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## First Self-aligned Heliostat Prototype at the Plataforma Solar de Almería

R. Monterreal<sup>1</sup>, R. Enrique<sup>2</sup>, G. Barrera<sup>3</sup>, R. Sanchez-Moreno<sup>4</sup>, T. J. Reche<sup>5</sup>, J. Rodriguez<sup>6</sup>

<sup>1</sup>Researcher. Point Focusing Solar Thermal Technology. CIEMAT-PSA. Tabernas (Almería), SPAIN. e-mail: <u>rafael.monterreal@psa.es</u>.

<sup>2</sup>CESA-I Facility Manager. Scientific Facilities and Technical Services. CIEMAT-PSA.

<sup>3</sup>Researcher. Materials of Energy Interest Division. CIEMAT.

<sup>4</sup>Researcher. Materials for Concentrating Solar Thermal Technologies. CIEMAT-PSA.

<sup>5</sup>Lab technician. Institute of Solar Research, German Aerospace Center- DLR.

<sup>6</sup>Facility Manager. Point Focusing Solar Thermal Technology. CIEMAT-PSA.

**Abstract**. It is a generally admitted fact that the optical aligning process of faceted heliostats in a Solar Power Tower Plant (SPTP), also called heliostat canting, introduces an assembly time penalization as well as a potential error in heliostat optics conformation [1, 2]. This double penalization influences both the solar field setup time and the optical quality of the SPTP. Aware of this fact, in 2014 the Plataforma Solar de Almeria (PSA) developed and patented a method to self-align facets and thus avoid the critical canting phase of a heliostat [3]. To experimentally demonstrate the feasibility of the self-aligning facet process, a small reflector composed of six facets and 9m<sup>2</sup> of reflecting surface was designed and fabricated. The success of that experience has led to the development of a first 18.5m<sup>2</sup> prototype of a self-aligned heliostat, which has been installed at the CESA-1 Heliostat Field (PSA) in 2022.

Keywords: Heliostat canting, facet self-aligned process, heliostat set-up optimization.

### **Content of article**

The processes of design, development, as well as outdoor assembling of the first selfaligned heliostat prototype, carried out by a multidisciplinary team of CIEMAT-PSA, are all detailed in this article according to the following milestones:

- 1. Design considerations: advantages associated with the self-aligned heliostat concept.
- Facet: It is no longer an imaging system per se. It is now a simple reflecting element without any kind of associated revolution geometry for optical purposes. Figures 1A, B, C, D show a prototype of this kind of facet throughout the manufacturing process, consisting on a sandwich of metallic substrate glued to a second surface high specularity mirror under vacuum conditions. This square facet of 0.86m side can be screwed to the heliostat supporting structure. The implications of this change in the facet paradigm are: a) it simplifies and cheapens the manufacturing process, because the optical and careful forming process is suppressed; b) there is a single *universal* facet model for the entire heliostat field, i.e., from the point of view of the initial assembly of facets in the SPTP, as well as for the successive replacements, any facet can be

mounted on any heliostat of the field, since it does not have its own optical characteristics (geometry and focal length) but copies those imposed by the heliostat's support structure, and it is thus automatically focused and aligned.





Figure 1A. ANSYS model of the individual facet.

Figure 1B. Facet components before the glass-metal sandwich fabrication process.





Figure 1C. Facet during the glass-metal sandwich fabrication process under vacuum condition.

Figure 1D. Facet after the glass-metal sandwich fabrication process.

• **Supporting structure**: It now takes the relevant role of the new heliostat concept, so it is not only the structure supporting of the facets, but it is also provided with a well-defined geometry with feasible technological construction and affordable cost. This is achieved through a novel design and manufacturing process by means of a water-jet machine. The design affects not only the elements of which the supporting structure is composed, but also the particular way in which they are assembled together to achieve a perfectly finished surface of revolution. The surface of revolution, whatever it may be, is achieved by simply screwing the trusses of which it is composed according to an assembly protocol, requiring neither qualified personnel nor precision instruments.

As a result of the above, the facets are already focused and aligned to the support structure after the assembly process and the heliostat thus achieves its specularity and right focal length without any further task. Figure(s) 2A, B shows the understanding facets self-alignment concept.



Figure 2A. Understanding facets self-alignment concept (I).



**Figure 2B.** Understanding facets self-alignment concept (II). <u>Up</u>: After trusses assembling (left), heliostat supporting structure fits to a revolution surface (right). <u>Down</u>: After facets assembly to the supporting structure (left), the reflecting structure fits to the previous revolution surface (right), thus achieving the focusing and alignment (canting) of the facets at once. Precision instruments and expert personnel are therefore removed from the heliostat setup process at the SPTP.

