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Optical qualification of a solar parabolic concentrator using photogrammetry technique

Safa Skouri [a,*], Abdessalem Ben Haj Ali [a], Salwa Bouadila [a], Sassi Ben Nasrallah [b]

[a] The Research and Technology Center of Energy, The Thermal Processes Laboratory, HammamLif, B.P. 95, 2050 Tunis, Tunisia
[b] National Engineering School of Monastir, Street Ibn El Jazzar, 5019, Tunisia

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ABSTRACT

The purpose of this work is to determine the optical performance of a solar parabolic concentrator which was designed and realized in the Research and Technology Center of Energy in Borj Cedria Tunisia in order to improve its thermal efficiency. In this order an experimental and optical study was carried out and Photogrammetry measurement technique has been used to determine geometric errors of the solar concentrating system. Intercept factor, slope error and displacement error has been identified and analyzed. Analytical calculation of the intercept factor for parabolic reflector with a spherical receiver under Gaussian distribution along with optical efficiency has been developed and determined according to the experimental results given by the Photogrammetry technique. Obtained results showed a relevant impact of the solar concentrator optical analyze on the overall system efficiency.

1. Introduction

Today the fossil energy situation indicated several weakness aspects due to its limited and pollutant character [1]. Therefore, the investment in the renewable energy sector especially solar energy seems to be one of the potential solutions [2,3].

Several under-developed regions around the world receive large amounts of sunlight. Northern Africa and Central Asia receive around 7.5 kWh/m^2/day of global solar irradiance [4]. There is great opportunity to use solar power to provide basic energy needs in these regions. The CSP (concentrated solar power) is considered as the most prominent solar energy technology. There are four types of CSP technologies: parabolic trough, linear Fresnel, solar tower and solar dish [5–7].

Point focus parabolic reflectors concentrate the direct solar irradiation in the focal position, which is one of the main methods to produce heat from solar energy [8–10]. Nepveu et al. [11] presented a global thermal model of the energy conversion for a 10 kWel Eurodish dish/Stirling unit erected at the CNRSPROMES laboratory in Odeillo. Optical measurements to determine reflectivity and spillage losses has been done by the German Aerospace Center. A nodal method is used to calculate the heat losses in the receiver. The model gives results fitting with experimental measurements.

To obtain an optimal focused solar flux at the CSP receiver, it is necessary to develop an accurate measurement method to facilitate the installation and operation of the solar concentrator system. Shuai Y et al. mentioned that the optical error of the reflector affects the system optical performance [12]. It is relevant to identify the influence of the optical errors on the direction of the reflected ray to calculate the optical performance of the system. Traditionally, the optical analysis of concentrated irradiations has been carried using ray-tracing programs [13,14]. Bendt P et al. [15] simulate various optical behavior including different parameters such as reflector material, contour errors, tracking errors and different receiver's shapes.

Authors [16–18] used Monte Carlo ray tracing method to determine the thermal performance of a SPC (solar parabolic concentrator) based on optical and geometrical studies which validated the method experimentally. Zhiqiang et al. [19] presented a procedure to design a facet concentrator; the optimum size and position of each facet are determined using Monte Carlo ray tracing analysis to achieve the most concentrated flux.

* Corresponding author. Tel.: +216 97595855; fax: +216 79 325 825.
E-mail address: safa.skouri@crten.rnrt.tn (S. Skouri).

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Nomenclature

$B_{eff}(\theta)$	normalized distribution of the reflected irradiation
$B_{eff,Gauss}(\theta)$	reflected brightness distribution in Gaussian
D_0	aperture diameter of the concentrator, *m*
f	focal length of the solar concentrator, *m*
f_p	distance from point P to the focus of the reflector, *m*
$g1$	coordinate along $(O, \vec{z})$ of the point P of the parabola, *m*
h	depth of the parabola, *m*
I_{in}	reflected irradiation from the reflector surface per unit area, *W*
$m1$	distance between two points of the receiver, *m*
R	parabola radius, *m*
R_a	receiver radius, *m*

