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Alignment method of segmented primary mirror for the solar concentrator in Temixco-México, using optical technique

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Abstract

This paper is focused on the alignment of panels that conform the primary mirror of the solar furnace of high radiative flux (HFSF) using geometrical optics with an arrangement similar to that of the Ronchi test but without the grid. Considering the optical design of the HFSF which involves 409 hexagonal mirror facets, grouped in 5 sets according to their focal length. The general idea is to align each section separately, taking advantage of the different curvature radii. A quasi-point source is placed near in the center of curvature of one of the set of mirrors to be aligned, and the divergent light coming from the source illuminates the whole region of the concentrator. Then, the light directed to the region under consideration is reflected by the group of mirrors and the reflection from each mirror forms a separated image over an observation screen. In this screen, the actual image of the source is compared to the theoretical image, using a previously produced map of their positions, by means of ray trace software. The alignment procedure consists on forcing the real image to coincide with that expected from the computation, by rotating the mirror around its supporting point.

Keywords: solar furnace, segmented mirror, facet alignment.

1. Introduction

Technologies for solar concentrator systems have been developed since Archimedes times, but the efficiency thereof is linked to the geometric shape of the concentrator. Recently, a new solar concentrator have been built in Temixco-México [1], known as Solar Furnace of High radiative flux (HFSF), with the particularity of a segmented primary mirror [2]. The arrangement of mirrors is comprised of five regions with different radii of curvature, that is, the mirrors within a region share the same radius of curvature and are spherical. This configuration allows the individual alignment of each region, setting each mirror in order to make up to the desired focus.

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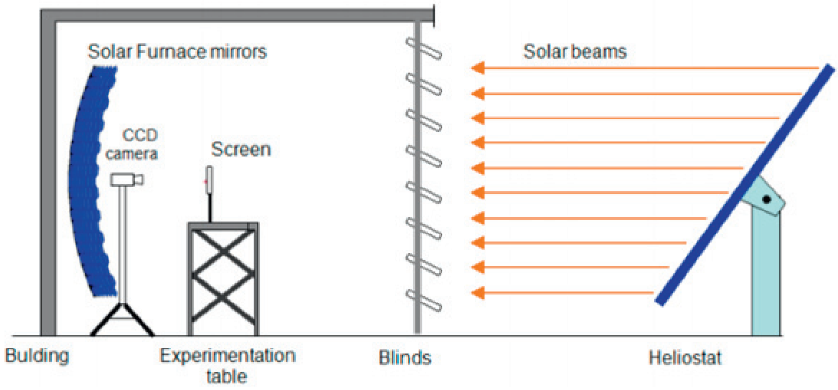

Fig. 1. Diagram of the Solar Furnace of High Radiative Flux (HFSF). Consists of a heliostat of 81 m^2 (9m by 9m), a shutter and a multifaceted concentrator of 409 spherical mirrors. This figure was taken from [3].

The purpose of the HFSF is to serve as an experimental installation for the research and development of solar concentration technologies at very high fluxes and temperatures, in particular, the development of receivers/reactors for the production of solar fuels and the study of physical properties of materials at high temperatures and high solar fluxes. The target peak concentration is approximately 10,000 Suns, and the global standard deviation of the optical design must to be less or equal to 4 mrad in order to reach the goal of the 10,000 Suns. The Fig. 1 was taken from [3] and shows the diagrams of the Solar Furnace of High Radiative Flux (HFSF).

In order to satisfy the requirements of the optical design described above, a new method was proposed for the alignment of the facets of the primary mirror in HFSF, and is being published somewhere else. In general, the idea is to carry out all the alignment process taking into account each region with its own curvature radius, placing a point source in the locus of the curvature radius and a sensor forward to the source, the real images due to each mirror must match the theoretical images generated with ray tracing. Settings for proper alignment test involve the placement of the point source on the curvature radius of the region under test, generating different images close to it. On the other hand, when the furnace is in operation, an extended source from the infinite is considered, as a result, the image of all the mirrors forming the primary mirror form an image on the focal length of the optical system. In this paper we discuss the angular effect in the image plane when the furnace is operating due to misalignment when the method for alignment is applied.

2. Angular arrangement and ray tracing.

The tolerances established for the correct operation of the Solar Furnace of High Radiative Flux, implies that all the energy concentrated when the furnace is operating must to be within a volume not greater than 8cm. The system characteristics for one of such regions are shown in the Fig. 2 and similar configurations are established for the rest of the region. The alignment method involves placing a point source in the radius of curvature and individual images are formed close to it. The mirrors are attached to a mechanism that enables their movement in six degrees of freedom: displacement in three perpendicular directions and rotation around three axes. The study in this work is focused only on the X axis, regarding to the symmetry of the optical design these results are equivalent for the others degrees freedom associated with tilts.

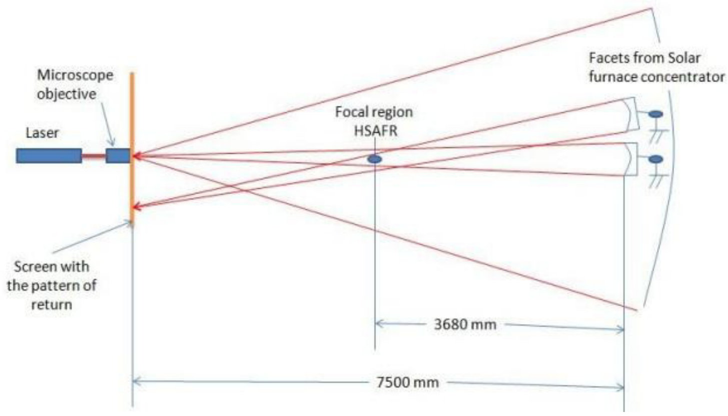

Fig. 2. Scheme of the optical arrangement, two mirrors are using to shows the alignment of the HRFSF facets. This diagram was provided by Dr. Sergio Vázquez.