# 2. Description of the tasks performed in the development of the first self-aligned heliostat prototype, to be assembled and evaluated at the CESA-1 Heliostat Field Facility.

**2.1** On the design of the prototype heliostat support structure. Case studies of structural deformations of the heliostat in different loading states. Conclusions.

Figure 3 shows the results of the optimization with ANSYS Mechanical concerning the material and thickness of the trusses and facets of the 18.5m<sup>2</sup> heliostat prototype developed by PSA-CIEMAT, under 2 heliostat load states, corresponding to an elevation angle of 23° with and without 25 km/h headwind (load conditions 3 and 4 respectively).



Figure 3. ANSYS Mechanical analysis of structural deformations in different heliostat loading states vs. nominal support structure (spherical, 256m focal length)

Conclusions:

Trusses.- Material: steel. Thickness: 10mm.

<u>Facets</u>.- Metallic part. Material: Steel. Thickness: 2mm. Specular part. Material: Second surface silver-glass mirror. Thickness: 1mm.

With this configuration of materials and thicknesses, the best compromise between the nominal and the expected real support structure is achieved, in terms of minimizing costs while maintaining the stiffness and shape compatible with the demanding optical quality.

**2.2** Testing facets with glass-metal sandwich typology, including: Accelerated Aging Tests campaign of glass-to-metal samples with different types of adhesives and thicknesses, carried out at the PSA Optical Aging Characterization Laboratory (OPAC). Result and conclusions.

An accelerated aging test campaign was performed at the OPAC facilities (in cooperation between CIEMAT and DLR), under the framework of the SOLTERMIN Project, in order to analyse the durability of a new reflector material developed by CIEMAT. This reflector material (facet) is composed by a silvered-glass reflector glued to a steel support. The main goal of this durability analysis is to assess the performance of the glass-metal assembly and different adhesive options.

#### Methodology

The reflector materials are composed by a silvered-glass reflector sample of 10 x 10 cm<sup>2</sup> and 1 mm thickness glued to a steel support of 1 mm thickness and approximately the same area of the reflector. Three different adhesives (A1, B1, B2) were tested (see Figure 4 as an example), and a fourth material only with the silvered-glass reflector was also included as a reference. A1 adhesive is the model S20 by SIKA. For confidentiality issues the data of adhesives B1 and B2 cannot be disclosed. All samples contain edge protection in each of the 4 edges. The edges were bevelled to increase the durability of the material but do not correspond to factory-like c-shape edge protection. 3 samples per material and test were included. The accelerated aging tests carried out on the 4 reflector materials are summaried in Table 1.



**Figure 4.** Picture of a SIKA S20 sample supplied, before accelerated aging testing. Left: front side (reflective side). Right: back side (reflector sample glued to a steel structure).

Table 1. Summary of accelerated ageing tests carried out in this study.					
Accelerated	Standard	Test conditions			
aging test					
Condensation	UNE	40°C with 100% relative humidity			
	206016 Test	Total testing time = 480 hours			
	6.7 [5]				
Thermal	UNE	85°C and -40°C for 4 hours respectively at ambient			
cycling +	206016 Test	humidity. Afterwards, the samples are exposed to high			
Humidity	6.8 A [5]	relative humidity of 97±3% during 16 hours at 40°C			
		Number of cycles = 10; total testing time = 240 hours			
Humidity freeze	IEC 62108	First step: 400 cycles from -40°C to 65°C. A dwell time			
cycle	Test 10.8 [6]	of at least 10 min within ±3°C of the high and low			
		temperatures			
		Second step: 40 times to the humidity freeze cycle			
		Total testing time $\approx$ 1500 hours.			
UV + Humidity	UNE	4 hours at 60°C to UV-radiation + 4 hours at 50°C to			
	206016 [5]	condensation (100% relative humidity without			
		irradiation).			
		Total testing time = 2000 hours			
Damp heat IEC 62108 65°C with 85% relative humidity		65°C with 85% relative humidity			
	Test 10.7 [6]	Total testing time = 2000 hours			

The characterisation of the samples was carried out before and after subjecting them to the different tests described in Table 1. The parameters used for the evaluation of the durability of the samples were the solar-weighted near-normal hemispherical reflectance ( $\rho_{s,n,h}$ ), the monochromatic near-normal hemispherical reflectance ( $\rho_{\lambda,n,h}$ ), and the monochromatic

near-normal near-specular reflectance ( $\rho_{\lambda,n,\varphi}$ ). The corresponding differences of the above mention reflectance parameters were obtained with the final and initial values,  $\Delta \rho_{s,n,h}$ ,  $\Delta \rho_{\lambda,n,h}$ , and  $\Delta \rho_{\lambda,n,\varphi}$ . In addition, a photographic inspection and an optical microscopy analysis was carried out. Reflectance measurements were performed according to the actual SolarPACES reflectance measurement guideline [7].

