Research on Automatic Adaptation Method for Reflector of Linear Fresnel Collector

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Abstract. For the solar linear Fresnel collector, the arc of the primary reflective mirror is usually fixed to a certain degree, because of which, the light spot will be oversized when the solar incident angle varies within a certain range, thus affecting the concentration effect and the collecting efficiency. Moreover, the "edge effect" of the reflective mirror also has a detrimental effect on the concentration accuracy. Based on the theoretical analysis, this paper proposes a method to automatically adjust the arc of the primary reflective mirror in accordance with tracking angle, and then the method of solving the problem of edge effect is also suggested.

1. Introduction

As the core technology of medium- and high-temperature solar thermal power, solar concentration technologies are mainly divided into four types: solar power tower, parabolic trough solar power, solar dish-Stirling engine and linear Fresnel reflector power. Among them, the linear Fresnel solar reflective concentration system is simple in structure and production, low in operation costs, excellent in wind resistance, and more easily commercialized [1].

For the past decades, domestic and foreign technicians have conducted extensive researches on this technology. References [2], [3], [4], [5], [6], etc. have conducted deep studies on the most critical part, that is, the concentration system, and also have thoroughly analyzed the parameter optimizations on the aspects of the mirror width, mirror spacing, height and type of the receiver tube, and the secondary mirror curve and so on. Through these researches, useful explorations were made for linear Fresnel reflector power's practical application.

As shown in Figure 1, in linear Fresnel heat collection, the incident sunlight is firstly reflected by several rows of primary reflective mirrors to the heat collection pipe that are erected in the air, and then is collected into the heat collection pipe by the secondary concentrator outside the heat collection pipe, and finally solar energy is converged and absorbed. In the linear Fresnel concentration system, the performance of the primary reflective mirror has a great influence on its heat collection efficiency. Moreover, the accuracy of manufacturing and installation also greatly influences the heat collection efficiency.

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According to the material types, primary reflective mirrors can be divided into glass silver mirrors, high reflectivity aluminized mirrors, reflective film mirrors, among which glass silver mirrors are mostly used. According to the structure, there are mainly two kinds: single materials (glass silver mirrors, polished aluminum plate, etc.) and composite structures (reflective film + substrate). From the perspective of profile, the primary mirrors have two major categories: plane and micro-arc.

If the plane mirror is used as the primary reflective mirror, in order to prevent the light spot width from being too large, the demand of the opening width of the secondary reflective mirror is too strict, thus the width of the primary reflective mirrors at every row has to be compressed. To keep the same concentration effect, the rows of the primary reflective mirrors have to rise, and so does the cost. To solve the problem, the primary reflective mirror is usually designed to have a slight arc to reduce the spot width and improve the collection effect. However, the location of the receiver tube of the linear Fresnel system is fixed, a micro-arc mirror cannot always ensure normal incidence like trough system during tracking the sun, so the distance from the primary reflective mirror to the smallest spot always varies with light incident angle, that is, the spot size at the receiver tube varies. As shown in Figure 2, in certain angle range, larger width spot will occur at the receiver tube (this phenomenon is more pronounced on the outside mirrors), which leads the secondary concentrator to leaking light more seriously. To analyze this case, assuming the height $H$ of the receiver tube equals 4m, the horizontal distance $L$ from the primary reflective mirror to the receiver tube equals 5m, and the influence of the angle flare of sun is not taken into consideration. As is shown in Figure 2 (a), when the incident angle of the sun is 90°, the spot size of the reflected light on the receiver tube gets minimum, meanwhile, the focal length of the parabolic micro-arc reflective mirror is 6.61m. The situations of the incident angle being 30° and 150° are also respectively shown in Figure 2 (b) and Figure 2 (c). The calculation results of spot location and spot size based on different incident degrees are shown in Table 1. Obviously, position and size of the smallest spot on the receiver tube are very different with different incident angles, and such large spot on the receiver tube inevitably greatly affects the heat collection efficiency (The solar flare angle, processing and installation errors are not taken into account).
(a) Incident angle equals 90°

(b) Incident angle equals 30°

(c) Incident angle equals 150°

Figure 2. Focus situation of the micro-arc at the fixed focal length.

