Available online at www.sciencedirect.com
SCIENCE DIRECT®
Solar Energy 79 (2005) 280–289
SOLAR ENERGY
www.elsevier.com/locate/solener

Report on the second prototype of non-imaging focusing heliostat and its application in food processing

Y.T. Chen *, K.K. Chong, C.S. Lim, B.H. Lim, B.K. Tan, Y.F. Lu

Department of Astronomy and Applied Physics, University of Science and Technology of China, China

Received 12 January 2004; received in revised form 13 November 2004; accepted 13 November 2004
Available online 31 December 2004

Communicated by: Associate Editor Lorin Vant-Hull

Abstract

Following our previous report on the first prototype of non-imaging focusing heliostat, this second prototype has presented much improvement not only in the respect of structure but also in the method of controlling. The principle and practice of these changes have been reported in the article. The development of the new heliostat which is closer to cost effectiveness may bring some commercial interest. Solar potato peeling studied here is provided as one example.

Keywords: Non-imaging focusing heliostat; Spinning-elevation tracking; Solar potato peeling; High temperature solar furnace

1. Introduction

In contrast to the traditional heliostat, a non-imaging focusing heliostat has no fixed optical geometry but consists of an array of many small movable element mirrors to eliminate first-order aberration during the sun tracking. The merit of this new device is that the use of spinning-elevation tracking method (in this method, the array of mirrors spins about an axis pointing towards a fixed target, such that the normal of the array remains within the tangential plane (the plane including the sun, central mirror, and target). See (Chen et al., 2001) and also briefly as in the appendix of this article) allows the movements of all the mirrors in the heliostat frame to be grouped according to a certain regulation. The theory and practice of the new heliostat were studied in the previous publications for various applications to harness solar energy (Chen et al., 2001; Chen et al., 2002; Chen et al., 2003; Chen et al., 2004). In the first publication, new sun tracking formulas were derived based on the non-imaging optical concept to focus the solar beam (Chen et al., 2001). The subsequent publication in 2002 reported the practical experience of the first prototype in the mechanical design, optical alignment and its application as high temperature solar furnace (Chen et al., 2002). However, further study shows that the design of first prototype can be improved by modifications to simplify driving mechanism and make the device much more cost effective.

There are two major drawbacks in the design of the first prototype of non-imaging focusing heliostat. First drawback is that the centre of gravity of the heliostat frame is too far away from the central line of the pedestal and that will pose structural problems during the designing of a larger device. Second drawback is that each heliostat with $M \times N$ element mirrors shall require

* Corresponding author. Fax: +86 551 3606941.
E-mail address: ytichen@ustc.edu.cn (Y.T. Chen).

0038-092X/$ - see front matter
doi:10.1016/j.solener.2004.11.008

Nomenclature

L	horizontal distance from the intersection point between spinning-axis and elevation-axis to target point (or so-called slant range)
H_x	perpendicular distance between the centre of master mirror and the central line of the row where the slave mirror concerned is located
H_y	perpendicular distance between the centre of master mirror and the central line of the column where the slave mirror concerned is located
H_z	offset distance between reflector and the plane that contains elevation-axis (it is normally identical for all the mirrors)
θ	incidence angle of sunlight relative to the heliostat frame
H_x°	average of all the absolute values of H_x for every row excluded central row
H_y°	average of all the absolute values of H_y for every column excluded central column
$\sigma^\circ_{\text{upper}}$	tilting angle of slave mirror about the axis parallel with the row of mirrors for those mirrors located at upper rows (or those mirrors above central row). It is expressed in Eq. (2)
$\sigma^\circ_{\text{lower}}$	tilting angle of slave mirror about the axis parallel with the row of mirrors for those mirrors located at lower rows (or those mirrors below central row). It is expressed in Eq. (3)
γ°	tilting angle of slave mirror about the axis parallel with the column of mirrors. It is expressed in Eq. (4)
β	sun altitude angle defined in the fixed coordinate system
ρ	rotation angle of the spinning axis of the heliostat frame or sun azimuth angle defined in the fixed coordinate system
λ	target angle of non-imaging focusing heliost at ($\lambda = 0^\circ$ if the heliostat is of the same level height as the target and $\lambda = 10^\circ$ if the line along the spinning axis of heliostat to the target is rotated clockwise by 10° from horizontal line)

$M + N - 2$ additional mechanisms to adjust the slave mirrors, making the design much more complicated and costly. In this paper, we would like to report on the second prototype heliostat that was designed intending to overcome the above problems.

One of the major applications of this second prototype is to peel potatoes using highly concentrated sunlight. In fact, potato is the most demanded food in the world with annual production of nearly 400 million tonnes. One of the major losses of the product is peeling. Mechanical peeling or even steam peeling will make 12–15% of loss, with an effect not only in material loss but also environmental impact due to the waste. Laser peeling can bring less loss e.g. 4% or so (Rigdon, 1991; Teresko, 1991). The high cost in equipment and running have greatly hindered the prevailing use of this technology. For an alternative method, we studied the possibility of potato peeling using concentrated solar energy. In this respect, the results of solar potato peeling with different experimental set-ups using the second prototype of new heliostat are discussed.

2. Second prototype of non-imaging focusing heliostat

Non-imaging focusing heliostat performs two functions concurrently, they are primary tracking so that the focusing spot is always at a fixed target and secondary tracking to correct the aberration spread of the focusing spot. Hence, the heliostat will have two major tracking mechanisms: global movement of the heliostat frame and local movement of the slave mirrors relative to the heliostat frame. The second prototype heliostat consists of 81 glass mirrors, each with a dimension of 40 cm × 40 cm. Mirrors are arranged into nine rows and nine columns with gap spacing of 0.5 cm between them to avoid blocking each other when tilted.

The second prototype is more than three times larger than the first prototype with a total collecting area of 12.96 m^2. When the scale goes up, more challenges in mechanical design arise. One of them is the rigidity of the heliostat structure. It was realized that when the large-scale heliostat is designed, the U-shape arm in the first prototype would become impractical. The second challenge is the number of driving devices for the slave mirrors. According to our first prototype, the more mirrors there are, the more driving devices would be needed. Therefore, how to simplify the driving mechanism of slave mirrors becomes a research topic in the further development of designing of non-imaging focusing heliostat.

2.1. Simplification of the secondary tracking

To consider the simplification form, let us go back to the mathematical analysis for aberration correction,