METHOD FOR FACETS' ALIGNMENT FOR THE HIGH-FLUX SOLAR FURNACE AT CIE-UNAM IN TEMIXCO, MEXICO. FIRST STAGE

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Abstract

The new high radiative flux solar furnace is being developed in Mexico at the Centro de Investigación en Energía of the Universidad Nacional Autónoma de México. The alignment of the facets of the concentrator is a key procedure to obtain the required energy distribution in the focal zone and to keep the global standard deviation of the optical errors low. We present a novel method for optical alignment of the facets; this alignment procedure requires a simple optical system, allows rapid alignment and guarantees the required accuracy. Preliminary results obtained with this procedure are discussed, which show that the facets alignment satisfactorily meets specifications.

Keywords: Solar furnace; Optical alignment; Solar concentration; Segmented concentrator; Radiative flux.

1. Introduction

In september 2007, with the aim of promoting the development of Concentrating Solar Technologies in Mexico, the *Centro de Investigación en Energía* (CIE) of the *Universidad Nacional Autónoma de México* (UNAM) in collaboration with the *Instituto Nacional de Astrofísica, Optica y Electrónica* (INAOE) started the construction of a High Radiative Flux Solar Furnace (HFSF). This infrastructure is located at CIE-UNAM, in the city of Temixco, in the state of Morelos. Its development has been funded by the *Consejo Nacional de Ciencia y Tecnologia* (CONACYT) and UNAM.

The optical design of the concentrator of the HFSF was carried out through ray tracing simulations, and has been described elsewhere [1]. The design considers an intercepted power of approximate 30 kW, with a target peak concentration of approximately 10,000 Suns. A global standard deviation of the optical errors less or equal to 4 mrad was targeted in order to reach such a goal [1].

The optical configuration for the concentrator consists of an arrangement of 409 mirror facets of hexagonal contour, each one being a spherical first surface mirror. These facets are grouped in 5 sets of different focal length, placed on a spherical supporting structure, and with corrected orientations in order that the incident radiation of each facet is reflected to the same focus (see Fig. 1 and Table 1) [1]. The heliostat was designed in order to achieve at least 3 hours daily operation in the summer solstice, which is the critical season of the year. To this end, the heliostat dimensions were determined as 81 m^2 (9m × 9m).

Let us point out that the results presented are provisional, as they were obtained with only part of the furnace mirrors was installed, in order to check the progress of the alignment procedure. Also, the first tests of the furnace were carried out with a 36 m^2 heliostat provisionally, while the final 81 m^2 heliostat is being fabricated. In particular, the results reported here for mirror alignment correspond to 100 mirrors, the whole of the A and part of the B groups.

Group	Numbers of facets	Radius of curvature (mm)	Focal distance (mm)
A	85	7500	3750
B	104	8000	4000
C	130	8500	4250
D	64	9000	4500
E	16	9500	4750

Table 1. Number of facets in each mirror group, corresponding to different radii of curvature.

