CONCENTRATION IMAGE PROFILES OF THE HIGH-FLUX SOLAR FURNACE OF CIE-UNAM IN TEMIXCO, MEXICO. FIRST STAGE

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Abstract

In the present work, the analysis of the first images obtained from de Solar Furnace of High Radiative Flux in Mexico is presented. The solar furnace has five different focal distance groups. The images were acquired using the first two groups of mirrors from complete optics of main concentrator. We used a Heliostat with a reflective surface of 36 m². The Images was captured with a CCD camera and the irradiance profile was modeled with a ray-tracing program in order to estimate the global optical error for the concentrator-heliostat optical system. The results shows that the optical error is less to 3 mrad and the calculations indicates that the flux peak for the complete groups of mirrors could be higher than 12 000 suns and the average flux could be higher than 5,000 suns.

Keywords: Optical error, Optical design, Ray tracing, Solar furnace, Solar concentration system.

1. Introduction

In March 2011, a high flux solar furnace (HFSR) (figure 1) was officially inaugurated in the *Centro de Investigación en Energía* (Center for Energy Research) of the Universidad Nacional Autónoma de México (CIE-UNAM) [1]. The optical design of this facility was carried out through simulations with the ray-tracing program Tonalli [2], looking for an optimal ratio between the number of facets, the optical error and the focal length of the focusing system [3]. The optical design includes a total of 409 facets, divided into 5 different focal lengths (figure 2). In the first stage of this project a 36 m² heliostat was installed for the initial operation tests. This heliostat is not specifically designed for the solar furnace and a second 81 m² heliostat is being installed to cover the complete reflective surface of the main concentrator.

Fig. 1. Outside picture of the HSAFR with groups A and B mirrors and 36 m² heliostat.

The mirrors and structure for the main concentrator were provided by the *Instituto Nacional de Astrofísica Óptica y Electrónica* (INAOE). The mirrors were made using floating glass with thin layer of aluminum and Silicon dioxide coating to avoid the corrosion. The effective reflective area of the main concentrator is 36 m², and the nominal power on the focal zone is 30 kWt approximately. A second 81 m² heliostat is been installed to cover the complete reflective surface of the main concentrator and the following studies will be realized to evaluate

We began the testing of the different components of the solar furnace, including the tests for acquisition data system, the vision system and the optical evaluation and the measurement of solar concentrated flux. This paper presents a comparison of the first images obtained experimentally from the HFSF for the 36 m² heliostat and the modeling images obtained by ray tracing program. An estimation of the global optical error of the Heliostat-Concentrator system is done on this basis.

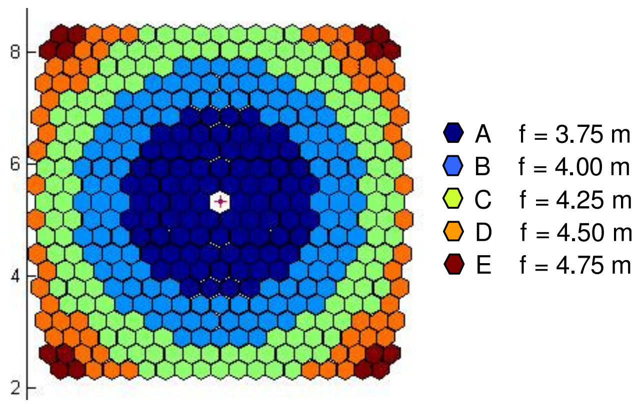

Fig. 2. Focal length groups for the HFSF

2. Methodology

We conducted an experimental campaign using the 36 m² heliostat and the group of mirrors A from HFSF. To obtain the concentrated solar irradiance profiles from the Heliostat-Concentrator system, a cooled diffusing screen was placed at the focal zone. A CCD sensor *Allied pike*, was fixed in front of screen (figure 3). Several optical filters were used for optimize the resolution of the camera and the blinds were fixed with an aperture of 100%.

Each image was analyzed with a computer program to obtain a centred image from the solar spot and the irradiance profile at two orthogonal directions. Figure 4 shows and example of experimental image, the following steps to process the image and the resulting irradiance profile from the computer code.

