Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 111 (2015) 252–263

SOLAR ENERGY

www.elsevier.com/locate/solener

Study on the heliostat tracking correction strategies based on an error-correction model

Feihu Sun, Minghuan Guo, Zhifeng Wang *, Wenfeng Liang, Zijian Xu, Yulei Yang, Qiang Yu

Key Laboratory of Solar Thermal Energy and Photovoltaic System of Chinese Academy of Sciences, Institute of Electrical Engineering, Beijing 100190, China

Received 6 January 2014; received in revised form 29 May 2014; accepted 9 June 2014
Available online 22 November 2014

Communicated by: Associate Editor Lorin Vant-Hull

Abstract

A more accurate heliostat tracking model is needed because current low cost heliostats have error sources that increase the complexity of the heliostat tracking control system and reduce heliostat tracking accuracy. This paper presents the computational process of the six angular parameters, including tilt angle and tilt azimuth angle of the azimuth axis, initial azimuth angle, dual-axis non-orthogonal angle, initial elevation angle and canting angle of the mirror surface plane relative to the elevation axis, as determined by the authors' tracking error correction model and the Hartley–Meyer solution algorithm. To effectively improve the heliostat tracking accuracy, this paper uses two sets of the six angular parameters from the heliostat tracking test data with segmentation of the daytime at the solar noon. Tracking tests with a beam characterization system (BCS) performed on two heliostats in the DAHAN solar power tower plant showed that the calculated heliostat tracking angles corresponding to these two sets of angular parameters were more accurate and could effectively reduce tracking errors. In order to maximize heliostat tracking accuracy, a preliminary combination of the tracking angle bias strategy and the error-correction model was also successfully conducted in this paper.

Keywords: Heliostat; BCS; Geometrical errors; Tracking error; Tracking angle

1. Introduction

Solar power tower plants use heliostats to reflect incident sunlight onto a receiver to convert the reflected solar beam into thermal energy. Electricity is then generated from a high temperature heat transfer medium. Tracking accuracy is a significant matter in a solar power tower plant. Improvements in heliostat tracking accuracy may significantly increase power plant performance.

The ideal heliostat tracking angles without any tracking error can be precisely calculated based on the accurate solar position angles calculated using astronomical formulas (Reda and Andreas, 2004; Blanco-Muriel et al., 2001). However, various tracking errors (Baheti and Scott, 1980; Stone and Jones, 1999; Berenguel et al., 2004) result from the manufacturing, installation and operation of the heliostat. Errors may include the tilt angle and tilt azimuth angle of the azimuth axis in the vertical direction, the mirror-pivot offset from the heliostat pivot to the mirror surface plant, the dual-axis non-orthogonal angle, the canting angle of the mirror surface plane relative to the elevation axis, azimuth reference bias, elevation reference bias, sun position algorithms, atmospheric refraction, gravity bending and computation time errors. Therefore, correction strategies are needed to improve heliostat tracking accuracy.

* Corresponding author. Tel.: +86 10 62520684; fax: +86 10 62587946.
E-mail address: zhifeng@vip.sina.com (Z. Wang).

http://dx.doi.org/10.1016/j.solener.2014.06.016
0038-092X/© 2014 Published by Elsevier Ltd.