• Results and conclusions

As example of the results, Table 2 shows the values of  $\Delta \rho_{\lambda,n,h}$ . In general, no remarkable degradation was seen in the new reflector materials designed by CIEMAT, with respect to silvered-glass reflector (REFERENCE) used as reference. The only exception are the materials made with adhesives B1 and B2 which present significant silver corrosion after the damp heat test, as can be observed in Table 2 and Figure 5. According to these results it seems that a chemical reaction happened with these two adhesives under the testing conditions of the damp heat test, see Table 1.

<b>Table 2.</b> Monochromatic near-normal near-specular reflectance differences, $\Delta \rho_{\lambda,n,h}$						
(final – initial).						
	A1	B1	B2	REFERENCE		
Condensation	-0.002 ± 0.001	-0.002 ± 0.001	-0.003 ± 0.001	-0.002 ± 0.001		
Thermal						
cycling +	-0.001 ± 0.001	-0.001 ± 0.001	-0.001 ± 0.000	0.000 ± 0.001		
Humidity						
Humidity	-0.003 ± 0.001	-0.004 ± 0.001	-0.003 ± 0.001	-0.002 ± 0.001		
freeze cycle						
UV +	$-0.003 \pm 0.002$	$-0.003 \pm 0.001$	$-0.004 \pm 0.002$	$-0.003 \pm 0.001$		
Humidity	$-0.003 \pm 0.002$	$-0.003 \pm 0.001$	$-0.004 \pm 0.002$	$-0.003 \pm 0.001$		
Damp heat	-0.003 ± 0.002	-0.004 ± 0.002	-0.006 ± 0.005	-0.003 ± 0.001		



Figure 5. Picture of the B1 sample (left) and B2 sample (right) after both samples were subjected to 2000 h of the damp heat test.

Conclusions: i) the new reflector material manufactured by CIEMAT showed adequate durability under the testing conditions, ii) specially recommended the application of the adhesive SG20 by SIKA.

**2.3** Installation of the self-aligned heliostat support structure in CESA-1 Heliostat Field (PSA), with only central facet assembly.

The milestone of the installation, i.e., assembly + self-canting of the heliostat in the CESA-1 field, is to demonstrate that this process can be performed under the following conditions:

(i) Machinery: one crane and one work platform.

ii) Personnel: two mechanics, one crane operator.

- iii) Tools: fixed or motorized torque key.
- iv) Neither instrumentation nor qualified personnel shall be involved in the process.

As already mentioned at the beginning of the article, once the heliostat support structure is assembled and the facets are screwed, the heliostat will be already focused and canted, without requiring any additional task for this process, so it is already an optical system ready to work in the solar plant. According to Figure 2A, Figure(s) 6A, B, C, D, E, F, G show now the real assembly process of the heliostat at the CESA-1 Heliostat Field on September 14, 2022.



A. Trusses

B. Assembling stage 1

C. Assembling stage 2 (I)



E. Assembling stage 3

F. Assembling stage 4

G. Final assembling

Figure(s) 6A, B, C, D, E, F, G. Heliostat assembly sequence

Figure 7 shows the heliostat tracking on the CESA-1 target and the corresponding image of the sun reflected by the central facet.



Figure 7. Self-aligned Heliostat on sun-track (left) and the reflected sun image from central facet (right).

## **Conclusions and outlook**

It has been experimentally demonstrated at PSA that it is possible to build and assemble the reflecting surface of a heliostat starting from a modular trusses structure, whose geometry and simple way of assembly lead to a heliostat whose facets need neither to be focused nor aligned. Neither instrumentation nor gualified personnel are required for this type of heliostat assembly process. Moreover, the facets are very simple reflective elements, which adapt to the shape of the supporting structure to which they are screwed to achieve both the geometry and alignment required in such kind of imaging system. Our PSA experience has shown us how much time is spent in building facets that are themselves imaging systems, packing and transporting them carefully, sorting them on site by focal length zones, mounting them on the heliostats and finally aligning them (canting), and all that just for a field of only 300 heliostats. We are here only talking about the time invested in the new heliostat optical set-up at the CESA-1 Heliostat Field, and how the so called self-aligned process reduces it, in a first approximation, by more than 50%. The advantage of this proven fact would apply immediately to a commercial solar tower power plant, not only in its construction phase, also in the successive campaigns to replace facets due to breakage and/or corrosion. As an outlook, we mention the remaining task of assembling the rest of the facets pending of delivery (24) for this prototype, as well as carrying out an evaluation campaign regarding the optical guality that would be associated with this heliostat concept.

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