



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-1327

PERFORMANCE ANALYSIS OF A LINEAR FRESNEL CONCENTRATOR WITH A MOVING ABSORBER

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Abstract. *The end losses have a great impact on the optical performance of small solar concentrators. In order to reduce the effect of these losses, an innovative concept was developed and installed on the linear Fresnel prototype developed by the LEPTEN laboratory, at the Federal University of Santa Catarina, in south Brazil. For that, the receiver was mounted on rails that allowed it to move to north and south, to compensate the end losses. The LEPTEN workbench has 54 m² of primary mirror area and operates with Direct Steam Generation. This work shows the importance of this mobile absorber system and its performance compared with fixed absorber systems, for this small linear Fresnel prototype. There was a significant difference of the moving system and the fixed one regarding the absorbed energy along the year, showing how significant and relatively efficient is the moving absorber system. For the winter the end losses were reduced from 39.17 % to 8.17 % by using the moving system.*

Keywords: *Linear Fresnel Concentrator, Moving Absorber, Solar Energy.*

1. INTRODUCTION

The increasing research in renewable energy allows the improvement of the technologies, being able to provide lower cost, increase of energetic performance and less environmental impact. Automating the existing processes in the energy matrix tends to make possible the greater use of the natural resources provided. Solar energy becomes a promising energy source to be studied and applied. Thus, one way to harness solar radiation for energy generation is through concentrated solar power technology (CSP), which uses mirrors to reflect and focus solar radiation into a smaller area (receiver) achieving higher temperatures. In the LEPTEN Linear Fresnel Concentrator (LFC) workbench, the working fluid is water, and the steam is generated inside the absorber tubes. This possibility is called Direct Steam Generation (DSG). Several studies showed the technical feasibility of the DSG process on solar concentrators (de Sá et al., 2018; Zarza et al., 2004). Solar energy has a great potential for industrial process heating, providing steam for process like distillation, drying and cooking (Sharma et al., 2017). The LFC has some advantages over the parabolic trough concentrators as it is less expensive and simpler to build (Barlev et al., 2011; Morin et al., 2012).

Pulido-Iparraguirre, D. et al, 2019 presents in his work the configurations for displacement of the absorber receiver taking advantage of the incidence of radiation for the different days of the year. Pulido-Iparraguirre, D. et al, 2019 also shows the possibility of axial displacement of the receiver, taking advantage of the rays that normally do not find the end of the receiver due to the position of the sun and thus provides a significant reduction of the geometric losses of the collector end.

The analyzed LFC has a north-south orientation, so the mirrors track the sun as it moves from east to west. Along the year the sun also varies its position in the north-south direction, between winter and summer. In the winter there is high incidence angle on the longitudinal plane, and the radiation would be reflected out of the receiver if it could not move to compensate this effect.

The objective of this study is to evaluate the influence that a mobile absorber has on the performance of a small scale LFC at LEPTEN laboratories at the Federal University of Santa Catarina (UFSC).

2. LEPTEN LFC

The LEPTEN LFC is a workbench to study the viability of this type of technology, locally developed and manufactured, that operates with DSG. This prototype can be seen in Fig. 1, and it was entirely designed and constructed by the Heliotérmica group from the LEPTEN laboratory inside the project Heliotérmica CNPq (Proc. 406357/2013-7). An overall description and preliminary analysis of the workbench and initial results can be found in (PIGOZZO F. et al., 2018).



Figure 1. LEPTEN LFC workbench.

The final configuration of the workbench, as seen on Fig. 2, is an LFC of 5 m x 12 m, with ten mirror lines, each containing 12 mirrors of 1000 mm x 450 mm. The total mirror area is of 54 m². The spacing between mirror lines is equal for all lines. The receiver was set on a multi-tube trapezoidal cavity configuration, with 346 mm of aperture on its bottom, and located at a height of 3.75 m. The LEPTEN LFC uses flat mirror modules, cold bent to a small curvature. Each module has 1000 mm x 450 mm of common mirrors locally manufactured to reduce cost.

A trapezoidal cavity with multi-tube configuration was adopted as the receiver. A flat glass plate of high transparency is positioned at the lower part of the cavity in order to minimize the convective losses to the environment while allowing the entrance of the solar irradiation.

The receiver is fixed at the bench structure by two rails, which allows it to move to south and north direction as seen in Fig. 2. This innovative design was developed in order to compensate the end losses during tests analyzed throughout one year.

A solar tracking system was developed in order to rotate the mirror lines to correctly compensate the solar displacement throughout the day. The solar angles relations and the calculation of the angular offset between the mirror lines can be seen in (Bittencourt de Sá, A., 2018).