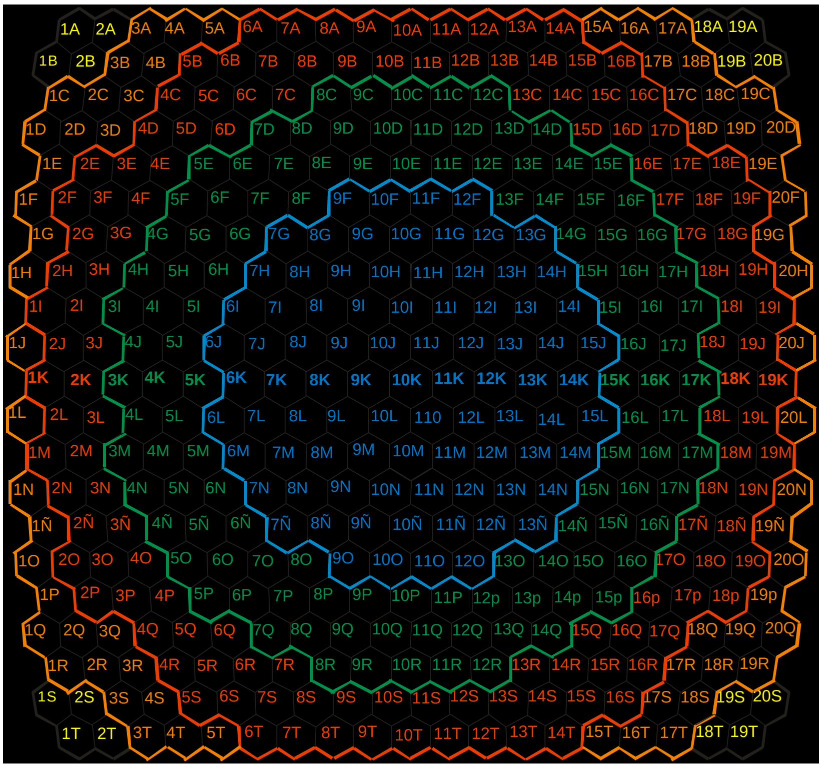

Figure 1. Arrangement of facets in the concentrator. Each color corresponds to a single focal length group.

One of the virtues of the concentrator optical design is that all the mirrors are spherical, which facilitates manufacturing, and reduces costs and production time. On the other hand, this means that the spatial and angular position of each mirror is calculated to compensate for the aberrations and to reduce the spot size. Therefore, the precise alignment of each mirror is essential for the proper operation of concentrator.

The position of each mirror is calculated for collimated light. However, it is not possible to use the sun as light source for the alignment process due to the high temperature obtained in the focal region (above 2000 K). Another reason for excluding the use of solar radiation in the alignment is that such a procedure would require the use of the HFSR heliostat to illuminate the concentrator. This would introduce an additional source of uncertainty, due to the imperfections in heliostat facet alignment and due to the sun tracking mechanism accuracy. To decouple these sources of error from the process of concentrator facets alignment, a different procedure had to be proposed.

2. Facets alignment method

According to the above, the goals sought with the proposed method of alignment of the concentrator are as follows:

- A light source other than the sun can be used.
- The positioning of each facet can be achieved with the required accuracy.
- It is easy to implement.
- It works well outside the laboratory; i.e., in the environment where the concentrator is installed, independently of weather conditions.
- It does not require the use of the heliostat of the HRFSF.

To fulfill those requirements, a method was proposed which uses a quasi-point source, generated by a 25 mW HeNe laser (wavelength of 633 nm), together with a 60X microscope objective of 0.65 numerical aperture. The quasi-point source is placed near the center of curvature of the set of mirrors to be aligned and the divergent light beam illuminates the concentrator. The light so generated is reflected by each of the group´s mirrors. The reflection from each mirror forms a separate image at an observation screen. In this screen, the theoretical image produced by each mirror is drawn previously, as calculated from ray trace software. The alignment procedure consists on making the real image to coincide with that expected from the calculation, by rotating the mirror around its supporting point. To this end, mirrors are attached to mechanisms enabling their movement in six degrees of freedom: displacement in three perpendicular directions and rotation around three axes. Each mirror is moved until the image matches the image generated theoretically. Figure 2 shows the optical arrangement used.

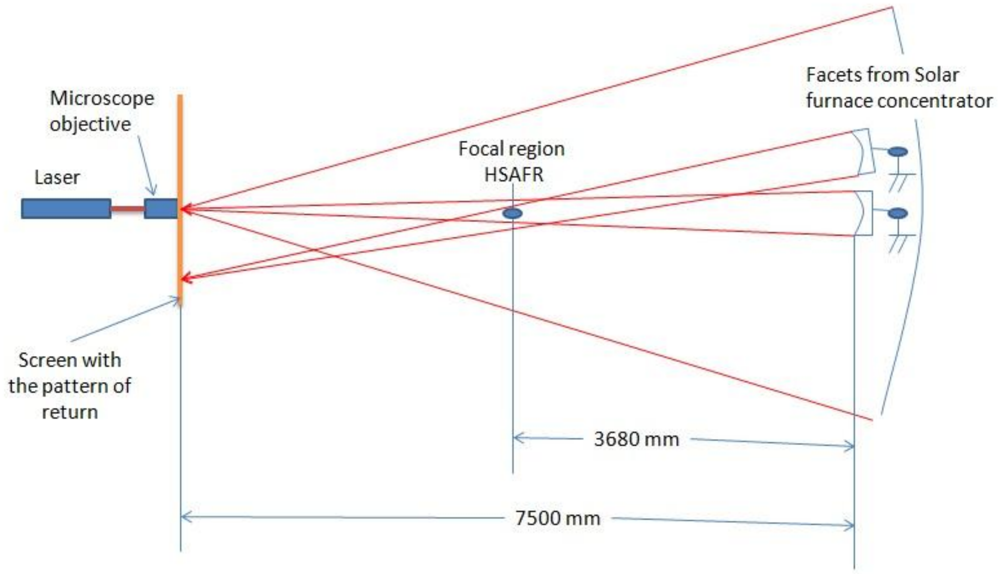

Figure 2. Scheme with the optical arrangement for the alignment of the HRFSF facets.

