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A review of available methods for the alignment of mirror facets of solar concentrator in solar thermal power system ☆

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ABSTRACT

In the concentrated solar power system, the mirror facets of the solar concentrator have to be aligned correctly in order to obtain an optimally focused solar flux at the receiver. In mirror assembly, therefore, it is necessary to develop an accurate, inexpensive and fast measurement method to facilitate the installation and operation of the solar concentrator. In this paper, the available methods for the mirror facet alignment are reviewed. Three kinds of methods including on-sun single mirror facet alignment, mechanical alignment and optical alignment are reviewed in detail. The advantages and disadvantages of these methods are analyzed and discussed. Finally, some future developments are considered.

Contents

1. Introduction

The concentrated solar power (CSP) technology is playing an important role in the expansion of renewable energy applications [1–4]. This technology encompasses four main technologies: the power tower, the parabolic trough, the dish/Stirling, the linear Fresnel. The beam-down is also gaining recognition. In the CSP system, the solar radiation is firstly focused by the concentrator onto the receiver. Circulating fluid in the receiver is heated to provide conventional thermal power generation. The solar concentrator occupies 30–50% of the total cost [5] of the CSP system and its optical performance greatly affects its efficiency. In order to obtain the maximum concentrated solar flux on the receiver, the mirror facets of the concentrator have to be aligned precisely. The mirror facets need to be aligned in orienting (normal direction)

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the mirror surface and in some cases also involves properly shaping (vector height) the mirror. The normal direction alignment of the mirror facets is more important due to the larger influence of the normal direction on the solar flux concentrated on the receiver. The normal direction of a mirror facet can be aligned by canting the mirror surface.

With the development of the CSP, many available methods for the mirror facets alignment have been proposed. In the late1970s, Oldham developed a collimated laser beam method to align the heliostats in a 5 MW Solar Thermal Test Facility [6]. The mirror facets were aligned by reflecting a 1.2 m wide collimated laser beam off from each facet to a specific position on the tower. This method is accurate but very time consuming. In addition, the alignment equipment is huge. About one decade later, Wood developed a distant observer technology to align a parabolic trough concentrator with much more compact equipment [7]. For this technology, the observer can see the Heat Collector Element (HCE) black color completely filling the mirrors, when the concentrator is pointing straight at the observer, the mirrors and HCE are perfectly aligned. This method permits rapid alignment of the mirrors, but the calculated distance needs to be long enough so that it is effectively infinity for the concentrator. Therefore, the above method has its own shortcoming. In 1995, Diver proposed specific requirements for the mirror facet alignment method. These requirements include: (1) the method should be easy to setup and implement; (2) the method has minimum requirement on the sophisticated hardware; (3) the method allows the accessibility to the mirrors for adjustment without needing to remove the receiver and without requiring an absence of sunshine. In addition, there are normally thousands of concentrators in a CSP system and each concentrator has a large size and many mirror facets in general. Therefore, a fast measurement method for the mirror facet alignment in the installation and operation of the solar concentrator field is needed.

Many methods have been put forward and applied in the past 30 years. These methods can be divided into three main kinds based on the alignment characteristics. The first kind is the on-sun single mirror facet alignment method. The second kind is the mechanical alignment method by using gauge blocks or

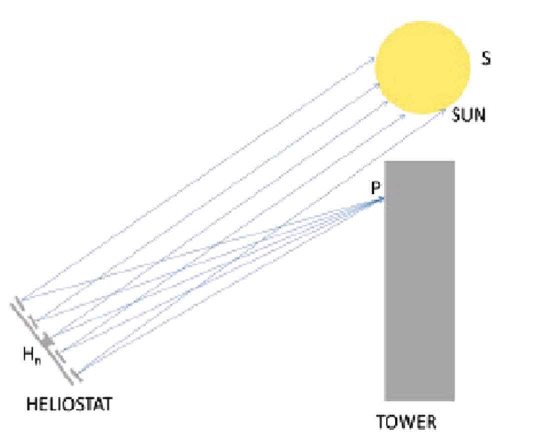

Fig. 1. Schematic of the on-sun single facet alignment method [9].

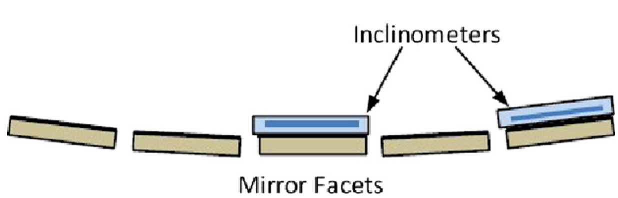

Fig. 2. A schematic of the inclinometers method to cant the mirror facets [13].

inclinometers. The third technique is the optical alignment method based on image processing and photographic techniques. In this paper, these three kinds of the mirror facet alignment methods are presented. The advantages and disadvantages of these methods are analyzed and discussed in detail. And finally, the outlook for this evolutionary technology is examined.

2. Techniques for the mirror facet alignment

2.1. On-sun single mirror facet alignment method

The on-sun single mirror facet alignment method was widely used in CSP systems in the early years of development [8–12]. In this method, the position of the sun is assumed unchanging during the alignment process of the solar concentrator. The central mirror facet is aligned first, and then the remaining mirror facets are aligned sequentially. One can assess the positional displacement of any facet by comparing the observed beam 'spot' at the receiver with the predicted 'spot' for an ideal concentrator. In the 1970s, the NSTTF began to use this method to align the heliostats [8]. A schematic of this method is shown in Fig. 1.

In order to implement the above technique, it is not necessary to know the surface shape of the solar concentrator. The alignment is easy and relatively inexpensive. However, this method can only be used on an already installed CSP system, and only during periods of good sunshine. Moreover, when the chosen mirror facet is being aligned, the remaining already focused facets have to be covered to prevent their light spots from hindering adjustments on the facet of interest. Therefore, although this method is qualitatively simple, it is more time consuming and less accurate than some alternatives.

2.2. Mechanical alignment methods

The heliostats employed in the power tower system have the longest focal length of currently available solar concentrators. It usually consists of an array of rectangular mirror facets which have small curvature. The mirror surfaces can generally be regarded as flat surfaces. In this case, the heliostats can be aligned in the factory by employing the mechanical methods outlined below.

During early development of the power tower system, the gauge block method was used to set the mirror facet angles [13]. The position of the heliostat with respect to the tower in the center of the heliostat field needs to be known in order to determine the canting angle of each mirror facet. The heliostat is positioned horizontally during the alignment process. The reference plane can be defined by calculation, and hence the gauge blocks can be made for aligning the mirror facet. The specified gauge block is then used to set up the 'ideal' position of the mirror facet to as high accuracy as the manufacturing process allows.

Considering that the gauge blocks method requires a very large number of blocks, an improvement called the inclinometers method has been evolved and applied by the NSTTF [9,13]. Before aligning the mirror facets, the theoretical tilt angles of the mirror facets are calculated according to the position of the heliostat. The face of the heliostat is inclined upwards when aligning the mirror facet. Since the inclinometer in question can only measure one angle accurately, the vertical tilt of the mirror facet and the horizontal tilt angle must be measured separately. A schematic of the inclinometers method used to determine the cant of the mirror facets is shown in Fig. 2.

Other inclinometer mechanical methods employing linear displacement transducers have been implemented at Solar One station [9,10]. This method uses a transit made of a bubble-leveled rod to provide the reference plane for displacement measurement.