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Geometrical-optical performance studies of a linear Fresnel reflector

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1. Introduction

A linear Fresnel reflector is a concentrating device which is made up of long narrow, flat, or curved mirror elements mounted on a flat frame. Each mirror element is placed in such a way that all the incident parallel rays of light intercepted by the concentrator aperture are reflected to a common focus. In an ideal case, smaller mirror elements must be parabolic in shape but flat mirror elements are commonly used to simplify the manufacturing and assembly procedures. Such systems have been found advantageous for both photovoltaic and thermal conversion of solar energy [1]. A conventional linear Fresnel reflector produces a non-uniform illumination over the receiver and suffers from partial blocking of radiation reflected from a mirror element by its adjacent mirror elements. Such problems, however, can be avoided by suitable choice of design parameters associated with each mirror element [2-4]. This paper presents the detailed geometrical-optical performance characteristics of such a linear Fresnel reflector system using ray tracing techniques. The results of some typical numerical calculations are shown graphically and their significance is discussed.

2. Analysis

Figure 1 shows the geometry of a symmetrical linear Fresnel reflector. C_1, C_2 represents the aperture of the concentrating system consisting of $(2k+1)$ mirror elements, k being the number of mirror elements on each side of the central mirror element along the y-direction. The absorber aperture plane A_1 A_2 and concentrator aperture C_1, C_2 are both perpendicular to the optical axis CR of the concentrating system. The three parameters, namely position, shift and tilt associated with the n-th mirror element are denoted by R_n, S_n and Θ_n, respectively. The shifting of the mirror elements is introduced so as to avoid blocking of radiation reflected by a particular mirror element by its adjacent mirror elements and the incident radiation is concentrated at a distance f from the concentrator aperture.

If d is the size of each constituent mirror element, the effective value of the aperture (D_e) achieved in any practical case may be given by

$$D_e = d + 2 \sum_{n=1}^{k} (d \cos \Theta_n + S_n). \tag{1}$$

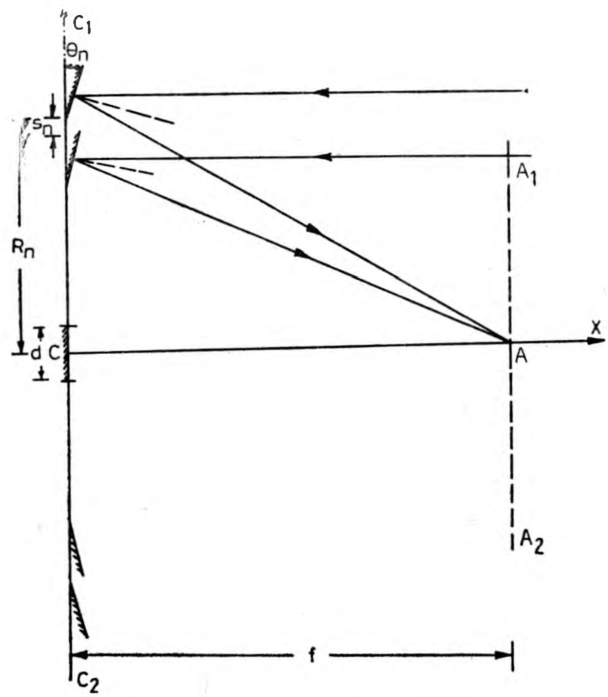

Fig. 1. Cross-sectional geometry of a linear Fresnel reflector

If desired, the mirror element placed at the shadow of the absorber on the aperture of the concentrator may be eliminated. It may be noted that D_e depends on both d and f which are considered as the primary specifications determined at the system's design stage.

Elementary geometrical considerations enable us to obtain the following expressions for the position, shift and tilt associated with an n-th typical mirror element (Fig. 1):

$$R_n = R_{n-1} + d \cos \Theta_{n-1} + S_n, \tag{2}$$

$$S_n = \frac{(R_{n-1} + d \cos \Theta_{n-1}) \, d \sin \Theta_{n-1}}{f - d \sin \Theta_{n-1}}, \tag{3}$$

and

$$\tan(2\Theta_n) = \frac{\left(R_n + \frac{d}{2}\cos\Theta_n\right)}{\left(f - \frac{d}{2}\sin\Theta_n\right)} \tag{4}$$

where $R_0 = -d/2$, $S_0 = 0$, $\Theta_0 = 0$, and n takes up values from 1 to k.

