Development status of Concentrating Collector with Stationary Reflector (CCStaR)

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Abstract

Tecnología Solar Concentradora SL and the University of the Balearic Islands have developed an innovative concentrator with fixed mirror and tracking focus called CCStaR (Concentrating Collector with Stationary Reflector). Its geometry is based on the Fixed Mirror Solar Concentrator (FMSC) concept. The main difference between other FMSC designs and CCStaR is the curved reflector in spite of flat mirrors. In this work the analysis of the quality of the geometry, the Incidence Angle Modifier calculated by a Forward-Ray-Tracing and the thermal efficiency curve of the first CCStaR prototype are presented.

1. Introduction

It is commonly accepted that there is a great potential for the use of solar thermal collectors in industrial applications as well as other process heat uses such as solar cooling. Although the foundations of this technology are well established, there are still a great number of open issues demanding for thorough research activity and innovative technological solutions. One of these open issues is the lack of a real market of reliable, cost effective, solar collectors designed specifically to meet the requirements of industrial applications, which are, in some aspects, quite different from domestic hot water or space heating applications.

There is a previous work of CCStaR description in EuroSun 2008 [1], in which the geometry optimization, the concentrator design and the receiver are described. The reflector has been manufactured as a sandwich structure with a high reflectivity aluminium sheet. Each collector has a 4.5 x 6 m reflector that consists of 16 pieces of 1 x 1.5 m assembled together by 5 laser cut steel profiles. Each reflector contains two parabolas, so 32 parabolas form the entire reflector. The receiver consists of 32 standard U-pipe Sydney tubes, see Figure 1. The first prototype has started operation in July 2008. In the present work we present the results of a complete evaluation of the solar concentrator.

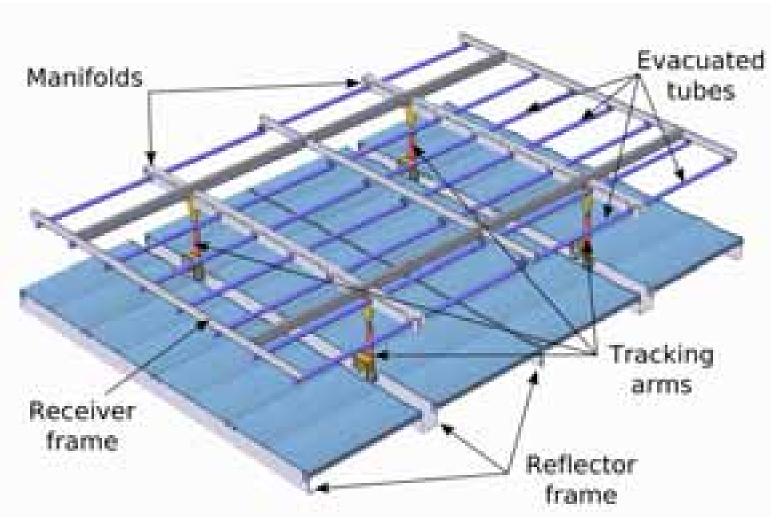

Figure 1. CCStaR 3D model

2. Geometric characterization

In a development process of a concentrator that requires a high geometrical precision it is necessary to know the final achieved geometry for two reasons: first to know the errors in the process of manufacturing and assembly; and second to be able to calculate the Incidence Angle Modifier by a Ray-Tracing procedure. The later is very important to estimate the thermal efficiency curve.

The method to characterize the geometry is based on a laser meter and caliper. It is possible to measure deviations of 0.5mm precision between the theoretical position and real position. The characterization was conducted as follows: relative vertical position between tracking receiver and supporting reflector structure, relative vertical and horizontal (transversal) position between receiver and reflector, relative horizontal position between evacuated tubes, deformation of the girders that support the concentrator, deformation of the evacuated tube supporting girders, quality of the steel profiles which support the reflectors, relative position between reflectors and the steel profiles, quality of the plane containing the reflector.

Figure 2. Positioning measures during the characterization

From the known measures of relative positioning of all the elements of the CCStaR prototype which are not presented here because of their size, the 3D coordinates of the reflectors and vacuum tubes, in a coordinate system in which origin lies in one of the vertices of the reflector, has been calculated. After knowing the theoretical and the actual coordinates in the 3D CAD model, the positioning error of reflectors and vacuum tubes respect to the 3D CAD model was calculated. These results are used in the Ray-Tracing to calculate the IAM of the solar concentrator. The relative positioning error in the transversal axis and perpendicular to the plane of the concentrator between the reflectors and the tubes are shown in the Table 1 and Table 2.

We can see that errors in the transverse direction are not greater than 4mm. This positioning error, despite being very small compared with overall dimensions of concentrador, could cause significant losses in energy captured for low sun angles. In general, the values are less than 3mm. See Table 1. With regard to errors in the perpendicular direction to the plane of the concentrator, it appears that the central part of the tubes manifold is well positioned. However, in the end, where the arrow of deformation of the support structure is greater, there are too large errors on the correct positioning of the vacuum tubes with respect to the corresponding parabola. These errors at the ends reach values of up to 18mm between the theoretical and actually executed distance between the reflector-tube. See Table 2.