Table 1. Light spot size of the micro-arc at the fixed focal length.

| Micro-arc focal length (mm) | Solar incident angle (°) | Distance from mirror to minimum spot (mm) | Receiver tube spot width (mm) |
|-----------------------------|--------------------------|------------------------------------------|-------------------------------|
| 6610                        | 30                       | 3868                                     | 449                           |
| 6610                        | 90                       | 6021                                     | 14                            |
| 6610                        | 150                      | 6576                                     | 115                           |

In order to reduce the negative impact of the unfavorable situation mentioned above, even if a micro-arc mirror is used, the width of the primary reflective mirror cannot still be designed too large, which limits the benefits of the micro-arc scheme (namely maximizing the mirror width and reducing the number of rows number).

In addition, the cost of thermo-refracting mirrors is high, so the external force is generally used to form the arc. Because the glass deformation belongs to the elastic deformation, there will exist so-called “edge effect problem”. That is, the part near the edge of a curved surface has a problem of insufficient deformation due to its large rigidity, thus resulting in a certain gap between the curved surface and the ideal paraboloid, thereby leading to the problem of insufficient focusing accuracy.
2. Micro arc follow-up adjustment

According to the analysis above, if the condition that the smallest reflection spot exists on the receiver tube whatever the incident angle is can be ensured, the focal length of the reflective mirror should be constantly adjusted according to the variety of the incident angle. Under the condition of the previous assumption, the ideal focal lengths and arc heights required for the reflective mirror at each incident angle are calculated and plotted as shown in Figure 3 and Figure 4.

![Figure 3. The demand of focal length by ideal focus.](image)

![Figure 4. The demand of arc height by ideal focus.](image)

From the above calculation results, the range of the ideal focal length varies from 6021 mm to 10311 mm, and the corresponding arc height varies from 4.9 mm to 8.4 mm. It means that a follow-up mechanism on the reflector bracket needs be introduced to regulate the reflective mirror arc height to regulate the arc of the mirror in a wide range. This regulation certainly exists errors and it is difficult to achieve the desired level, but it is still sufficient to significantly improve the collection effect, thereby improving the heat collection efficiency of the system.

As mentioned above, there are two types of primary reflective mirrors at the aspects of structure: single material (glass silver mirror, polished aluminum plate, etc.) and composite structure (reflective film + substrate). In the first type, the ultra-thin reflective mirror (its thickness is about 1 mm) is glued on the prefabricated micro-arc component to form the mirror with the desired arc. In the second type,
the required arc is produced by the mechanical deformation of the plate mirror (its thickness is generally 2 ~ 4 mm). The mechanical deformation is produced by the pulling force, which is exerted by the reflective mirror, on the back of the mirror. The first type reflective mirror is manufactured in the factory with molds and bonding equipment. It is suitable for mass production and the installation cost is low, however, the manufacturing cost is high and it cannot adjust its arc during tracking the sun. The arc of the second type mirror is formed by the pulling force exerted by the bracket. The structure of the bracket is complicated and the on-site installation workload is heavy. However, it needs no mold, and the mirror manufacturing cost is low. What is more, the arc changes with the pulling force. Thus it is more suitable for small batches and personalized manufacturing. The micro-arc follow-up regulation scheme described here is only applicable to the first type reflective mirror.

The key to realize the micro-arc follow-up regulation is to make the structure simple, easy to manufacture and debug, and the cost should be controlled. Specific designs that includes levers, cams, and other options are no longer being described here.

