Optical testing of a parabolic trough solar collector by a null screen with stitching

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ABSTRACT

In this work we report a method for testing a parabolic trough solar collector (PTSC) based on the null screen principles. For surfaces with symmetry of revolution a cylindrical null screen is used, now, for testing the PTSC we use a flat null screen. The design of the null screen with ellipsoidal spots is described; its image, which is formed by reflection on the test surface, becomes an exact square array of circular spots if the surface is perfect. Any departure from this geometry is indicative of defects on the surface. The flat null screen design and the surface evaluation algorithm are presented. Here the surface is tested in sections and the evaluation of the shape of the surface is performed with stitching method. Results of the evaluation for a square PTSC with 1000 mm by side (F/0.49) are shown.

Keywords: Null screen, Parabolic Trough Solar Collector, Optical Testing

1. INTRODUCTION

The optical performance of solar concentrating collectors is very sensitive to inaccuracies of components and assembly. Because of a finite size of the sun and present imprecisions of the collector system (e.g., tracking, receiver alignment, mirror alignment, mirror shape, and mirror secularity) the interception of light at the focal receiver is reduced.

Among the principal methods for testing optical surfaces, the Ronchi and Hartmann tests have been popular for many years for testing slow (F/# >> 1) spherical and aspherical surfaces[1,2]. Both methods for testing optical system are useful only for surfaces of revolution. Previous work[3,4] has described the application of photogrammetry to the characterization of solar collectors. Briefly, close-range photogrammetry involves the use of a network of multiple photographs of a target objet (a solar collector component in this case) taken from a range of viewing positions, to obtain high-accuracy, 3D coordinates data of the object being measured. Furthermore, photogrammetry is self-contained and requires little external information if only the shape and size of the object is of interest.

In this work we propose to use the null screen principles[5,6,7] for the testing of a solar collector component (PTSC). The null screen principles consists of a screen with an array of points that by reflection we can see its image at the CCD sensor as a perfect square array of points, while any departure of this geometry is indicative of the shape errors of the surface. This shape can be obtained through the general and exact formula proposed by Díaz-Uribe [5].

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2. PROPOSED METHOD

In the traditional test of aspherical surfaces with symmetry of revolution a cylindrical null screen is used. The spots of the design screen are plotted on a sheet of paper with the help of a laser printer, and then the paper is rolled into a cylindrical shape and inserted into a transparent acrylic cylinder which supports the screen. In this paper, we propose to use a flat null screen for the testing of a PTSC. The proposed test is made by testing one profile at a time with two flat null screens and by scanning the PTSC, the whole surface is tested; the arrangement is shown in the Fig. 1.

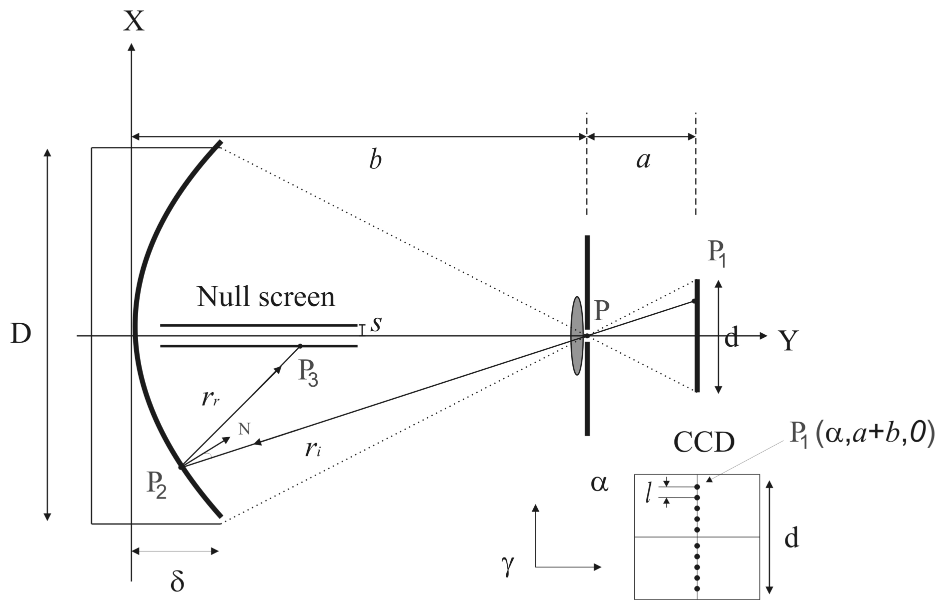

Fig.1. Layout of the testing configuration.