In fig. 3, a picture of the laser and the microscope objective used for generating the quasi-point light source is shown. In figs. 4 and 5, examples of the screens that were theoretically calculated and the corresponding mirrors are shown.

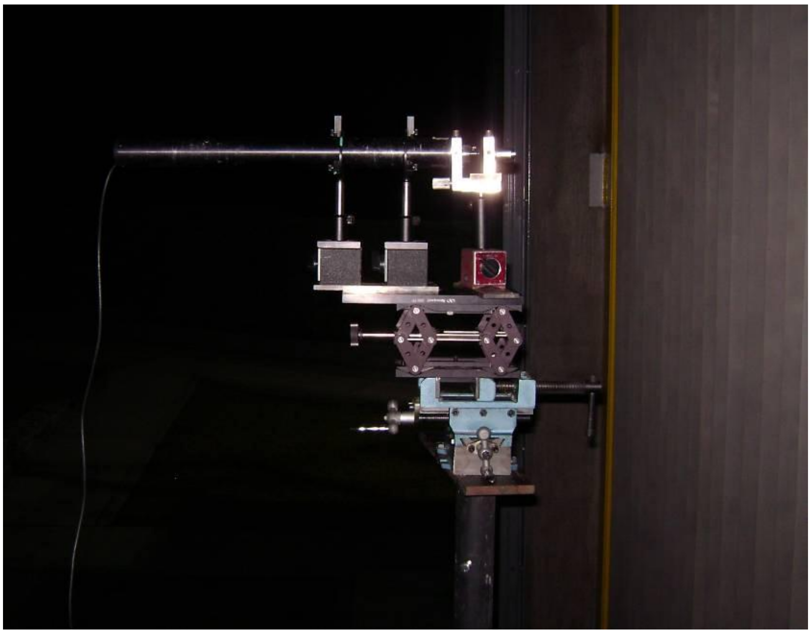

Figure 3. Optical components for generating the quasi-point light source.

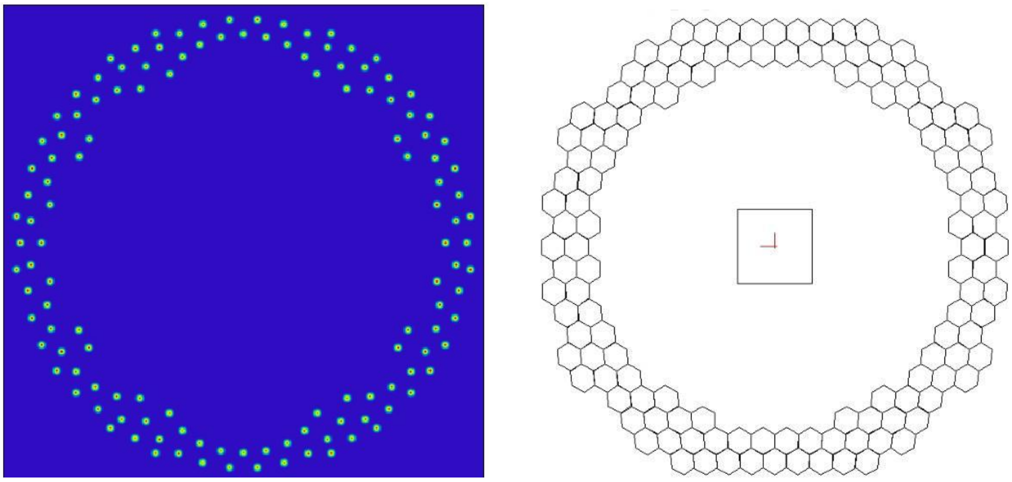

Figure 4. Screen and mirrors corresponding to 8500 mm curvature radius.