Table 1. Relative positioning errors between reflectors and vacuum tubes in the transversal direction

Relative positioning errors in mm			*Longitudinal row*							
			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Transversal row	*1*	front edge	-1	0	1	0	-1	2	2	0
		back edge	-1	-1	0	0	0	0	-1	-1
	2	front edge	0	1	0	0	-1	-1	1	2
		back edge	1	1	1	1	3	2	4	2
	3	front edge	0	1	0	1	1	1	0	1
		back edge	1	1	1	1	2	1	0	0
	4	front edge	0	1	-1	0	0	0	2	2
		back edge	0	0	-2	1	-1	1	2	-1

Table 2. Relative positioning errors between reflectors and vacuum tubes in the perpendicular direction

Relative positioning errors in mm			*Longitudinal row*							
			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Transversal row	*1*	front edge	-1	-4	-5	-6	-8	-10	-11	-12
		back edge	2	-2	-3	-1	-1	-1	0	0
	2	front edge	1	1	1	1	2	1	5	3
		back edge	-1	-1	0	0	2	2	3	0
	3	front edge	0	-1	0	2	1	2	2	2
		back edge	2	2	1	1	1	0	0	3
	4	front edge	0	-2	-3	-3	-2	-3	-2	-4
		back edge	-8	-10	-13	-14	-14	-15	-15	-18

The positioning error of the longitudinal axis is not exposed here because as the performance of the collector is less sensitive to errors in this direction all errors found were considered negligible, showing high precision manufacturing and assembly in longitudinal direction of the solar concentrator.

3. Forward-Ray-Tracing

By means of a Forward-Ray-Tracing (FRT) procedure, made by the authors, the IAM was calculated. The program of FRT was initiated in 2006 [2] and it is in continuous upgrade. Through the FRT the real geometry has been modelled, introducing the exact position of the reflectors, tubes and manifold support from the previous geometric characterization. The specifications of each surface were also introduced like reflectivity, absorptive and its angular dependence, refraction coefficient of the glasses. A value of $\sigma=10mrad$ for the dispersion of the reflectors was assumed in the FRT. The size of the sun was taken into account with Buie's equations [3] assuming a value for the *circum solar ratio* CSR = 0.2 In the Figure 3 it can be seen an image of the FRT. Figure 4 shows the calculated IAM with de FRT program. The transversal and longitudinal IAM has been calculated from 0º up to 90º in steps of 2º and 10^6 rays were emitted for each transversal and longitudinal sun angle.

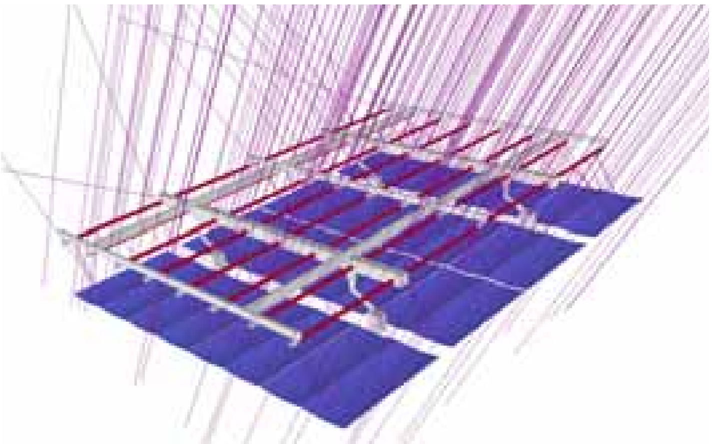

Figure 3. Image Forward Ray Tracing

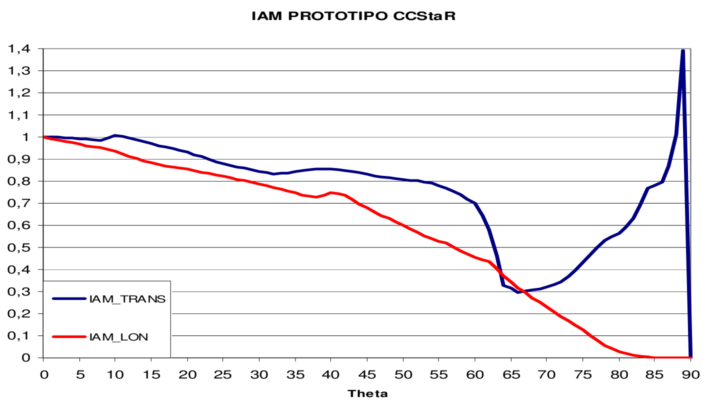

Figure 4. Transversal and longitudinal incidence angle modifier of CCStaR

The optical efficiency at normal incidence was calculated by the FRT procedure giving a value of η_0=68.5±0.5%.

