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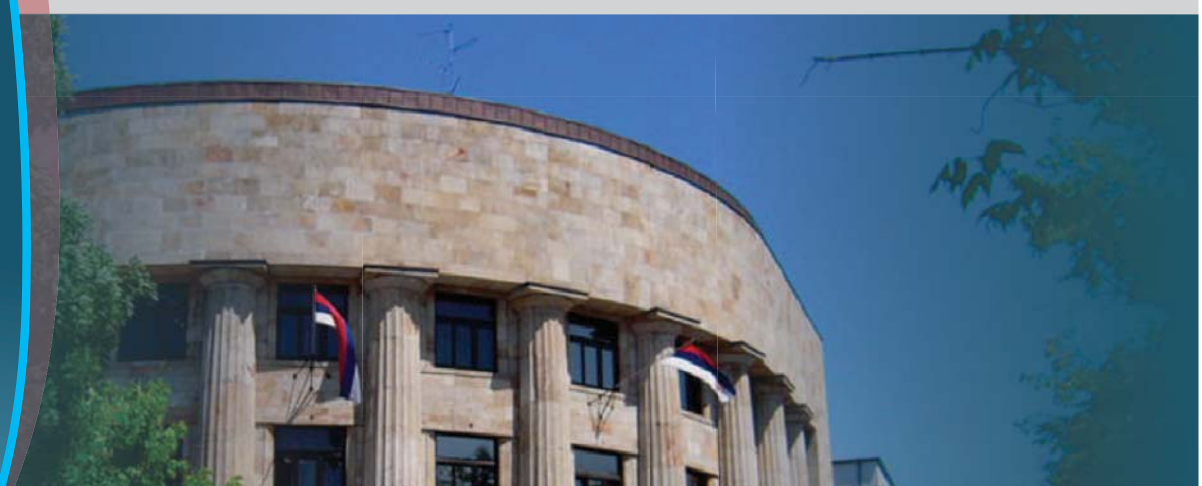
Faculty of Mechanical Engineering

11th International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology DEMI 2013

PROCEEDINGS



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OPTIMAL REFLECTOR POSITION OF A DOUBLE EXPOSURE FLAT-PLATE SOLAR COLLECTOR

Novak Nikolić[1], Nebojša Lukić[2], Dragan Taranović[3]

Summary: *The double exposure flat-plate solar collector (DEFPC) is a solar collector that can absorb solar irradiation from its upper as well as lower absorber surface (LAS). Absorption of a solar irradiation from its LAS is achieved using flat plate reflector placed below the collector. Compared to a conventional flat-plate solar collector, the insulation of the analyzed collector, placed in the bottom of the box, is replaced by glazing. In this paper the optimal reflector positions of the DEFPC are presented. They were obtained for the optimal yearly position of the collector at 44° N Latitude (Kragujevac, Serbia) and for equal dimensions of the collector and the reflector. The range of the reflector movement during a single year as well as the optimal reflector dimensions for minimum movement, were determined, too.*
Keywords: *double exposure flat - plate solar collector, reflector, simulations*

1. INTRODUCTION

A double exposure flat-plate solar collector (DEFPC) is a solar collector which can absorb solar irradiation simultaneously from both its upper and lower absorber surfaces (LAS). Absorption of irradiation from the LAS is accomplished using a flat-plate reflecting surface (reflector) placed below the collector. On the other side, absorption from the upper absorber surface is the same as that in the conventional flat-plate solar collector. To enable absorption from the LAS it is necessary beside the reflector that insulation in lower part of the collector box be replaced with glass (glazing). In this paper the optimal reflector positions of the DEFPC are presented. They were obtained by simulating the mathematical model given in [1]. This case is unique because the reflector is placed in parallel below the collector and is moveable in all three orthogonal directions, north-south, east-west and normal to the collector plane.

The optimal reflector positions were obtained for the optimal yearly position of the collector at 44° N Latitude (Kragujevac, Serbia) and for equal dimensions of the collector and the reflector (as in the experiment). The range of the reflector movement during a single year as well as the optimal reflector dimensions for minimum

[1] PhD student, Novak Nikolić, Kragujevac, Faculty of Engineering Kragujevac, (lepinole@yahoo.com)
[2] Dr, Nebojša Lukić, Kragujevac, Faculty of Engineering Kragujevac, (lukic@kg.ac.rs)
[3] Dr, Dragan Taranović, Faculty of Engineering Kragujevac, (tara@kg.ac.rs)

movement, were determined. The experimental setup of the investigated collector-reflector system (CRS) with its components is presented in this paper, too.

