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Geometrical concentration characteristics of a linear Fresnel reflector using a fin receiver

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The possibility of using a fin receiver with a linear Fresnel reflector has been explored. The geometrical design and performance characteristics of such a concentrator-receiver system have been studied. Numerical calculations have been made for some typical concentrator-receiver designs. Results are plotted graphically and discussed.

1. Introduction

The cost of electric power generation using photovoltaic systems may be reduced by using optical concentrating devices for increasing the incident flux [1-4]. This necessitates the development of suitable solar concentrators which provide: i) a concentration in the range $5<C\leqslant 50$, and ii) a uniform illumination over a desired receiver plane. Earlier we have proposed a modified design of a linear Fresnel reflector which produces a uniform illumination over a flat receiver of prespecified size [5]. However, sometimes it is advantageous to use a fin receiver, i.e., a flat receiver, placed along the geometrical axis of the concentrator and illuminated on both its sides. For example, such a concentrator-receiver system may add to the performance of double sided solar cells and multijunction edge illuminated solar cells [6]. In the present paper we have studied the geometrical-optical performance characteristics of a linear Fresnel reflector using a fin receiver. The gen-

eralized formulae for the necessary design parameters associated with each mirror element have been derived and some numerical calculations made. To bring out salient features of the concentrator-receiver system the results have been represented graphically.

2. Analysis

Figure 1 shows the cross-section C_1C_2 of a linear Fresnel reflector concentrator. It consists of a large number of flat front reflecting mirror elements of a finite width and length equal to the length of the line focus receiver. A receiver of width W_R is placed along the geometrical axis of the concentrator at a distance f from the aperture C_1C_2. Each of these mirror elemets will have a different location, orientation and size; thus three parameters: shift (S_n), tilt (θ_n) and width (W_n) are associated with each mirror element. The values of the shift, tilt and width for any mirror element will clearly depend on the size W_R of the receiver and the distance f. Therefore, W_R and f may be considered as the primary specifications determined at the design stage of the solar concentration system. Since the mirror elements placed at the central position C of the concentrator aperture will not contribute effectively to the concentration over the fin receiver, it is suggested that the laying down of mirrors be started at a certain distance h_0 from the centre in both halves of the concentrator (Fig. 1). In any typical case the numerical value of

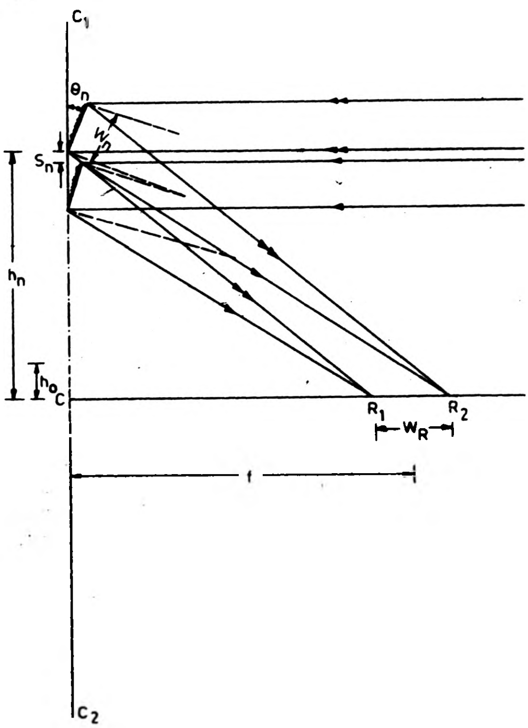

Fig. 1. Fresnel reflector geometry with a fin receiver

h_0 may be established by giving a proper consideration to the contribution of each mirror element to the local concentration ratio over the receiver. However, in our present calculations we have chosen h_0 equal to half the receiver size W_R. Therefore, the actual value of the concentrator aperture D_p, achieved in any case, may be given by

$$D_p = 2\left[h_0 + \sum_{n=1}^{k}(W_n \cos\theta_n + S_n)\right], \tag{1}$$

where k is the number of mirror elements in either half of the concentrator. It should be noted that D_p depends on both primary specifications W_R and f. However, for a given receiver aperture, the geometrical concentration ratio and, therefore, the concentrator aperture D are also generally included in primary specifications at the systems design stage. In practice, the value of k for a concentrator is chosen to make (D_p - 2h) as near to D as may be possible in a typical case. The concentration ratio calculated from D_p in a practical case will then differ somewhat from its specifications and suitable alterations in the systems design will have to be made.