In order to find the distribution of light rays reflected from the Fresnel reflector system onto the absorber a simple ray-trace procedure is developed. A computer programme developed for this purpose divides the concentrator aperture into a large number of small intervals with uniform ray distribution and goes through a ray tracing procedure to find out the points of impact the reflected ray at the absorber surface.

If an axially incident ray coming at a distance Y_D (Fig. 2) from the optical

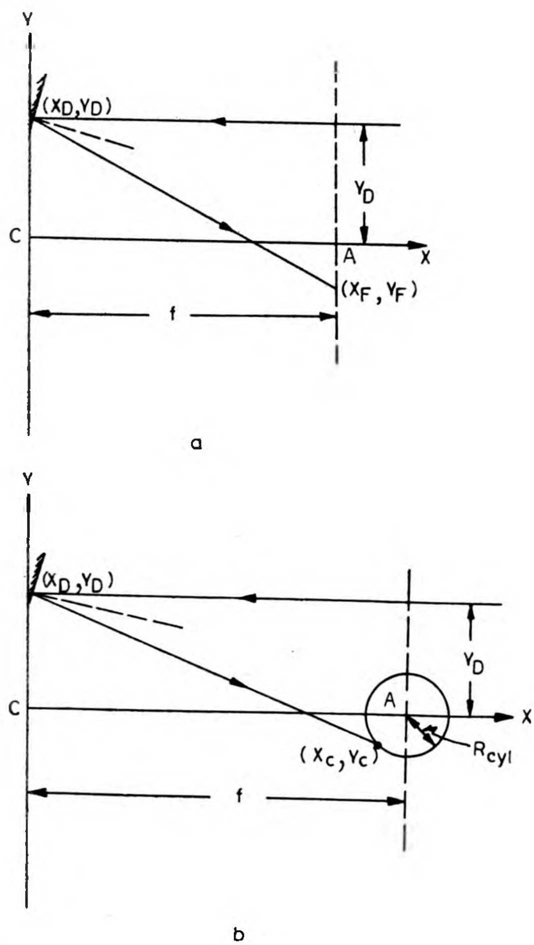

Fig. 2. Geometry for calculating intersection points: flat absorber (a), cylindrical absorber (b)

axis of the concentrator is incident upon a mirror element with tilt angle Θ_n at point (X_D, Y_D), then the point of intersection (X_F, Y_F) of this ray with a flat absorber placed at a distance equal to the focal length (f) from the reflector base may be given by

$$X_F = f, \tag{5}$$

$$X_F = Y_D - (f - X_D)\tan(2\Theta_u). \tag{6}$$

Similarly, the point of intersection of axially incident ray with a cylindrical absorber radius R_{cyl} may be calculated as

$$X_C = \left[Y_C + \left(X_D \tan(2\Theta_n) + Y_D\right)\right]\cot(2\Theta_n) \tag{7}$$

and

$$Y_C = \frac{Y_1 \pm \sqrt{B(B-1)R_{\text{cyl}}^2 - (B-1)Y_1^2}}{B} \tag{8}$$

where

$$Y_1 = Y_D - (f - X_D)\tan(2\Theta_n) \tag{9}$$

and

$$B = \sec^2(2\Theta_n). \tag{10}$$

The absorber surface is divided into a number of zones. The distribution of rays over the absorber surface is then obtained by counting the number of rays incident in each zone. The local concentration ratio at any point of the absorber may be determined by dividing the number of rays in the corresponding zone by the number of rays incident on the concentrator aperture over a width equal to that of the zone.