2. EXPERIMENTAL SETUP OF THE COLLECTOR-REFLECTOR SYSTEM

The collector-reflector system (CRS) is installed and experimentally tested in the open area of the Thermodynamics and Thermotechnics Laboratory, at the vertical south-west wall of the Faculty of Engineering Kragujevac. The mentioned system consists of the supporting construction (Fig. 1, position 1), the DEFPC (Fig. 1, position 2), the reflector (Fig. 1, position 3) and the construction for reflector movement (Fig. 1, position 4). In the following text every of its component is described in detail.

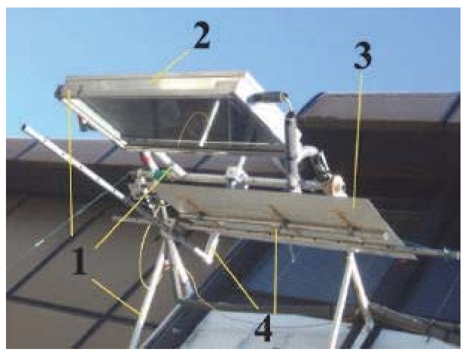

Fig. 1 *The collector-reflector system: 1-supporting construction, 2-DEFPC, 3-reflector and 4- construction for reflector movement*

The supporting construction of the CRS includes two cantilevered brackets (Fig. 2 (left), position 1), the axle with dividing head (Fig. 2 (left), position 2) and the collector bracket (Fig. 2 (left), position 3). The connection between the vertical wall of the Laboratory and the CRS is accomplished by steel cantilevered brackets. The aluminum collector bracket (Fig. 2 (left and right)) beside carrying weight of the collector carries weight of the construction for the reflector movement as well as weight of the reflector.

FIg. 2 *The supporting construction of the CRS (left) : 1-cantilevered bracket, 2-axle with dividing head and 3-collector bracket, and the collector bracket (right)*

The connection between the collector bracket and the cantilevered brackets is accomplished by the axle on which the collector bracket is attached. On the axle, the dividing head with 7 holes is welded. Every hole presents certain tilt angle of the collector. The angular axial distance between holes is 15˚.

The analysed solar collector, presented on Fig. 1, has dimensions 945 x 483 x 105 mm. The housing and absorber of the collector are made from aluminum while the absorber tubes as well as connecting tubes are made from copper.

Absorption of the solar irradiation from the LAS is enabled using the reflector (Fig. 3 (right)). The chosen reflector presents plexiglass mirror with dimensions of 1000 x 500 x 2 mm.

The reflector is manually moved in three orthogonal directions, direction normal to its plane, direction normal to its lenght (north-south) and direction normal to its width (east-west). In order to do that the aluminum construction for its movement is designed (Fig. 3 (left)). It consists of the rectangular frame (Fig. 3 (left), position 1) and the reflector frame (Fig. 3 (left), position 2).

FIg. 3 *The construction for reflector movement (left): 1-rectangular frame and 2-reflector frame, and the reflector (right)*

By the vertical part of the rectangular frame the distance between the reflector and collector changes in direction normal to their planes. Moving of the reflector on the horizontal part of this frame the distance between the reflector and collector axis changes but in direction normal to their lenght. The axial distance between holes on the vertical part of the frame is 50 mm, while the same distance on the horizontal part is 100 mm. In order to move the reflector in direction normal to its width the frame on which the reflector is attached was designed. The axial distance between holes on this frame is 100 mm.

