.

5. Acknowledgments

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