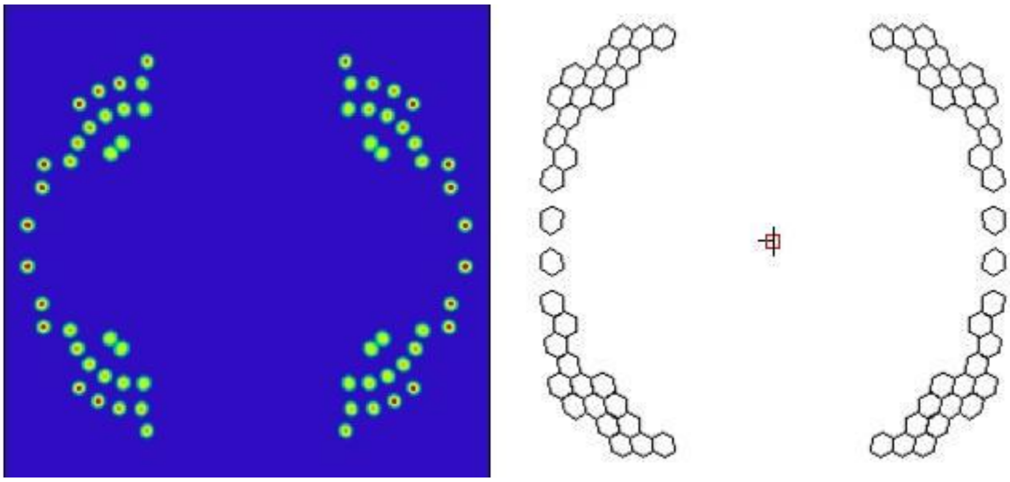

Figure 5. Screen and mirrors corresponding to 9000 mm curvature radius.

In figure 6 a picture with the real spots on the alignment screen is shown. In the picture the spots generated by the mirrors with radius of curvature of 8500 mm and 9000 mm can be appreciated.

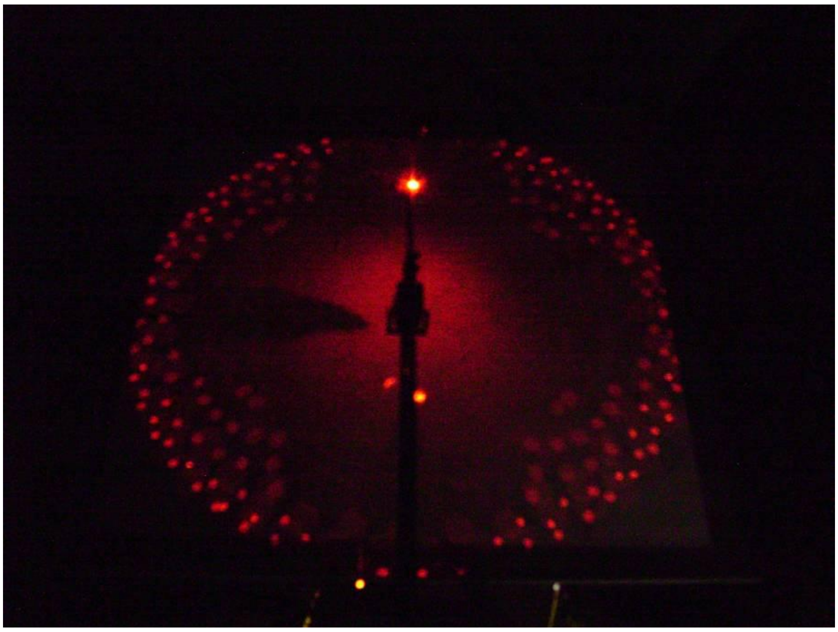

Figure 6. Picture with the real spots on the alignment screen.

3. Results

Once the alignment procedure for each of the concentrator mirrors was applied, several tests were carried out to check for the accuracy of the alignment. The first test was qualitative, and consisted in observing the images of objects reflected by the concentrator. The images display excellent continuity and quality as a result of the alignment of the facets. This itself is a very good indication of the proper alignment of facets.

The second test consisted of using the 36 m^2 heliostat in conjunction with the concentrator, and the sun as a source of light. A water-cooled Lambertian target was positioned on the focal plane, and pictures of the solar image produced by the HSAFR were taken with a CCD camera, as can be seen on figure 7. The first images analyzed correspond to mirrors to 7500 mm curvature radius and with a heliostat of 36 m² of reflective surface [2]. The MATLAB® software was used to obtain the distribution of irradiance and spot size (Fig. 8). The results allow estimating a visual spot diameter of 10 cm, while it is found that 90% of the energy falls into a diameter of 6 cm. By comparing this results with ray tracing simulations [1,2], it is found that the alignment seems to comply with the target spot size, and that so far the standard deviation of the global optical error is of 2.7 ± 0.2 mrad. These results show that the alignment procedure met all goals.