Figure 2. Fixation of the receiver on rails.

3. EXPERIMENTAL SETUP AND METHODOLOGY

The LEPTEN LFC receiver has a moving mechanism. This component has a great influence on performance of the system therefore it will be detailed in this section. Since the prototype is of a small dimension, being 5m wide and 12 m long, the end losses would have a great impact on its performance. With that in mind, the absorber was designed to be supported on rails, which allows it to be moved. Fig. 1 showed a photo of the LFC workbench and Fig. 3 shows the schemes of the moving absorber, with the displacement length for each direction. The workbench is installed on the southern hemisphere (Latitude -27.60°), hence the displacement course needed is larger due to south. The designed course of displacement is 3.72 m to the south and 1.16 m to north.

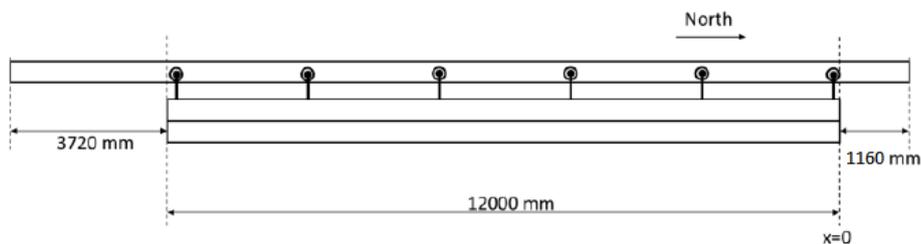


Figure 3. Scheme of the moving absorber

As shown in the Fig. 4 the rails of the absorber were marked in order to verify the position of the absorber during tests, and to compare with the calculated displacement. The verification is visual and not very precise, however, for qualitative purposes the calculated and verified displacement matched reasonably well.



Figure 4. Photo of the marked track of the moving absorber.

4. RESULTS AND DISCUSSIONS

The solar position was tracked throughout the year by using the solar equations. It was seen that the moving absorber compensate end losses for most of the time periods that a test would be performed during the year. Even at times where it did not eliminate it, it considerably reduced the end losses.

Figure 5 shows the results of the simulation for a whole year at the site of the LEPTEN prototype. This simulation was made using the solar position equations presented on (Duffie and Beckman, 2006), modeled in Matlab.

The two blue dotted lines on early and late hours represents respectively the sunrise and sunset hours throughout the year. In this figure four red curves can be seen, two at early hours, and two at late hours. The enclosure between them and the dotted blue lines shows the hours that the moving absorber cannot fully compensate the end losses due to North.

At periods below the two early hour curves, and after the two late hour curves the incidence angle is so inclined to south, that the end losses to North are bigger than the 1.16 m that the moving absorber can dislocate.

Ultimately, these periods are not very important in the overall analysis of the concentrator. Actually, most tests begin after 8:00 in the morning and stops before 17:00. In these early and late periods, it is very unlikely to have permanent regime required for the analysis of the concentrator, due to the high transversal angles and consequently the high shading between mirrors. It can be said that for all practical purposes the displacement due to north that the moving absorber has is enough to compensate the end losses in that direction for all possible operational periods for the workbench throughout the year.

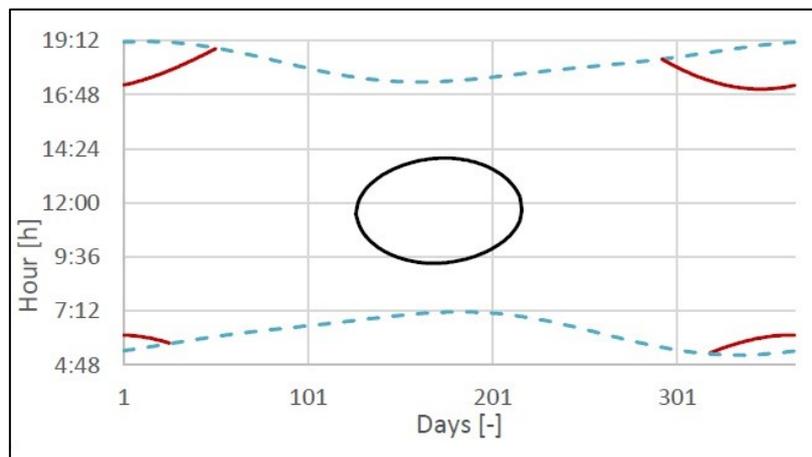


Figure 5. Results of the simulation of the moving absorber for a whole year.