4. Thermal efficiency curve

The method which has been used to test CCStaR is based on the European norm EN12975-2:2006 in quasi dynamic conditions [4]. Due to the complexity to obtain the IAM of a concentrator with a tracking absorber and with dimensions of about 4.5 x 6 m, the IAM used was the calculated with the FRT. The concentrator output is modelled with four parameters using the following equation

$$\frac{\dot{Q}}{A} = \eta_0 K_b(\theta_T, \theta_L) G_b - c_1(\vartheta_m - \vartheta_a) - c_2(\vartheta_m - \vartheta_a)^2 - c_3 \frac{d\vartheta_m}{dt} \qquad (1)$$

In contrast to the Standard, only the direct radiation G_b was considered because in the solar concentrator the solar energy captured from the diffuse radiation is almost negligible. Another difference from the Standard, the incidence angle modifier depends on both the longitudinal and transverse sun angles and the usual factorization approach can not bee applied in the case of CCStaR.

In order to operate the collector at different conditions seven test sequences have been used. The mean fluid temperature varied from ambient up to 120 °C. Table 3 summarizes the conditions of the seven test sequences used for the parameter identification.

Table 3. Test sequences used for parameter identification

Test sequence	Mean fluid temperature [ºC]	Ambient temperature [ºC]	Mean beam radiation on the aperture [W/m^2]
1	27	29	694
2	32	30	713
3	37	37	598
4	67	33	580
5	78	30	600
6	88	31	716
7	118	32	647

The optical behaviour (IAM) of the concentrator had to be calculated for each position of the sun with the FRT program and then introduced into the multilinear regression as known values. Although the conversion factor η_0 has been calculated by FRT it has been re-determined in the multilinear regression as an unknown parameter in order to validate the FRT program.

Table 4 shows the parameter set determined from seven test data series. The conversion factor η_0 calculated in the multilinear regression coincides with the value obtained with the FRT procedure, which implies that the CCStaR geometry has been well characterized, both the positioning of the elements and the physical properties. In Figure 5 the measured and calculated collector output for all points used in the MLR are plotted. The thermal efficiency curve describes fairly well the behaviour of the CCStaR.

Table 4. Determined collector parameters

η_0 [-]	c_1[W/(m^{2}K)]	c_2[W/(m^{2}K^2)]	c_3 [J/(m^{2}K)]
0,6803	0,6381	0,0054	6490

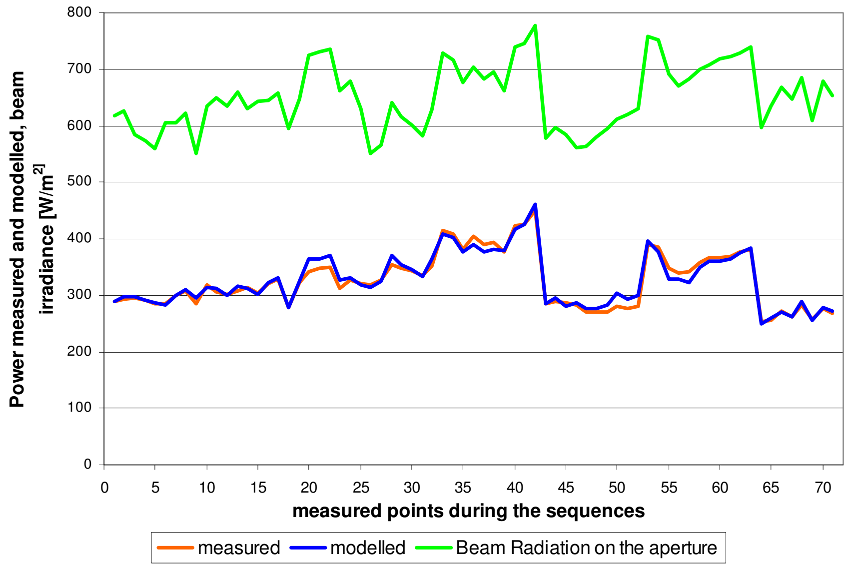

Figure 5. Measured and modelled collector output and beam irradiation of all points in the sequences test

5. Conclusions

The solar concentrator CCStaR has been characterized geometrically and it has been shown that the vacuum tubes at the ends of the mesh were not well positioned. This represents a loss in the captured energy during its operation. On the other hand, it has been shown that the combination of a FRT procedure for obtaining the IAM and the European standard EN 12975 for flat collectors and vacuum tubes presents a valid method to obtain the efficiency curve for complex systems with static reflector and tracking absorber such as CCStaR. The results show a high line between experimental values and the model.

This work has been very important to evaluate the first prototype and to improve the mechanical design of the next generation CCStaR prototype which is planed to start operation in September 2010 .

References

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