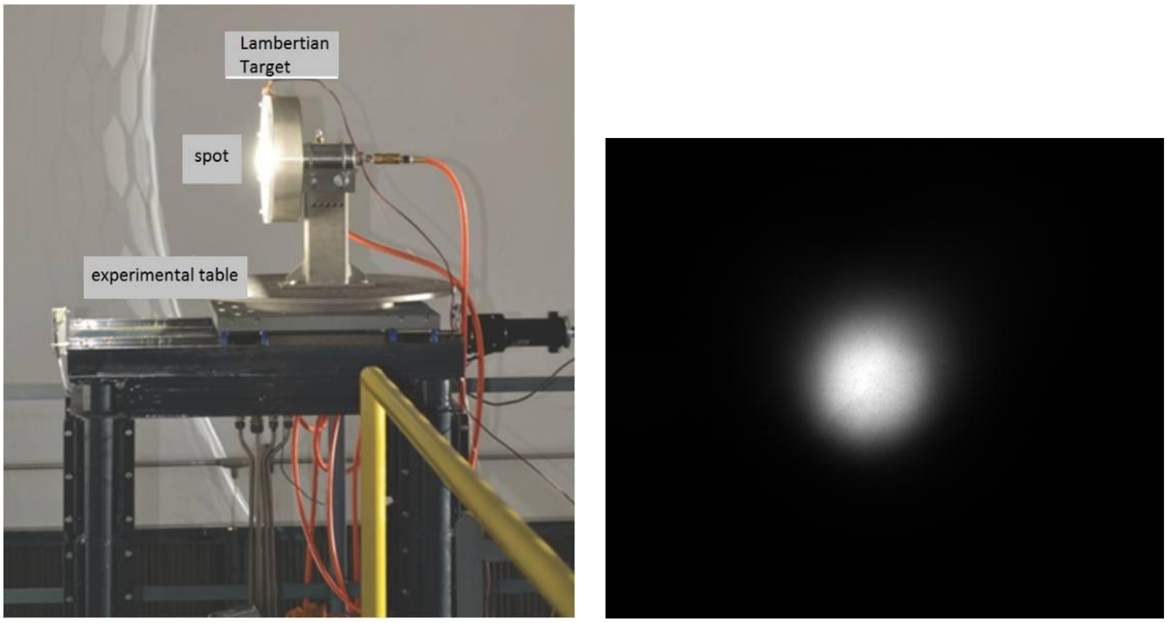

Figure 7. Water cooled Lambertian target and example of solar image on the target.

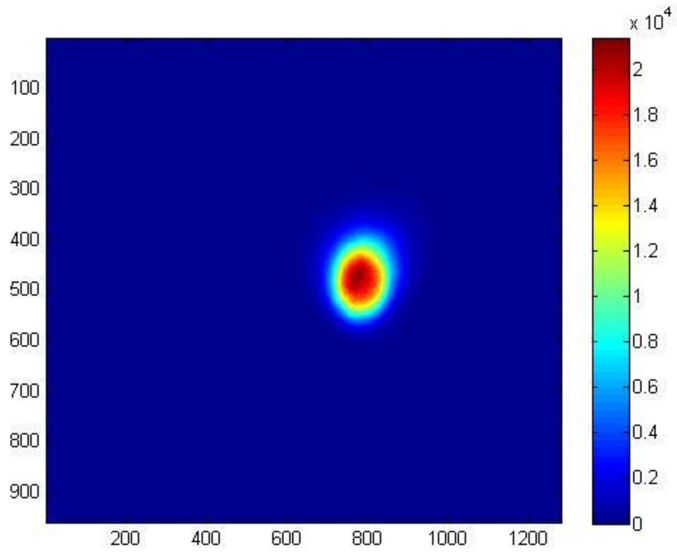

Figure 8. Energy distribution into the spot of figure 7, the position scales are in mm. The intensity scale is arbitrary.

4. Conclusions

A novel method to align segmented mirrors facets for a solar furnace was developed. The optical components needed for the alignment system are only a HeNe laser, a microscope objective and a viewing screen. This makes a system cheap and easy to implement.

The alignment procedure is independent of the heliostat, this makes it versatile and of wider application. The alignment can be done in day or night and is independent of weather conditions. The proposed method so far seems to meet the design targets for the high radiative flux solar furnace under construction in Temixco, Mexico. Nevertheless, results reported here are only provisional, because only one fourth of the total mirrors were installed and the definitive heliostat was not installed so far. Results are expected to improve as the heliostat of 81 m^2, more rigid, has been installed.

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