There is a black lined circle on the center of the graph. The period within the circle represent the hours where the moving receiver cannot compensate the end losses due to south. These periods are more critical, because they happen around the solar noon during winter. The ideal would be to increase displacement course in the south direction to 4.7 m, which would fulfill its purpose during all year. However due to space limitations the project was set on a displacement of 3.72 m.

One example of the periods where the displacement is not enough can be seen on Fig. 6, of the 143th day of the year, at a time where the maximum movement of the receiver was not enough to compensate the end losses. The exposure and saturation of the photo were adjusted in order to better verify the concentrated radiation encountered on the extremity of the absorber.



Figure 6. End losses with the moving absorber at the maximum movement position due to south.

The maximum displacement to the south occurs on June 21, the day of the solstice, when winter begins at the southern hemisphere. The end losses in this specific time of maximum displacement, at June 21, 12:53 of local time, is reduced from 39.17 % to 8.17 % comparing the fixed absorber configuration to the moving absorber configuration.

The average end losses, considering the movement due to south, for only the periods where the moving absorber displacement cannot fully compensate the end losses is of 3.82 % and 34.82 % considering a fixed absorber.

For the analysis of a whole year of operation, from sunrise to sundown, for end losses due to south of the collector, the mean end losses for the system with the moving absorber is of 0.37 %, while for a fixed absorber it reaches 14.64 %. The same analysis for the end losses due to north gives a mean value of 0.61 % considering the moving absorber and 5.80 % for a fixed absorber.

The end losses due to north that the moving absorber cannot compensate seems higher, however it happens on less hours during the year, and only on beginning and end of the day, as seen in Fig. 5, having therefore less impact on the thermal performance.

The critical periods are the ones that the moving absorber cannot compensate due to south, and they happened around solar noon starting at 8th of May (day 127) and end on the 5th of August (day 217). The early that this occurs is at 9:19 at June 19th, and the latter at 13:59 at June 25th. Overall the moving absorber is a design configuration that presents a great advantage for the research viability of small scale LFC prototypes.

As presented on, this prototype has a moving absorber to compensate the end losses. Although it does not influence the transversal IAM, it will have a direct effect on the longitudinal IAM. So, in order to properly determinate the IAM_L (Longitudinal Incidence Angle Modifier) on SolTrace, the position of the receiver has to be accordingly to the variation of the incident angle, up to a point where the moving absorber reaches a maximum dislocation allowed by the system.

Figure 7 shows the different IAM_L for three cases, one considering a fixed receiver (zero displacement), and the others considering a moving receiver with a maximum displacement to north and south of 1.16 m and 3.72 m, respectively. The latter two curves represent the IAM_L curves for the LEPTEN prototype when moving north and south respectively.

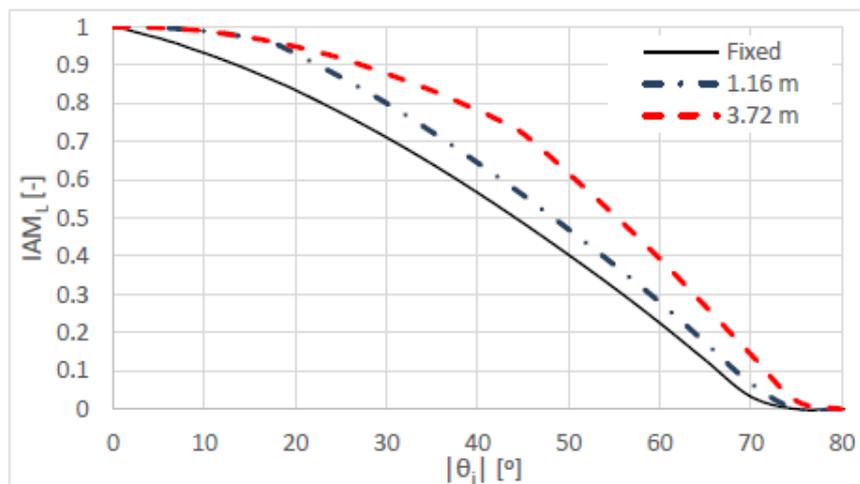


Figure 7. Longitudinal IAM for a fixed receiver and a receiver with a maximum dislocation of 1.16 m to north and 3.72 m to south.