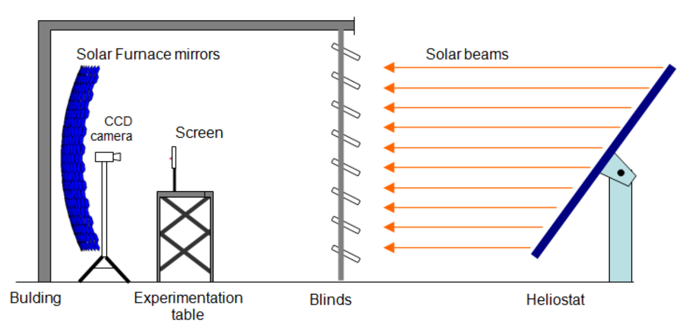

Fig. 3. Schematic arrangement of the experimental setup

The images obtained were compared with the results of the ray-tracing program Tonalli [2]. The code calculates the irradiance flux on a focal plane by using the convolution technique. We assume that the error distribution corresponds to a bidimensional Gaussian distribution characterized by a global standard deviation. The sun's model was taken from a standard solar radiation cone [4].

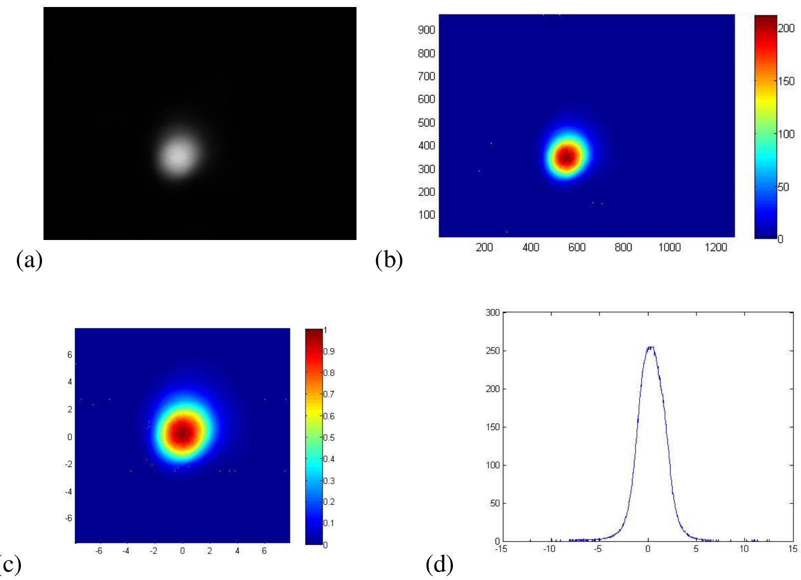

Fig. 4. (a) CCD picture from spot at the receiver at the focal point. (b) Picture translated to the computer for processing. (c) Image centered and processed. (d) Irradiance profile from the solar spot

3. Results

The images from CCD camera were analyzed, and we compared the profiles of irradiance in two orthogonal directions (horizontal and vertical) against the theoretical profile obtained for the global optical error, which gave the best fit with the experimental curve. Figures 5 and 6 shows examples of graphs obtained for the optimal adjustment in the horizontal and vertical image for first two images as an example. Table 1 shows the summary of results for each of the images. These values suggest that the global optical error, for 36 m² heliostat, is approximately 2.7 ± 0.2 mrad. It is important to note that this error does not include the tracking error of the heliostat along the solar day.

Image	**Optical error, horizontal profile [mrad]**	**Optical error, vertical profile [mrad]**
Image 1 (36 m² heliostat)	2.8	2.8
Image 2 (36 m² heliostat)	2.8	2.8
Image 3 (36 m² heliostat)	2.8	2.4
Image 4 (36 m² heliostat)	2.8	2.2

Table 1. Estimated optical error from different experimental images

Figure 5 and 6 only presents the adjustment in particular directions from the images, but they cannot show the symmetry of the image compared to those expected theoretically. Figure 7 shows theoretical and experimental comparison of the contours of the irradiance distributions at the receiver for image 2. The experimental and theoretical distributions were normalized respect the peak. The data correspond to theoretical modeling of group A with an optical of 2.8 mrad. The figure shows a relative good correspondence with experimental results except in the lower contour in which there is a deviation from the circular shape of the image.