Fig. 1 shows the reverse exact ray tracing and the variables involved in the design of the flat null screen. The exact ray traced along the test system, is intercepted in a plane instead of a cylinder as in reference [5]. All the calculations are made in a meridional plane (X, Y). A ray starting at point P_1 (α, β) on the image plane passes through the pinhole located on the Y axis at a distance b [point P ($0,b$)], away from the vertex of the surface; this ray arrives at the test surface at the point P_2(x,y). After reflection on the test surface the ray hits the surface at the point P_3 on the flat null screen.

3. CALCULATION OF THE POINTS ON THE SCREEN

The equation of a parabolic profile with vertex in the origin and parallel axis to the Y axis is determined by the equation

$$y = \frac{x^2}{4p} \quad , \tag{1}$$

where p is the focal length of the parabola.

The equation of the slope of the straight line (incident ray) m_{ri} that goes from P_1 to P_2 passing through point P ($0, b$) is

$$m_{ri} = \frac{y-\beta}{x+\alpha} = \frac{b-\beta}{\alpha} \quad . \tag{2}$$

Substituting the Eq. (1) in (2) and solving for x, we get

$$x = \frac{2pa - 2\sqrt{p^2a^2 + pb\alpha^2}}{\alpha} \quad . \tag{3}$$

Then the coordinates of the points that describe the parabolic profile, in terms of the parameters of the CCD are

$$P_2(x, y) \Rightarrow \left(\frac{2pa - 2\sqrt{p^2a^2 + pb\alpha^2}}{\alpha}, \frac{x^2}{4p} \right). \tag{4}$$

From the equation of slope of the normal to the parabolic profile given by

$$m_n = \frac{-2p}{x} \quad , \tag{5}$$

we can found the incident angle θ_i, from the slopes of the incident ray m_{ri} and of the normal m_n , as follows :

$$\theta_i = \tan^{-1}\left(\frac{m_n - m_{ri}}{1 + m_n m_{ri}} \right) = \tan^{-1}\left(\frac{-2p\alpha - \alpha x}{x\alpha - 2pa} \right) \quad , \tag{6}$$

we can rewrite the Ec. (6) for the reflected angle as

$$\theta_r = \tan^{-1}\left(\frac{m_{rr} - m_n}{1 + m_n m_{rr}} \right) \quad , \tag{7}$$

Now m_{rr}, is the slope of the reflected ray

$$m_{rr} = \frac{\tan\theta + m_n}{1 - m_n \tan\theta} \quad . \tag{8}$$

Finally the equation for the reflected rays is

$$y_{rr} = y - m_{rr}(x - x_{rr}) \quad , \tag{9}$$

here x_{rr}, and y_{rr} are the intersection points on the flat null screen $P_3(x_{rr}, y_{rr})$. The coordinate y_{rr} is constant on a one plane of the null screen; in Fig. 1, s is the distance between the axis Y and the position of the flat null screen.

4. PRACTICAL IMPLEMENTATION OF THE SCREEN

In this paper is proposed a linear arrangement of equally spaced spots formed on the image plane by reflection on the test surface, if this is perfect. An initial image observed on image plane consist of spots separated a distance *l*. In a meridional plane, with the inverse ray tracing only is possible to obtain the coordinates of the spots from the center and the vertexes along the Y-axis, of each spot on the CCD plane. For each spot from CCD we obtained tree points on flat null screen view Fig. 2, and according to reference [8] we can use an approximation using ellipses instead of drop shaped for simplicity in the calculus.

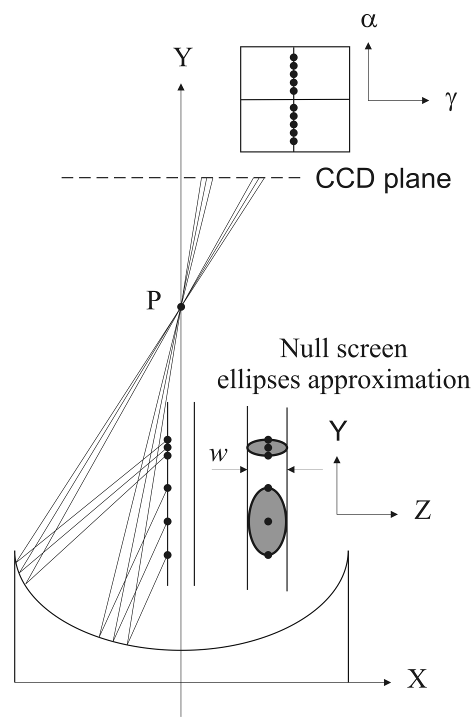

Fig.2. Inverse ray tracing on the XY plane and the elliptical approximation in an YZ screen plane.