It can be seen that the moving absorber has a great impact on the IAM_L, and this system allows for the workbench to make better use of the available solar radiation for a wider range of time periods. However, the moving receiver system is only adequate for small scale LFC, since the improve in the IAM_L curve is less appreciable on larger lines of collectors. This is because the end losses are inversely proportional to the total length of the collector (Bittencourt de Sá, A., 2018). This effect can be seen on Fig. 8, where different configurations of the LFC are considered. All of the LFC compared in Fig. 8 have the same transversal geometry of the LFC from LEPTEN, however they present different lengths. First, a case of an infinite LFC is analyzed, as seen on the black dashed line. This represents the maximum longitudinal IAM that this configuration of LFC can achieve, since an infinite collector does not take into account the end losses. Later, a case of the LEPTEN LFC with 120 m of length was simulated for a case considering the 3.72 m of moving absorber to south and a case of fixed receiver. This represents a case where 10 LFC modules are connected in series. And then the result of the simulations of the actual LEPTEN prototype are plotted for a case of fixed and moving absorber with 3.72m of maximum displacement to south.

The comparison shows that the moving absorber allows the LFC to operate with the same IAM_L as an infinite collector for incident angles up to 43°. This represents a great increase on performance when compared to a fixed receiver of 12m of length.

After 43° of incident angle, the maximum length of the moving absorber is reached, and the 12m of length of the LEPTEN LFC starts to weight heavy on the end losses, as it can be seen on the green curve. For the 120 m LFC, the total length diminishes the end losses effect and even after the final displacement of the moving receiver is reached, the IAM_L curve is still similar to an infinite LFC case. In fact, the IAM_L curve for the 120 m LFC with fixed absorber is also close to the infinite IAM_L . It is noteworthy that 120 m of collector line is not an unreal length, in fact, most linear concentrator solar plant has longer lines, which would reduce even more the effect of the moving absorber.

This shows both that the moving absorber is a powerful design advantage for small-scale prototypes, and that it is not viable for large scale LFC, since it requires a more complex system and it does not make a great impact on the overall efficiency.

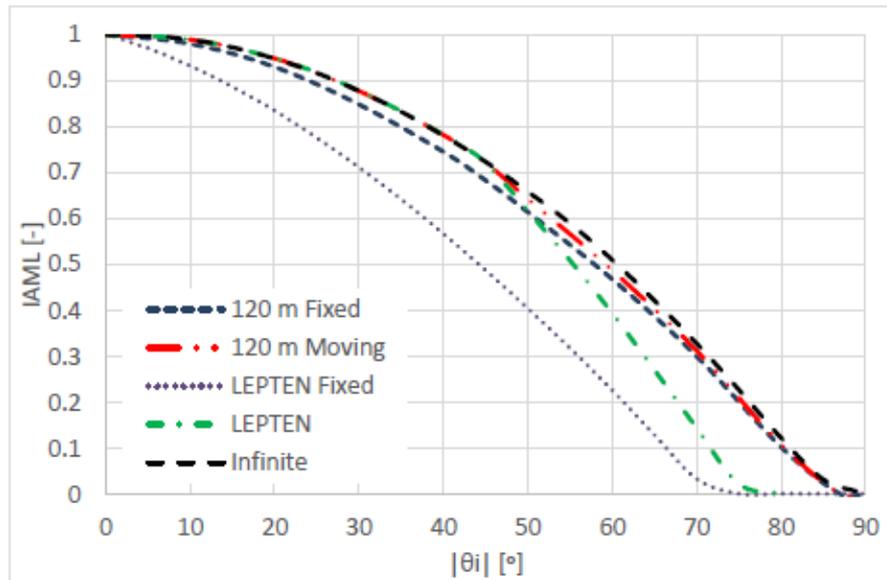


Figure 8 - Comparison of the IAM_L for different configurations of the LFC from LEPTEN obtained using SolTrace.

Solar linear concentrators usually present symmetry in both transversally and longitudinally. This means that the IAM curves are usually presented as showed in Fig. 7, and that these curves are symmetrical for positive and negative values of θ_i and θ_r . However, for the LEPTEN prototype it is important to know not only the magnitude of these angles, but the direction where they come from. Where θ_i and θ_r are the angles indicated in Fig. 9.