Nomenclature

O_0	origin of the heliostat field coordinate system
O	heliostat pivot
M	mirror surface center (orthogonal projection of the heliostat pivot on the mirror surface plane)
T_0	aim point or receiver aperture center
γ, α	Azimuth tracking angle and altitude tracking angle (°)
α_s, γ_s	solar altitude angle and solar azimuth angle along the north-to-east direction (°)
$OT_0, \vec{t}$	spinning axis vector of a receiver-oriented tracking heliostat or the vector for O to T_0; $\vec{t}$ is the unit vector of OT_0
L	length of OT_0 (m)
θ	nominal incident angle relative to the heliostat pivot (°)
τ	incident angle calibration for mirror-pivot offset (°)
H_z	mirror-pivot offset from the heliostat pivot to the mirror surface plane (m)
$\vec{n}$	unit mirror-surface-center normal vector
ψ_t, ψ_α	tilt angle and tilt azimuth angle of the azimuth axis from the vertical direction for altitude-azimuth tracking (°)
τ_1	dual-axis non-orthogonal angle (^{0})
μ	canting angle of the mirror surface plane relative to the altitude axis (°)
γ_0, α_0	initial azimuth tracking angle and the initial elevation tracking angle (°)
$\gamma_{0\text{-}pri}$, $\alpha_{0\text{-}pri}$	primary initial azimuth angle and primary initial elevation angle, derived at the beginning of the heliostat installation (°)
$\Delta\gamma$, $\Delta\alpha$	corrections of the γ and α, calculated by the tracking angle bias strategy (°)

The tracking angle bias strategy (Berenguel et al., 2004), aim point move strategy and the error-correction model (Baheti and Scott, 1980; Khalsa et al., 2011; Guo et al., 2012) are three common correction strategies (Jones and Stone, 1999) that are widely used to improve heliostat tracking accuracy. Baheti and Scott (1980) presented a mathematical model for the six installation coefficients and drive errors, and the difference between commanded and actual drive angles using the coordinate transformation method based on the azimuth-elevation tracking geometrical relationship. Khalsa (Khalsa et al., 2011; Smith and Ho, 2013) characterized the drive-axis non-orthogonality and the boresight error based on the mathematical model presented by Baheti and Scott. Here, an eight-dimensional error-correction model was presented and the eight coefficients were estimated by fitting observed errors in the reflected beam centroid to the error-correction model using the least squares regression technique. The observed errors were measured by the heliostat spot acquisition system comprised of a camera, zoom lens and image processing software similar to BCS.

The neural network model (Park, 2012), trained by the extended Kalman filter algorithm, was used to compensate the heliostat sun tracking error in a 200 kW solar thermal power plant (Daegu, Kyungsangbukdo, Korea). The observed errors were measured by BCS.

Guo et al. (2011) developed a set of general azimuth-elevation tracking angle formulas for a heliostat with a mirror-pivot offset and other geometrical errors. Guo et al. (2012) also presented an error-correction model with six angular parameters with respect to the fixed geometrical errors. The six angular parameters were the tilt angle, the tilt azimuth angle of the azimuth axis, the dual-axis non-orthogonal angle, the canting angle of the mirror surface plane relative to the elevation axis, the initial azimuth angle from the initial angle position to the zero angle position (also the angular difference between the real zero angle position and the nominal zero angle position of the azimuth axis), the initial elevation angle (the angular difference between the real zero angle position and the nominal zero angle position of the elevation axis) as shown in Fig. 1 (Guo et al., 2013). The six angular parameters for a specific azimuth-elevation tracking heliostat obtained from the experimental tracking data using the classical Hartley–Meyer solution algorithm were input into the set of general azimuth-elevation tracking angle formulas. Accurate heliostat tracking angles were then obtained.

In this paper, two potential application cases with different tracking test modes of Guo's heliostat tracking error correction model will be introduced. This paper will present the heliostat tracking model with two sets of the six angular parameters from the heliostat tracking test data with segmentation of the daytime at the solar noon in the case two test mode. This paper will also study a preliminary combination of the tracking angle bias strategy and the error-correction model.

2. Heliostat field control system

The DAHAN solar power tower plant (Wang et al., 2007) was constructed in Yanqing, Beijing as part of a China National High-Tech R&D project (863 plan). The power plant was completed at the end of 2011 by the Institute of Electrical Engineering, Chinese Academy of Sciences. The heliostat field consists of 100 heliostats. Each heliostat has a reflecting area of 100 m^2 and 64 square facets arranged in 8 rows and 8 columns. The local heliostat control system uses the azimuth-elevation tracking mode with the azimuth axis as the fixed primary axis and the elevation axis as the secondary axis.