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Long-distance flux mapping using low-cost collimated pyranometers

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Abstract

Concentrating solar thermal power tower plants with capacities of 100 MWe or greater require large heliostat fields with heliostats over 1500 m (nearly a mile) away from the tower. The accuracy and performance of these heliostats must be evaluated and understood as new heliostat designs emerge to reduce costs. Conventional beam characterization systems that use photographs of the reflected beam on a tower-mounted target are typically not large enough to capture the beam at long distances, and the magnitude of the irradiance for long-distance heliostats is quite low (only a fraction of a sun), which can make the beam image difficult to discern from the ambient lighting on the target. The Long-Range Heliostat Target (LRHT) implements a technique for mapping low density flux images from heliostats and reflectors at slant ranges up to approximately 1700 m.

The LRHT is a vertical array of collimated pyranometers deployed to a test site via flat-bed trailer and quickly erected on an aluminum truss tower. Once the sensors have been aimed at the heliostat, the heliostat beam is swept azimuthally across the array whereupon the data is stitched into a flux map indicating horizontal and vertical beam dimensions and flux intensities. The LRHT was used to evaluate and compare beam shape, peak flux, and total power of heliostats and single facet reflectors at distances from 300 to 1700 m. Results were compared to theoretically rendered flux maps created by computational ray tracing algorithms, and to photographs taken on the beam characterization system (BCS) at the National Solar Thermal Test Facility at Sandia National Laboratories.

Keywords: Collimated pyranometers; Flux mapping; Heliostat; Beam characterization

1. Introduction

Large capacity concentrating solar thermal power tower plants currently require large heliostat fields with heliostats over 1500 m (nearly a mile) away from the tower. As new heliostat designs emerge, there is a need to evaluate the accuracy and performance of these heliostats at great distance. Beam characterization systems (BCS) that use photographs of the reflected beam on a tower-mounted target are often not large enough to capture the beam at great distances. In addition, the magnitude of the irradiance for long-distance heliostats is only a fraction of a sun, which can make the beam image difficult to discern from the ambient lighting on the target. Furthermore, it is often necessary to test heliostats at multiple distances well before a site is even constructed. This paper presents a new portable Long-Range Heliostat Target (LRHT) that has been developed to evaluate the flux distribution received from these long-distance heliostats to ensure that they meet requirements for optical accuracy and intensity. Section 2 describes the set-up and use of collimated pyranometers to make flux maps. Section 3 evaluates the LRHT makes comparisons to other flux mapping techniques. Section 4 presents results from testing performed on the LRHT with an emphasis on the performance of the LRHT rather than the experimental conclusions.

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2. Approach

The reflected beam from the heliostat is characterized using low cost photodiode-based LI-COR LI-200SA pyranometers that were fitted into PVC collimators. The LRHT is comprised of a lightweight telescoping aluminum tower mounted on a mobile flatbed trailer. The collimated pyranometers were mounted in a vertical column over the height of the tower, aimed at the heliostat, and wired to an onboard solar powered data acquisition system (see Fig. 1). Set-up of the LRHT currently requires at least two people, a fork lift, a boom lift, and takes approximately 12 h to complete. Once set-up is complete, the sensors can be aimed at a new target within a 180° field in about 2 h. Aiming is performed by holding the beam on target while a technician in a boom lift swivels the sensors about two axes to maximize the flux reading in each sensor. Simple electronic tools have been devised to aid the technician in quickly finding the maximum reading with audio and visual indicators.

During a test, the heliostat beam is swept horizontally across the LRHT at an even rate. The values are logged at high frequency yielding an irradiance distribution along discrete horizontal transects corresponding to the heights of the sensors. The transects are then stitched together and interpolation is used to render the entire irradiance distribution.

2.1. *Collimated pyranometers*

The collimation process makes pyranometers respond like pyrheliometers by only allowing light at less than a 5° angle-of-incidence to reach the sensor. In this configuration the LI-COR flux reading agrees with the Eppley normal incidence pyrheliometer (NIP) within 0.5%, but costs approximately 90% less and has a much faster response time. (King et al., 1998) The cost of a LI-COR 200SL50 is approximately $300 plus inexpensive PVC collimator materials and assembly labor. A pyrheliometer can cost approximately $3000.

2.1.1. *Pyranometer response*

LI-200 pyranometers have a linear response range up to 3000 W/m^2 which is an adequate threshold for long distance heliostats but often too low to characterize heliostats at close range. Furthermore these pyranometers may warp if the temperature exceeds 80 °C. The pyranometers can detect small differences in flux levels with a resolution of approximately 0.1 W/m^2. LI-200 have a bias error of 1% up to 3000 W/m^2 and a random error up to 5% and a stability error less than 2% per 1 year period. The sensors used in this paper were less than 2 years old. The error statistics are a worst case value taken over the entire range of full light intensities form 0 to 3000 W/m^2 (LI-COR Biosciences, 2005). In addition to the error associated with the pyranometers there is a 2% error from the aiming process plus a .78% calibration error. The background irradiance entering the collimated sensor was on the order of 2 W/m^2 and was subtracted from the flux measurements. The error was lumped together into a generalized error of 10% and applied to stated flux values below. The pyranometer heights were measured from the deck of the trailer and are accurate to within 1.25 cm.

The LRHT requires a fast response time from the sensors. A complete beam sweep typically takes less than three seconds. The LI-COR LI-200 specifies a response time of 10 μs while the Eppley normal incidence pyrheliometer (NIP) specifies a 1 s response time. The LRHT uses sampling intervals on the order of 0.01 s so response time induced error is not a significant factor. A test was devised to compare the response of the Eppley NIP to the collimated pyranometer. Both devices were mounted and pointed at a heliostat beam while voltage was logged at 100 Hz in order to characterize the data from each type of sensor (Fig. 2). Fig. 3 shows that the LI-COR was able to reach its final voltage sooner than the NIP. Unlike the NIP, the LI-COR is sensitive to the periodic tracker adjustments which can be observed as little spikes in Fig. 3 occurring every 10 s.

2.2. *Flux mapping*

Calibrated data from the LRHT is rendered as a contour plot. The horizontal x-axis represents the beam width and is the product of beam's sweep rate ω_s, distance from reflector to target r, and time t. Sweep rate of the beam is a

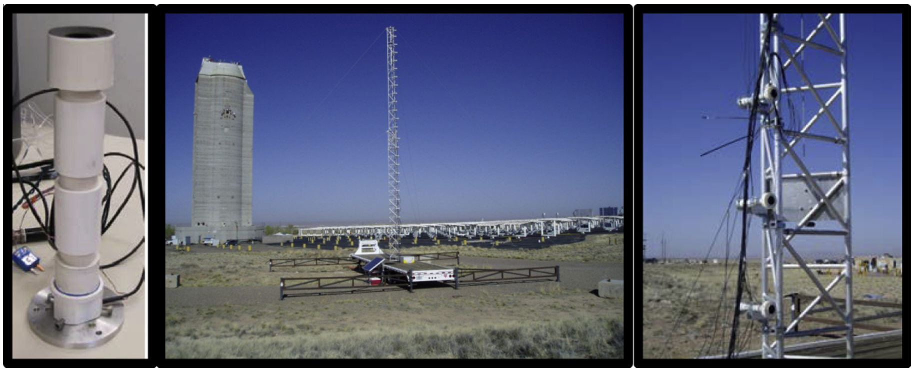

Fig. 1. Left: collimated LI-COR pryanometer. Middle: photo of trailer-mounted mobile heliostat target with NSTTF central receiver tower in background. Right: close-up of collimated pyranometers mounted on aluminum tower.