It is seen from Fig. 1 that the shift, tilt and width of a mirror element are determined by the condition that the marginal rays are reflected exactly to the rim of the receiver without being intercepted by adjacent mirror elements. Elementary geometrical considerations, similar to those developed in the case of a flat receiver [5], enable us to obtain suitable expressions for the shift, tilt and width associated with a mirror element. The formulae needed for the evaluation of these parameters are

$$\theta_n = \frac{1}{2}\tan^{-1}\left(\frac{h_n}{f - \frac{W_R}{2}}\right), \tag{2}$$

$$W_n = 2W_R \sin\theta_n, \tag{3}$$

$$h_n = h_{n-1} + S_n + W_{n-1}\cos\theta_{n-1}, \tag{4}$$

$$S_n = \frac{(h_{n-1} + W_{n-1} + \cos\theta_{n-1})W_{n-1}\sin\theta_{n-1}}{\left(f - \frac{W_R}{2}\right) - W_{n-1}\sin\theta_{n-1}}. \tag{5}$$

where $h_0 = W_R/2$, $W_R = 0.05$ m, and n takes values from 1 to k.

The distribution of local concentration ratio (LCR) over the fine receiver is now obtained by using simple ray optics. It should be noted that for a symmetrical concentrator receiver system the distribution of LCR will be identical. A perfectly tracking concentrator and a uniform solar disc have been assumed to be independent of the angle incidence and wavelength and is assigned a value of unity. Owing to the finite angular subtence of the sun the incident solar radiation, after being reflected from the n-th mirror element, is distributed in the receiver plane over a width greater than the specified receiver size W_R. Thus, if (2Φ) is the angle subtended by the sun's disc at the concentrator, the additional increase in the intercept width on both the sides of the receiver may be given by

$$L_n = \frac{\left(f - \frac{W_R}{2}\right)\sin\Phi}{\sin(2\theta_n + \Phi)\cos 2\theta_n}, \tag{6}$$

$$R_n = \frac{\left(f + \frac{W_R}{2} - W_n \sin\theta_n\right)\sin\Phi}{\sin(2\theta_n - \Phi)\cos 2\theta_n}, \tag{7}$$

where L_n and R_n correspond to the widths of the additional tails on the left and right sides, respectively. Now, the contribution of the n-th mirror element to the distribution of LCR over the fix receiver may be given by

$$CI_n = \frac{W_n \sin\theta_n}{L_n + W_R + R_n}. \tag{8}$$

Over the receiver width, reflections from all the mirror elements contribute to the local concentration ratio. The local concentration ratio within the receiver on its either surface is thus

$$C_R = \sum_{n=1}^{k} CI_n. \tag{9}$$

The distribution of LCR over the region outside the chosen receiver size may now be obtained by following a procedure similar to that used in the case of a flat plate receiver and our earlier calculations [5, 7]. Within the framework of the simple ray optical model used in this work it is clear that there will exist zones of different concentration levels in the region outside the receiver. However, the physical extent of these zones will in practice be such a small fraction of the receiver size that the midpoint of the zone alone may be assigned to the concentration of the zone itself. This will give rise to a smooth LCR distribution curve.

3. Results and discussion

Figures 2 to 5 illustrate graphically the three parameters, namely the shift, tilt and width of the various mirror elements of a linear Fresnel reflector concentrator having varying receiver to concentrator aperture separation f but the same receiver size W_R. The values of f are 0.25, 0.4, 0.6 and 0.8 m, respectively, W_R being chosen as equal to 0.05 m. It is observed that the shift, tilt and width associated with any mirror element increase as we move outward-towards the rim of the concentrator aperture. However, this rate of increase decreases with the receiver to concentrator distance f. The contribution of each individual mirror element is effective, hence it may be eliminated in design of the concentrator. A final decision about the extent of elimination can only be made after performing a detailed study giving due consideration to cost-economics and thermal performance aspects. In all the cases represented graphically in Figs. 2-5 the number of mirror elements has been suitably chosen to achieve the aperture diameter (D_p) equal to 1.0 meter.