3. Results and discussion

The simple procedure developed may be used for determining the geometrical optical performance characteristics of a linear Fresnel reflector. We have made some typical numerical calculations so as to exemplify the procedure. A linear Fresnel reflector with an aperture diameter of 1 m is chosen for this purpose. The size of each constituent element is 0.02 m. Figure 3 shows the distribution of normalized intensity on a flat absorber as determined by the ray tracing procedure. It may be noted that a more or less uniform distribution is obtained over a with somewhat larger than the size of the constituent mirror element. The angular distribution of rays reflected from the Fresnel reflector system onto a cylindrical absorber is presented in Fig. 4. It may be

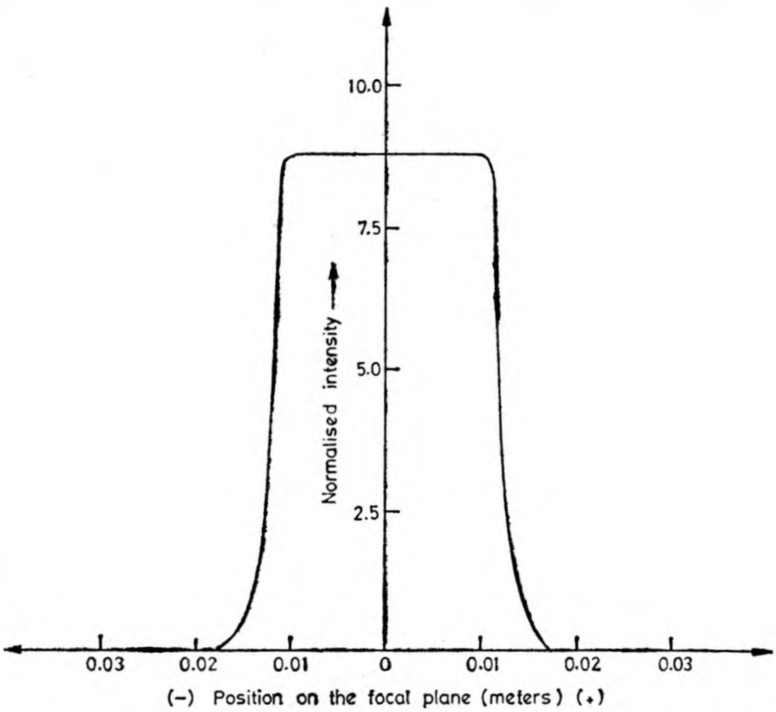

Fig. 3. Local concentration ratio distribution over a flat absorber (D = 1.00 m, d = 0.02 m, f = 0.75 m)

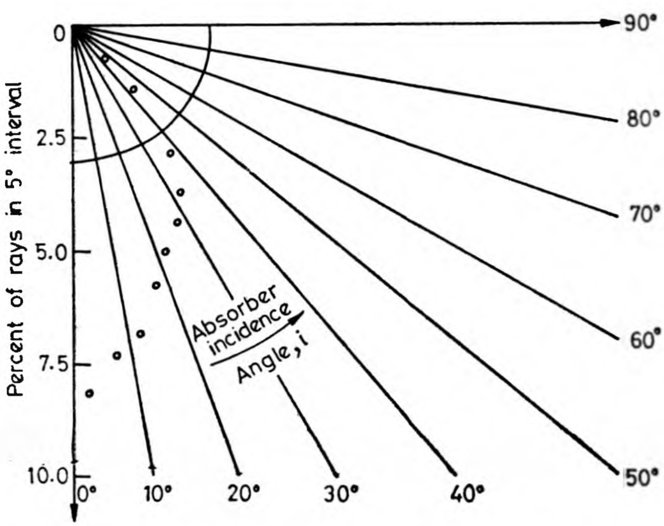

Fig. 4. Local concentration ratio distribution over a cylindrical absorber (D = 1.00 m, d = 0.02 m, f = 1.00 m)

observed that most of the rays lie in an interval of 0–35° from the normal incidence direction. Therefore, the part of the absorber which is not receiving radiation may be insulated in order to reduce heat losses. The variation of the intercept factor with the size of a flat absorber is shown in Fig. 5, while Fig. 6 gives an idea of the loss of energy due to spacing left between successive