(a) (b)

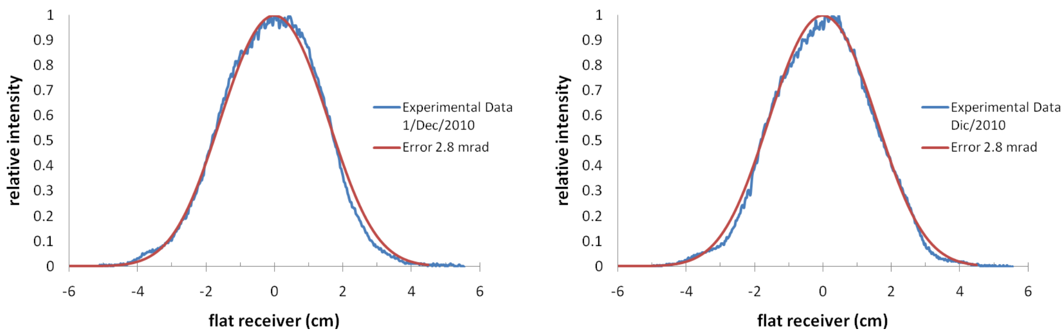

Fig. 5. Comparison of experimental and theoretical irradiance profiles for image 1taken with the heliostat 36 m². (A) Vertical profile. (b) Horizontal profile

(a) (b)

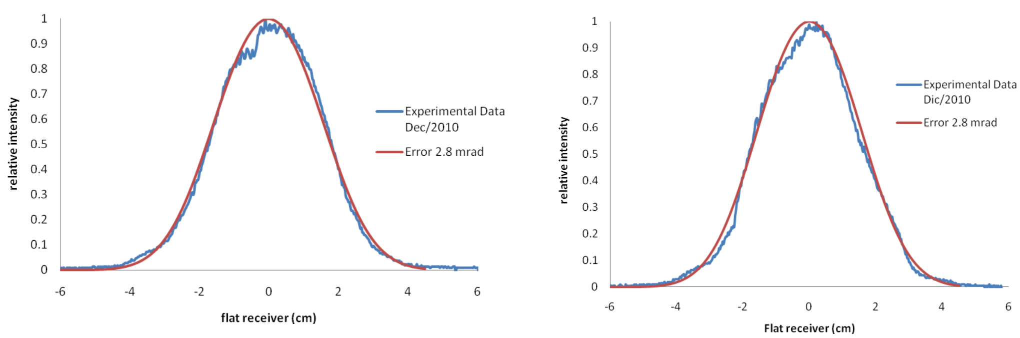

Fig. 6. Comparison of experimental and theoretical irradiance profiles for image 2 taken with the heliostat 36 m². (A) Vertical profile. (b) Horizontal profile

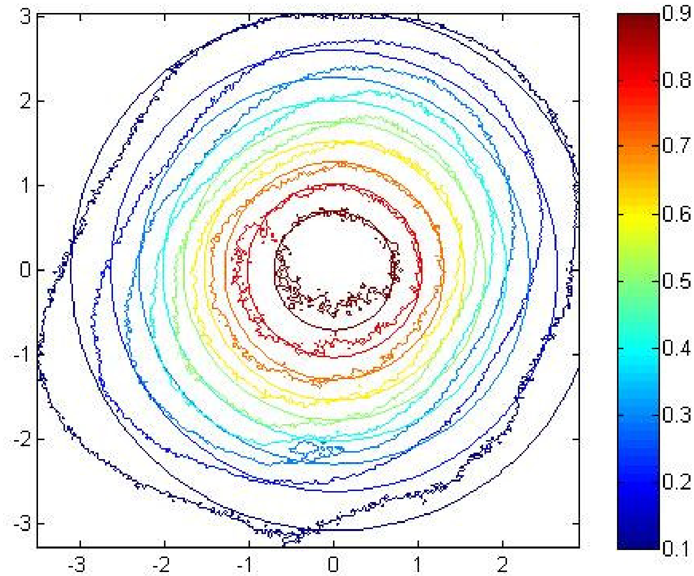

Fig. 7. Comparison of experimental and theoretical contours, for image 2

These results could be improved with the new heliostat of 81 m². This heliostat was design with a rigid structure in order to minimize the surface deflections along the sun tracking operation. Actually the complete groups of mirrors are installed and is necessary a new experimental study in order to obtain a precise value for the HFSF optical error.