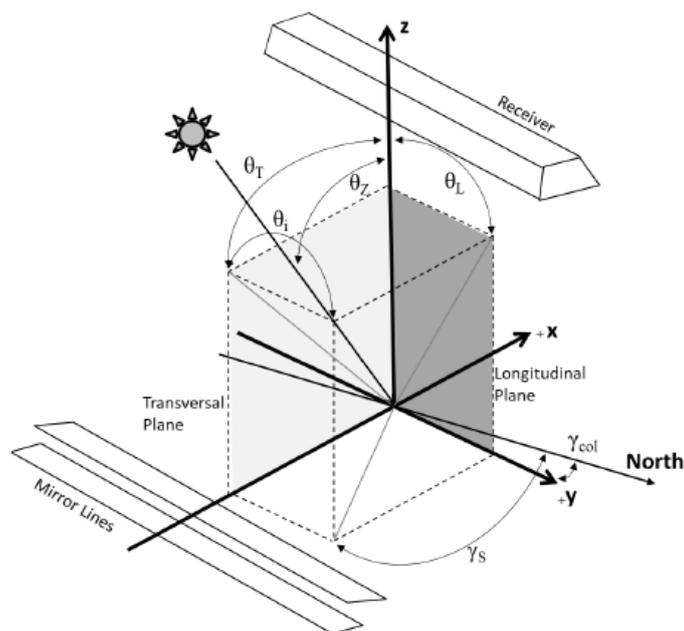


Figure 9. Sunray angles and relations with reference planes used on IAM factorization.
 Adapted from: (HEIMSATH et al., 2014).

The IAM_T (Transversal Incidence Angle Modifier) is symmetrical. And due to the design of the LFC the moving absorber has different maximum displacements regarding the direction of the θ_i . The final IAM curves covering all range of the incident and transversal angles are showed on Fig. 10.

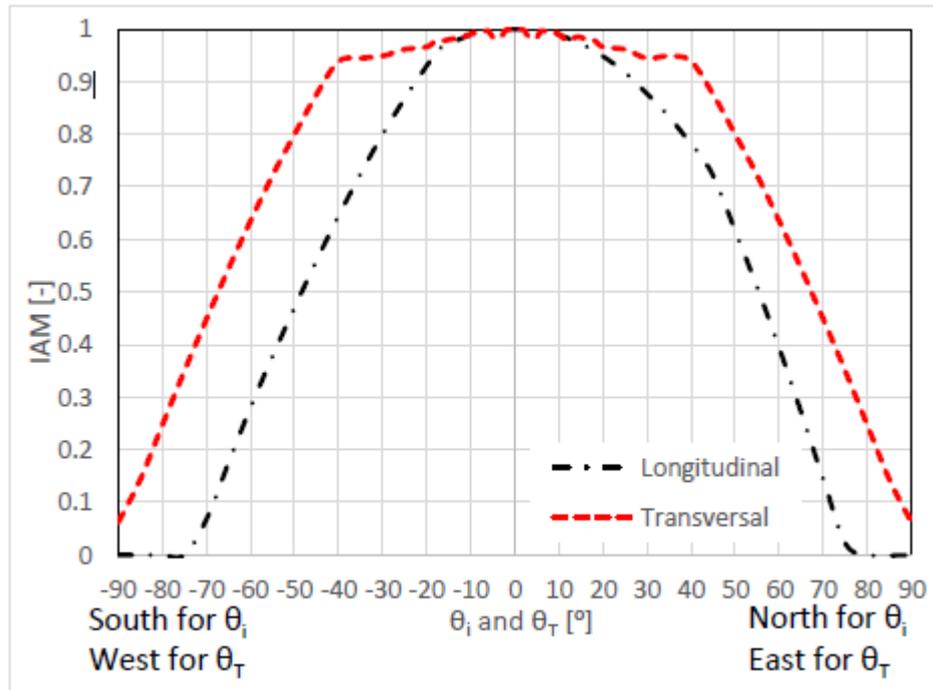


Figure 10. Final IAM curves obtained by SolTrace for the LEPTEN LFC.

As it can be seen, the θ_i is positive when directed to north and negative to south, and the θ_T is positive due to east and negative due to west. These IAM curves are used to simulate the LFC behavior on different incident angles.

5. CONCLUSIONS

The use of the mobile absorber has shown a considerable improvement in reducing the end losses.

When compared the fixed absorber with the mobile absorber, in the period of June 21, the final losses were reduced from 39.17 % to 8.17 %.

Analyzing over the whole year of operation, in the daily sun cycle, for the final south losses of the collector, the average end loss for the system with the mobile absorber was 0.37 % while for the fixed absorber it was 14.64 %.

The same comparison for the north was 0.61 % for the mobile absorber and 5.80 % for the fixed absorber.

The critical periods are the ones that the moving absorber cannot compensate due to south, and they happened around solar noon starting at 8th of May (day 127) and they end on the 5th of august (day 217). The early that this occurs is at 9:19 at June 19th, and the latter at 13:59 at June 25th.

The mobile absorber can operate with the same IAM_L as an infinite collector for angles up to 43°. Representing a large value over the fixed period of 12m in length.

Overall the moving absorber is a design configuration that presents a great advantage for the research viability of small scale LFC prototypes.

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support by CNPq (Project 406357/2013-7), CAPES and POSMEC-UFSC.

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