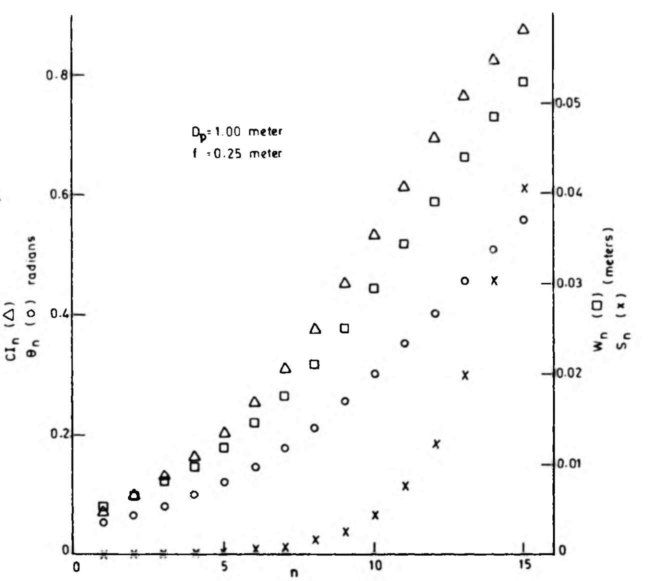

Fig. 2. Shift, tilt and contribution to LCR associated with various mirror elements, f = 0.25 m