Two independent simulations were carried out in Zemax software using non sequential ray tracing, where few mirrors for each region were selected taking into account the original angular position in order to not repeat the simulation for mirrors with similar angular set. We considered two cases: using a point source and using a extended source. For the first case, a simple methodology is performed: a point source is set, then, one by one, a selected mirror is “activated” in the simulation, while the rest of those within the region remain in the “invisible” mode. The value of the tilt in the X coordinate is changed one degree by steps of 0.02. With these simulations, we observe the effect when the mirrors are tilted in an observation screen placed 20 cm behind the radius of curvature. In the second case, the same methodology is applied, but the point source is replaced by an extended source, and the plane of observation is the focal plane.

3. Results and conclusions

In this section we discuss the spatial effects in the image plane when the furnace is operating, specifically angular misalignment, using our method. This study allows to quantify the maximum error possible between the real individual images generated by mirrors and the theoretically expected, to ensure an area of concentration less than 8 cm when the concentrator is active.

In Fig. 3, we show the plots of the simulations performed, considering the variation of tilt for each region of the primary mirror. Each figure plots the values of the position for the mirror images in the X axis in the image plane versus the angle of the mirror with respect to the original position according with the optical design. The blue line indicates the values obtained in the computer simulation for the case of extended source. On the other hand, the red line indicates the values obtained using the point source.

As the alignment procedure is performed by means of matching the real image reflected from the mirror with a theoretical image, a higher sensitivity would mean a significant departure of the real image from the theoretical one. In other words, if small deviations of the real image represent very small deviations, in tilt, of the facet, then the method allows high accuracy alignment. In order to test this, the simulations evaluate how much the image from the mirrors deviate as a function of misalignment angle.

For the central region of the furnace, even when using a point source would be better given that it is easier to match with its theoretical image, performing the test with such a source diminish the sensitivity of the method compared with the extended source version. For mirrors away from the optical axis (greater radius of curvature), the misalignment become equivalent, as shown by Fig. 3(c) and Fig. 3(d).

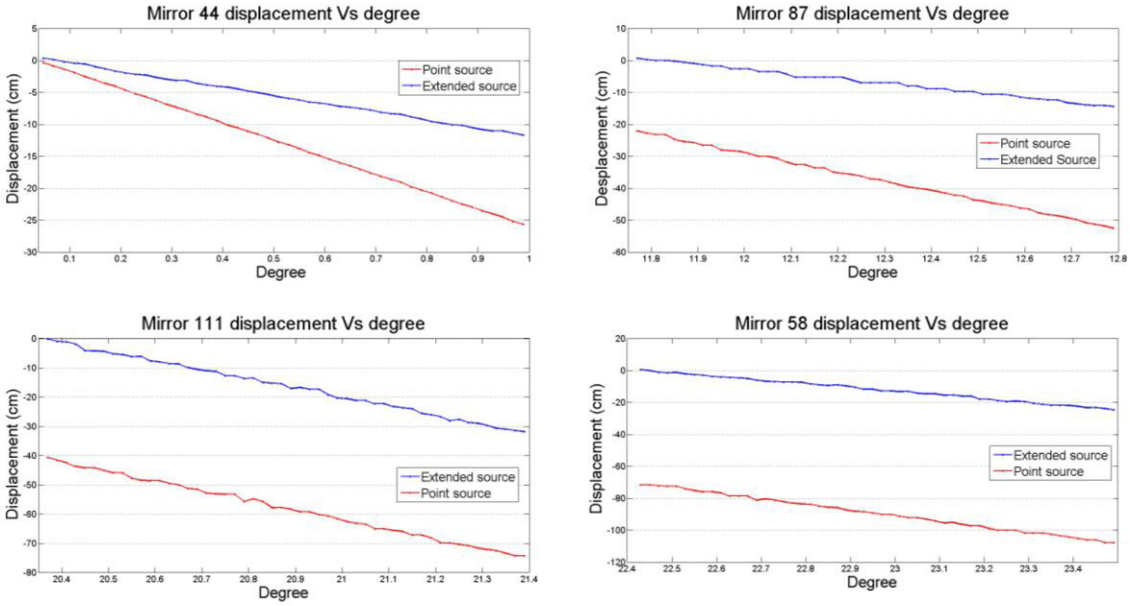

Fig. 3. Tilt mirror simulation. Mirrors: (a) 44 from 7500cm curvature radius.(b) 87 from 8000cm curvature radio.(c)111 from 500cm curvature radius.(d)58 from 9000cm curvature radius.

For example, in Fig. 3(a), the facet is aligned at 0°. If the mirror is misaligned by, for example, 0.5°, the image of the point source would be deviated by a very noticeable 5cm, and using an extended source, the deviation is considerably larger (about 12cm). In Fig. 3(b), the original angular position is 11.8° and the image, using the extended source method, is located 20cm away from the optical axis. Introducing a misalignment of, for example 0.2°, moves the image of the facet 10cm from its original position. Also can be observed that as we move to regions with greater radius of curvature, These results can be used to reduce the volume of operation and reach a smaller volume and hence a bigger temperature in the Solar Furnace of High radiative flux of Temixco.

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