3. Resolution of edge effects

Whether the first type scheme or the second type scheme is, the deformation of the glass is both belongs to the elastic deformation, so there will exist so-called "edge effect" problem mentioned above. The ultra-thin glass is utilized in the first type and its bending stiffness is small. Moreover, the reflector is totally adhered to the parabolic substrate by the adhesive, so the problem of the edge effect is not prominent, and the negative effect can be offset by optimizing the surface type of the shaped substrate. Thicker glass is selected in the second type, thus it has a higher stiffness. When a central point is extruded and emerge tensile deformation, the significant edge effect will appear, which results in insufficient focusing accuracy and a large spot size. In many cases, due to this reason, reflective mirror edge, whose width is 5 to 10 cm, is unable to participate in the heat collection.

For example, the thickness of the glass mirror is 2 mm, the width is 1076 mm, and the length is 1244 mm. The mirror is supported on both sides and its central tension arc is 12 mm high. In addition to the supporting forces on both sides, the mirror is also subjected to its own weight and central pull (or thrust) force. For the purpose of reducing the influence of the edge effect, the tension springs can be arranged at a certain distance from the two edges, as shown in Figure 5. The position of the tension spring and the strength of the tension force are optimally designed to maximally keep the arc of the curved surface of the glass close to the parabola, thereby enhancing the light concentration effect.

![Support](Figure 5. Stress condition of the reflective mirror.)

The three curves in Figure 6 represent the central single-point stretch (red), multi-point stretch with springs (blue), and the ideal parabola (green). Obviously, the central single-point stretch (without spring) curve is quite different from the ideal parabola, but the multi-point stretch curve with spring being applied is very close to the ideal parabola. The deviation, which is between the focal point and
the reflected light obtained at the focal plane by the normal incident light at different positions, is calculated and its curve is obtained as shown in Figure 7. The curve in Figure 7 shows that the spot size is narrow doubled after the multi-point spring tension method being used. The principle experiment also confirms this result.

Introducing the springs to realize multi-point stretching costs very little, and its workload of installation and debugging is nearly unincreased. So, by this method, the light collection effect can be improved at a small cost.

![Deflection (m) vs Width (m)](image1.png)

**Figure 6.** Comparison of mirror tensile deformation curves

![Light spot offset (m) vs Width (m)](image2.png)

**Figure 7.** Comparison of light spot size.
4. Conclusion
Aiming at the situation that light collection effect get worse because of the mechanical tensile deformation of the primary reflective mirror, the micro-arc follow-up regulation and multi-point stretching method can greatly improve the light collection efficiency under the condition of using the reflective mirror with large width, thus improving the heat-collecting efficiency of the linear Fresnel.

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References
[1] Xiong Yonggang, Liu Yuwei, Chen Hongjing, etc. Brief introduction of reflector linear Fresnel technology for high temperature thermal power generation in solar energy, J. Solar Energy. 6 (2010) 31-33
[2] Zhou Xiaoquan, Zhou Haini, Tan Yongchao, etc. Optimum layout of linear Fresnel reflector solar collector system and development & application of optical performance, J. Research & Exploration in Laboratory. 10 (2012) 306-309
[3] Du Chunxu, Wang Pu, Ma Chongfang, etc. Optical geometry method for unobstructed mirror field arrangement in linear Fresnel concentrating system, J. Acta Optica Sinica. 30 (2010) 3276-3282
[4] Ouyang Haiyu, Niu Yugang, Wang Haolin, etc. Design of the micro-arc linear Fresnel solar collector, J. Electrical Automation. 37 (2015) 41-44
[5] Du Chunxu, Wang Pu, Wu Yuting, ect. Comparison of optical properties of different Fresnel mirror fields, J. Solar Energy.34 (2013) 1353-1359
[6] Zhu Yanqing, Li Yujian, Wang Leilei, etc. Design and experimental study of linear Fresnel reflector solar collector system, J. Advance in the New and Renewable Energy. 2 (2014) 117-121