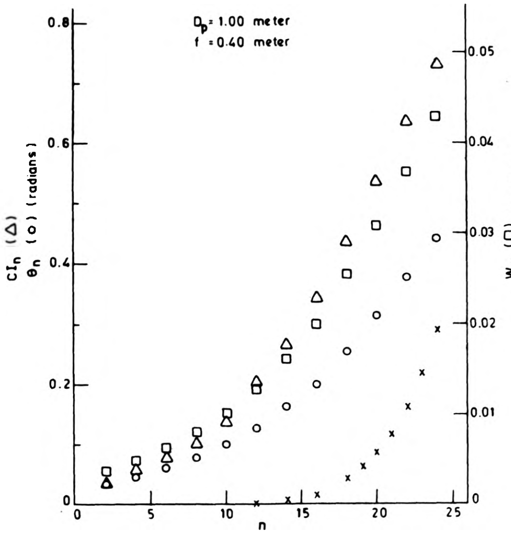

Fig. 3. Same as in Fig. 2.
f = 0.40 m

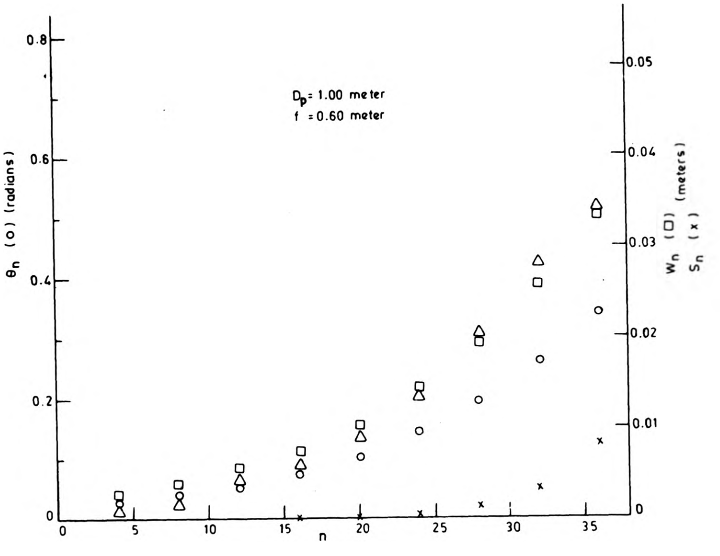

Fig. 4. Same as in Fig. 2, f = 0.60 m

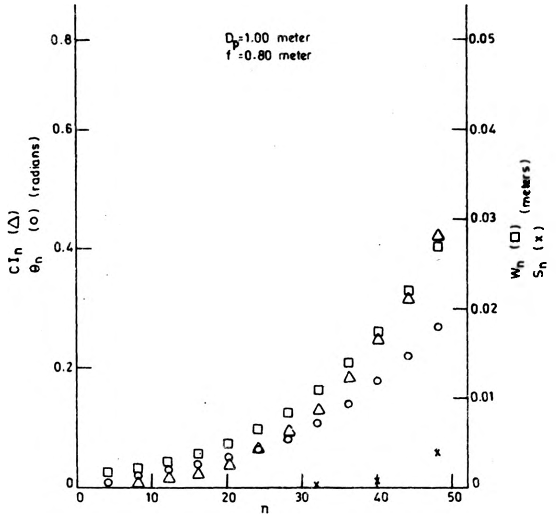

Fig. 5. Same as in Fig. 2, f = 0.80 m

Figure 6 presents the variation of C_R with the concentrator to receiver distance f for a receiver size of 0.05 meter and an aperture diameter (D_p) of one meter. It is found that the concentration is maximum at the focal length of 0.40 m. The distribution of local concentration ratio over the fin receiver for a typical case (W_R = 0.05 meters, D_p = 1.00 meter, and f = 0.40 meters) is presented in Fig. 7. It is found that a uniform concentration on the receiver is achieved by allowing for a variation in the width of the constituent mirror elements.

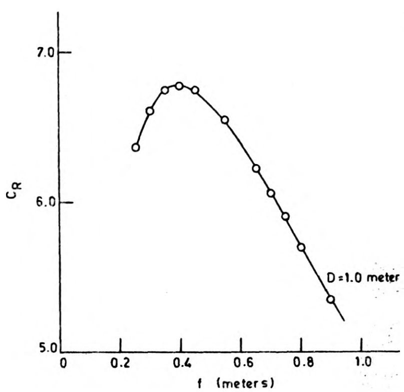

Fig. 6. Variation of θ_R with f

Finally, Fig. 8 gives an idea of the loss of energy due to the spacing left between constituent mirror elements to avoid the blocking of radiation. The variation of the sum of total required shifts $2\sum_{n=1}^{k} S_n$ with f has been plotted in this figure. It is observed that such loss decreases with increasing f. This may be attributed to the fact that at larger values of f a small shift of the mirror element is sufficient to avoid the blocking of radiation.

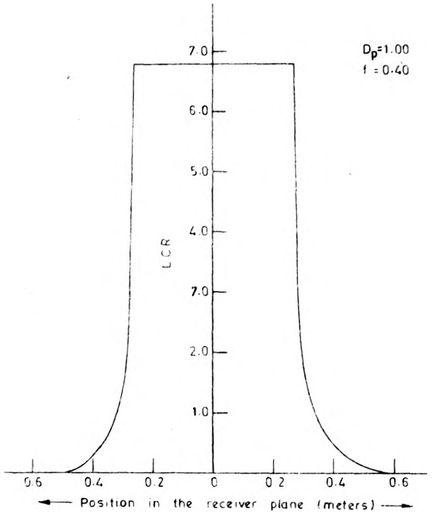

Fig. 7. Distribution of local concentration ratio in the receiver plane

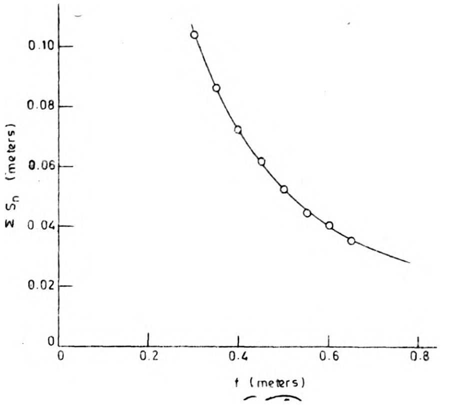

Fig. 8. Variation of $2\sum_{n=1}^{k} S_n$ with f

4. Concluding remarks

It may be concluded that a fin receiver may be used with a linear Fresnel reflector concentrator providing moderate concentration ratios. Both the sides of the fin receiver are illuminated uniformly, thus suggesting that such a concentrator receiver combination can be used as a potential candidate in photovoltaic concentrating systems. However, further studies are required to exploit the full potential of such systems from a practical point of view.

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ГЕОМЕТРИЧЕСКИЕ ХАРАКТЕРИСТИКИ ЛИНЕЙНОЙ КОНЦЕНТРАЦИИ РЕФЛЕКТОРА ФРЕНЕЛЯ ПРИ ПРИМЕНЕНИИ ПЕРЬЕВОГО ПРИЕМНИКА

Исследована возможность применения перьевого приемника совместно с рефлектором Френеля. Обсуждены геометрическая конструкция, а также характеристики действия систем концентратор-приемник. Произведены численные расчеты для некоторых типичных конструкций систем концентратор-приемник. Обсуждены результаты, представленные в работе в графической форме.