Assuming that all groups of mirrors have been installed in the main concentrator, we can estimate the irradiance levels that could be obtained by performing the corresponding experimental campaign. Figure 8 shows the results of the irradiance profiles from HFSF for different values of optical error. The calculation was considered an average reflectivity of 0.8 and a direct solar irradiance of 1000 W/m². Figure 8 shows the variation of the radius of the sun spot concentrated considering a percent uptake of 90% compared to the total energy captured by receiver. These figures shows that is possible, for optical error less to 3 mrad, to reach peak irradiances higher than 12 000 suns and average irradiances above 5 000 soles with 90% of the energy collected (figure 9).

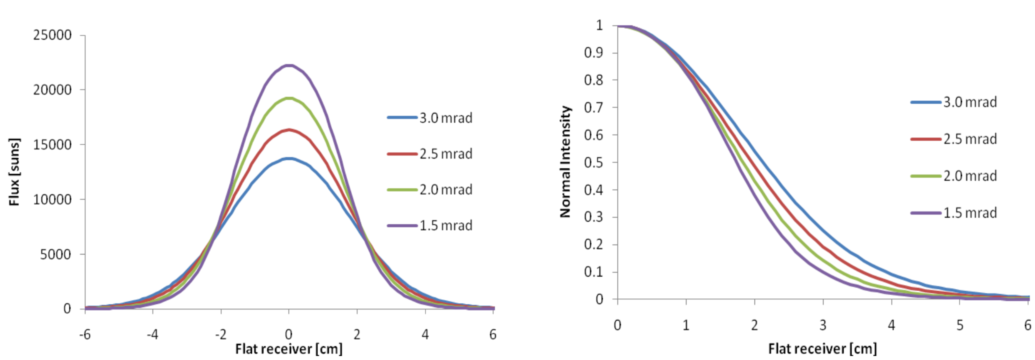

Fig. 8. Irradiance profiles from HSAFR. (a) Absolute, (b) Relative

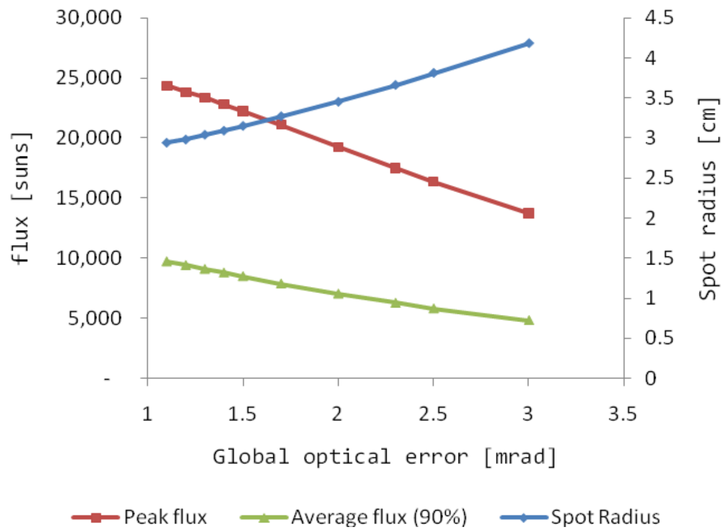

Fig. 9. Variation of theoretical peak flux, average flux and spot radius against optical error

4. Conclusions

The methodology gives us a useful technique to evaluate the global optical error from system Heliostat-concentrator. The analysis of the CCD images, from the group A of mirrors and the 36 m² heliostat, show a very good agreement with theoretical results for a global optical error lower to 3 mrad. The results suggest that the optical error could be improved in new experimental campaign with the complete groups of mirrors and the new heliostat of 81 m²

If the rest of mirrors groups present a similar optical behavior, we can anticipate a flux peak higher of 12000 suns and average irradiance at receiver above 5000 suns.

Acknowledgements

This work was partially supported by CONACYT (México) (Grant 56918) and UNAM (Grant 372311721). The authors thank Javier Arriaga Petrona, Claudia Carballo Manuel and Noé López Hernández of INAOE for unconditional support during construction and commissioning of the solar furnace. And J.J. Quiñones, J. Licurdo and L. Reyes-Ochoa Aguilar are acknowledged by technical support.

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