3. OPTIMAL REFLECTOR POSITION

The great impact on the value of the absorbed solar energy, the useful energy gain and the efficiency of the DEFPC has the value of the irradiated area of its LAS (A_{irr}). In order to have the maximum possible absorption of solar radiation by the DEFPC it is necessary that the LAS be fully irradiated in every moment. The irradiation of the LAS depends on the reflector position relative to the collector and the instantaneous position of the Sun in the sky. As the Sun changes its position during the day and year the reflector must changes its position too following the sun's path. The theoretical model [1] was simulated using FORTRAN in order to determine the optimal reflector positions for the yearly optimal collector position. The simulations were performed for selected days representing the spring (autumn) equinox and the summer and winter solstices. The optimal reflector positions were obtained for every hour of the daytime of the selected days. As in the experiment, the dimensions of the reflector were the same as the dimensions of the collector ($L_r = L_c = 1$ m, $W_r = W_c = 0.5$ m). In practice, these dimensions would be the minimum reflector dimensions relative to the collector for which it is possible to have full irradiation of the LAS. A CRS tilt angle of 37.5˚ and an orientation of 180˚ was chosen, according to [*2*], that is, the yearly optimal collector position for Kragujevac, Serbia. Other necessary inputs for the simulations were the location parameters for Kragujevac: latitude $\varphi = 44.1$˚N, time zone $TZ = 1$ and longitude $l_{geo} = 20.54$˚.

For the practical presentation of the simulated data, the variables *X*, *Y* and *Z* are introduced. The variable *X* represents the distance between the reflector and the collector axis in the EWGα plane, the *Y* parameter is the distance between the reflector and the collector axis in the NSGα plane, and the *Z* is the normal distance between their planes. It was decided that for obtaining the optimal reflector positions, the limits on the reflector movement in all three directons would be $-3 \le X \le 3$ m, $-1.25 \le Y \le 1.25$ m and $0 \le Z \le 3$ m. Negative values for *X* and *Y* indicate that reflector is positioned toward the east and north, respectively.

Upon simulating the mathematical model, it was determined that for every simulated hour of the selected days and moving range, there is more than one possible reflector position for which the LAS is fully irradiated. This is because the reflector and collector planes are parallel and allow for specular reflection. All of the possible reflector positions that allow full irradiation of the LAS ($A_{irr} = 0.5$ m^2) for the spring (autumn) equinox are presented in Fig. 4 (left).

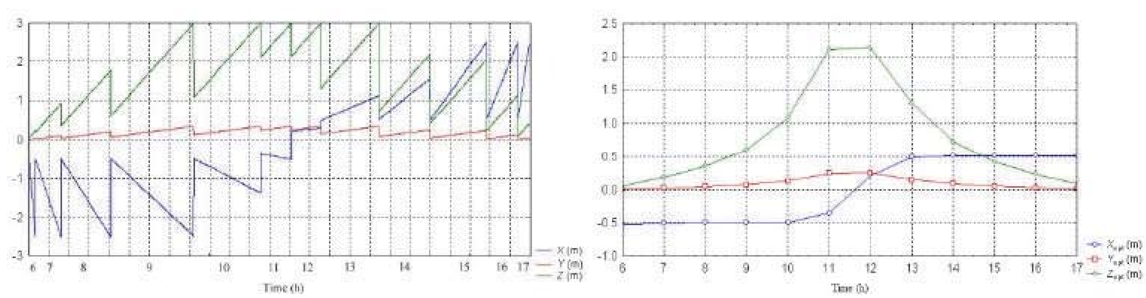

Fig. 4 *All possible reflector positions that allow full irradiation of the LAS (left) and the diagrams of the optimal reflector positions during the spring equinox (right)*

Fig. 4 also shows the nearest and farthest reflector positions for every simulated hour. For the nearest reflector positions, the distance between the reflector and collector is minimised, whereas for the farthest reflector positions, it is maximised. The diagrams for the other two selected days are similar and therefore did not presented here.

To minimise the reflector movement and because of the dimensions and complexity of the CRS construction, the optimal reflector positions are those nearest to the collector to enable full irradiation of the LAS. The optimal reflector positions for the selected days are presented in Fig. 4 (right) and Fig. 5 (left, right).

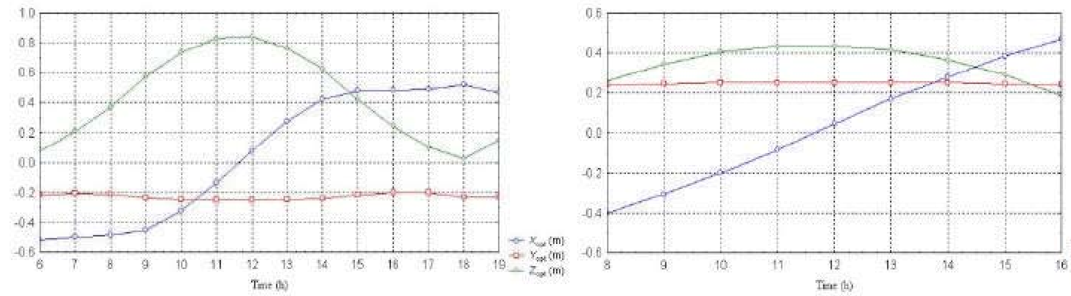

Fig. 5 *Diagrams of the optimal reflector positions during the summer (left) and winter solstice (right)*