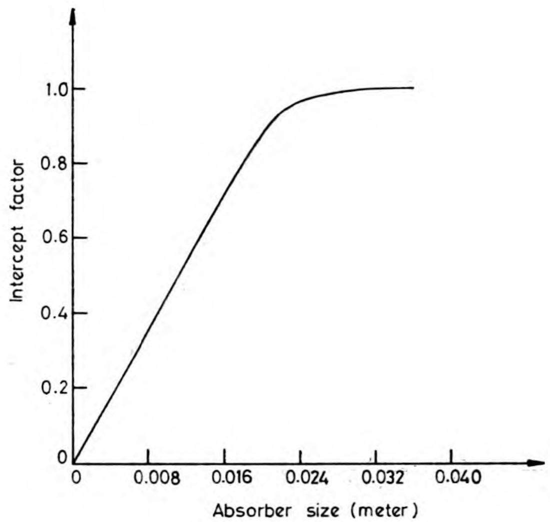

Fig. 5. Variation of intercept factor with the size of a flat absorber

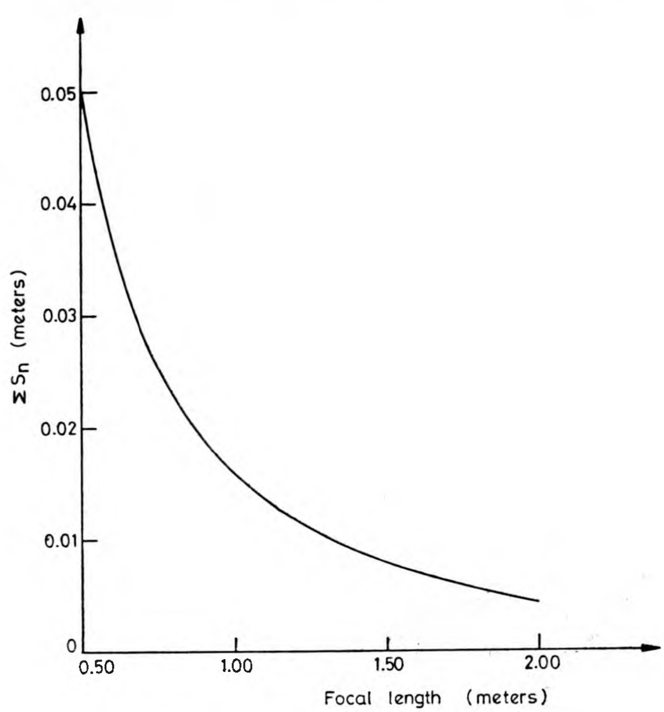

Fig. 6. Variation of $\sum S_n$ with f

mirror elements. The variation of the sum of shifts required, $\sum_{n=1}^{k} S_n$, for fixed k, with focal length f, has been plotted in this figure. It may be observed that for larger values of focal length a small shift of mirror element is sufficient to avoid the blocking of radiation thus reducing the loss of energy.

4. Concluding remarks

The simple procedure outlined in this short communication may provide important information about the geometrical-optical performance characteristics of the linear Fresnel-reflector-type solar concentrators. Of particular interest there would be the distribution of local concentration ratio over the absorber surface which may be helpful while designing the thermal absorber. The procedure may be also modified to include the finite angular subtense of the sun and the limb darkening effects by making appropriate changes in Eqs. (5)–(10).

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References

[1] Mathur S. S., Kandpal T. C., Singh R. N., *Solar concentrators,* A Bibliography, Innovative Information Inc., USA, 1982.

[2] Singh R. N., Mathur S. S., Kandpal T. C., Energy Research **4** (1980), 59–67.

[3] Singhal A. K., Singh R. N., Kandpal T. C., Mathur S. S., Optica Applicata **12** (1982), 273.

[4] Sharma M. S., Singhal A. K., Kandpal T. C., Mathur S. S., *Proc. of National Solar Energy Convention,* New Delhi, India, 1982.

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