Greek symbols

β	incident angle, *radian*
γ	intercept factor of receiver
γ_p	intercept factor at the point P
η_{op}	optical efficiency
$\sigma_{displacement}$	displacement error, *radian*
σ_{slope}	slope error, *radian*
$\sigma_{specular}$	specular error, *radian*
σ_{sun}	sun error, *radian*
$\sigma_{tracking}$	tracking error, *radian*
σ_{total}	total optical error, *radian*
$\sigma_{optical}$	optical error, *radian*
ρ	dish reflectance
$\tau\alpha$	transmittance–absorptance product
θ_y	half angle of the receiver, *radian*
ψ	rim angle of the solar parabolic concentrator *radian*
ψ_y	polar angle in the (y) position, *radian*

Subscripts

0	edge of the reflector
i	point P_i of the reflector
j	point P_j of the reflector
R	position of (y = R)
R_a	position of ($y = R_a$)
p	point P of the reflector
x	coordinate along $(O, \vec{x})$
z	coordinate along $(O, \vec{z})$

Superscripts

cal	calculated coordinate
mes	measured coordinate
level	level

Sellami et al. [20] developed a new geometry of a 3-D solar concentrator compact, which collect the maximum of solar energy. They obtained an optical efficiency around 70% for different dimensions of the Square Elliptical Hyperboloid.

Optical Analysis of 3-D static elliptical hyperboloid concentrator, using the ray tracing technique has been presented by Saleh Ali et al. [21]. They found that effective concentration ratio for different aspect ratios increases as the concentrator height increases and it is followed by a decrease of the acceptance angle. The optimum aspect ratio is equal to 5.

The surface shape and the optical quality of the solar concentrators have an important influence on its thermal efficiency, for this reason an accurate and practical tool to measure the concentrator optical aspect is needed. Generally, three types of measurement methods are used to define and analyze the optical errors and therefore to determine the intercept factor: VSHOT (Video scanning Hartmann optical test), Deflectometry and Photogrammetry.

Jun Xiao et al. [22] reviewed and compared many measurement methods for the solar concentrators systems. Authors [23–26] have adapted the deflectometry technique to enhance the optical shape quality of the reflectors for different solar concentrators.

Photogrammetry is a geometric analysis tool which was used for solar concentrators shape characterization. This measurement technique determines the slope and displacement deviations compared to the ideal shape of the concentrator. Authors [27–33] applied Photogrammetry technique to determine the real shape and the intercept factor for both solar dish and parabolic through.

This present study deals an interesting case of a solar parabolic concentrator equipped with a spherical receiver. This work reveals the impact of geometrical shape imperfections in a parabolic reflector on the SPC optical efficiency. For this purpose, analytical and experimental studies have been carried out. This paper is organized as follows. In section 2 the optical parameters of the SPC: optical efficiency and intercept factor with a spherical absorber were given. In Section 3, we present the Photogrammetry technique used to analyze both the slope and the displacement errors which determine the geometrical deformation of the SPC system. In Section 4, the experimental results of the optical study were analyzed. The main remarks of this work are reported in the conclusion.

2. Optical parameters of solar parabolic concentrator with a spherical receiver

2.1. Optical efficiency

The following equation form can be used to perform an approximated optical efficiency analysis [34]:

$$\eta_{op} = \gamma \, \rho \, \tau \, \alpha \, \cos \beta \tag{1}$$

ρ and $\tau\alpha$ are dish surface reflectance and transmittance–absorptance product, respectively. γ is the intercept

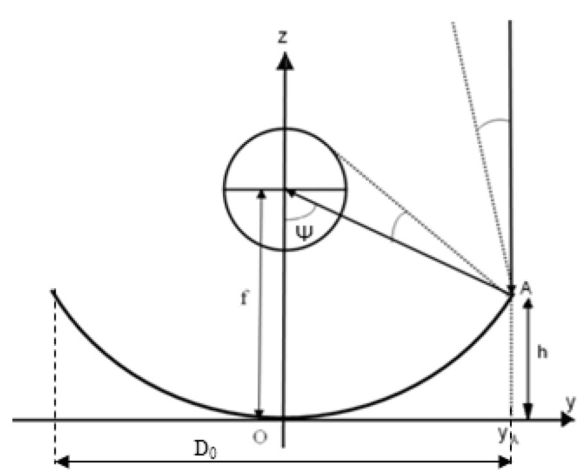

Fig. 1. Rim angle of the solar parabolic concentrator.