The above figures also represent the optimum reflector path for the selected days. Upon investigating these figures, it can be observed that the minimum values for *X* and *Z* are at approximately noon and sunrise (sunset) and that the maximum values are at sunrise (sunset) and approximately noon, respectively. This is because the sun altitude is lowest at sunrise (sunset) and highest at noon. The parameter *Y* is almost constant for the daily motion of the sun. Fig. 4 (right) shows that the minimum and maximum values are 0.21 and 0.515 m for *X*, 0.005 and 0.25 m for *Y* and 0.05 and 2.14 m for *Z*. Fig. 5 (left) shows that for the summer solstice, the minimum and maximum values are 0.08 and 0.52 m for *X*, 0.2 and 0.25 m for *Y* and 0.025 and 0.84 m for *Z*, whereas from Fig. 5 (right), they are 0.045 and 0.47 m for *X*, 0.24 and 0.25 m for *Y* and 0.185 and 0.435 m for *Z*. For all of the selected days, the maximum value for *Z* is 2.14 m at the spring equinox at 12:00 p.m.. The reason for this is that for a given CRS tilt angle (37.5˚), the incident angle of the sun beam is smallest. Additionally, because the altitude of the sun is the highest on the summer solstice, and for a given CRS tilt angle, the values of the *Y* are all negative during the day.

According to the optimal values of *X*, *Y* and *Z* for all the selected days, the limits on the reflector movement, which allow the LAS to be fully irradiated, can be reduced to $-0.6 \le X \le 0.6$ m, $-0.3 \le Y \le 0.3$ m and $0 \le Z \le 2.2$ m. Based on this interval, there are two solutions regarding the design of the CRS construction. The first is that the reflector is given the same dimensions as the collector (L_r = 1 m, W_r = 0.5 m) and allowed to move within the above ranges (as in the experiment). The second solution implies that according to the ranges for *X* and *Y*, the optimal reflector dimensions can be determined. That means that the reflector with optimal dimensions of L_r = 2.2 m and W_r = 1.1 m would be moveable in only one direction: normal to the CRS plane.

4. CONCLUSIONS

In this paper, the optimal reflector positions for the yearly optimal position of the double exposure flate solar collector are presented. They were determined by simulating the mathematical model given in [1]. The model was simulated using FORTRAN. The minimum reflector dimensions that enable full irradiation are equal to those of the collector. In the simulated case and in the experiment those dimensions would be: $L_r = L_c = 1$ m and $W_r = W_c = 0.5$ m.

Simulations were carried out for every hour of daylight of the spring equinox and the winter and summer solstices. For these days, the reflector positions for which the LAS is fully irradiated are obtained at the optimum yearly position of the CRS at a latitude of $\varphi = 44.1^{\circ}$N. Due to the reflector-collector parallel setting and specular reflection, there is more than one reflector position that permits full irradiation of the LAS. The first reflector position for every hour of the selected days is the optimal position because the reflector position is nearest to the collector. All optimal reflector positions for one day represent the optimal reflector path for that day. The limits for the yearly reflector movement for which LAS will be fully irradiated are $-0.6 \leq X \leq 0.6$ m, $-0.3 \leq Y \leq 0.3$ m and $0 \leq Z \leq 2.2$ m based on the optimal values for X, Y and Z for the selected days simulated. Because of the altitude of the sun and the yearly optimal CRS position, the minimum reflector movement occurs at the winter solstice, and the maximum occurs at the spring equinox. Based on the above ranges, there are two ways to optimise the design of the CRS construction. The first is for the reflector to have the same dimensions as the collector and move within the above ranges (as in the experiment), whereas the second solution implies that the optimal reflector dimensions can be determined (as $L_r = 2.2$ m, $W_r = 1.1$ m) according to the ranges for X and Y where the reflector can only move in the direction normal to the CRS plane. Both solutions must be analysed in detail regarding the available space for mounting the CRS, the complexity and the cost. A properly designed DEFPC could present a real alternative to the tracking system for an improvement in the performance of flat-plate solar collectors.

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