An arrangement of 15 spots on CCD plane to cover each semi diameter of the PTSC is proposed. The optical system is displaced a distance *K* and an image for each profile of the PTSC is captured.

In the flat null screen we can observe how the axis of the ellipses is changed according to the distance to the axis of symmetry (Y axis). In addition the width *w* of the linear arrangement is constant. In a previous works [5, 6] for surfaces with symmetry of revolution this width changes with the distance to the axis of symmetry.

The parameters used for designing the flat null screen are shown in Table 1. In fig. 4 the square PTSC is shown, this was built with an aluminum plate of high reflectivity.

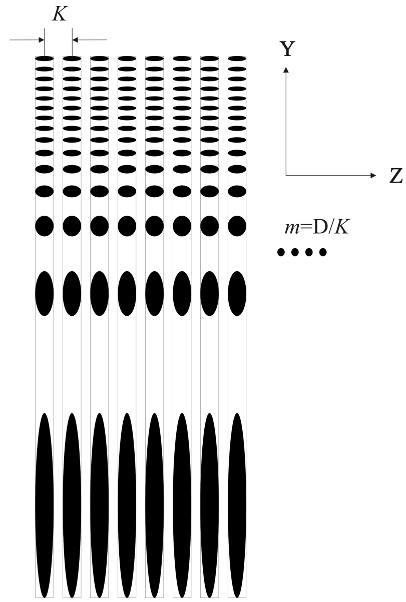

Fig.3. Flat null screen for testing the PTSC component.

Table 1. Set-up parameters used for the design of the flat null screen.

	Element	Symbol	Size
Surface	Width	*W*	1000 mm
	Length of trough	*L*	1000 mm
	Focal distance	*p*	490 mm
Distances	CCD pinhole	a	12 mm
	Stop aperture-surface vertex	b	1945.73 mm
	CCD length	d	6.6 mm

We only show qualitative results of the testing of a profile of the PTSC; currently we are working in improving the experimental setup to obtain better results. Fig. 5 shows the image of the null screen obtained by reflection on the PTSC surface. It can be seen an arrangement of 15 spots, obtained from one half of the PTSC profile. The image was captured with a digital camera Sony (cyber-shot DSC-P43) using a focal distance of 12 mm, the width *w* of the flat null screen is 16.62 mm and the diameter of the spots in a CCD plane is 0.1mm.

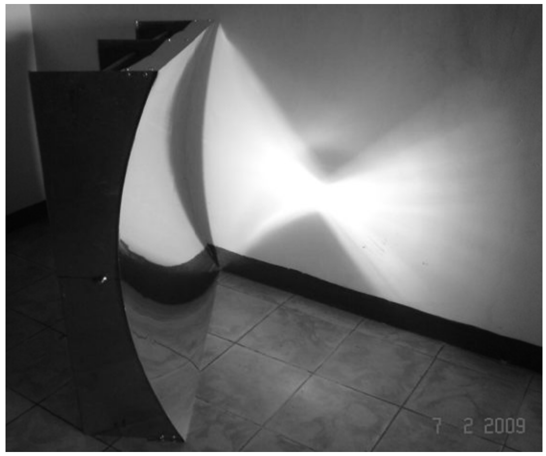

Fig.4. PTSC component

In fig. 5 we can see some of the errors involved in the molding of the aluminum and in the alignment of the optical system.

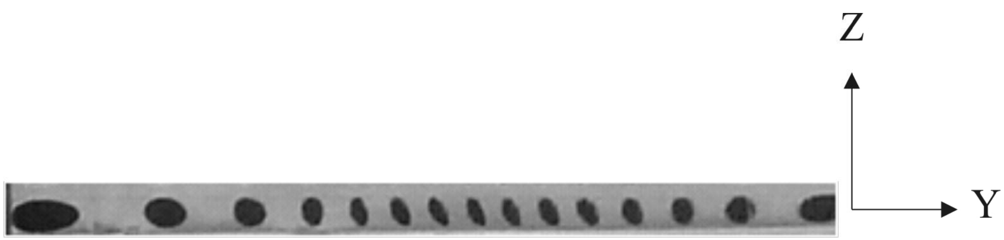

Fig.5. Image of the null screen obtained from a half profile of the PTSC

5. CONCLUSIONS

In this paper we have proposed a method for the testing a PTSC component based on null screen principles, the method does not require a special optical system and its implementation not is very expensive, it is an advantage in comparison with other methods. We show a qualitative result for only a half profile of the PTSC, we are still working in the implementation of the instrumentation for the complete evaluation and for obtaining quantitative results. For making the complete evaluation is proposed test profile by profile, because the length of the flat null screen is twice the length (along the Z direction) of the testing zone on the surface.

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