

# Development of a Concrete Parabolic Trough Collector

Dirk Krüger<sup>1</sup>, Sebastian Penkert<sup>2</sup>, Jürgen Schnell<sup>2</sup>, Nicole Janotte<sup>1</sup>, Patrick Forman<sup>3</sup>, Peter Mark<sup>3</sup>, Tobias Stanecker<sup>4</sup>, Joachim Krüger<sup>5</sup>, Alois Natterer<sup>6</sup>, Matthias Kintscher<sup>6</sup>, Reinhard Dasbach<sup>7</sup>, Johannes Wette<sup>8</sup>, Klaus Hennecke<sup>1</sup>, Timo Zippler<sup>5</sup>

<sup>1</sup> *German Aerospace Centre, Institute of Solar Research, Linder Höhe, 51147 Cologne, Germany, <sup>a)</sup>*

[dirk.krueger@dlr.de](mailto:dirk.krueger@dlr.de)

<sup>2</sup> *Institute of Concrete Structures and Structural Engineering, Technische Universität Kaiserslautern, Germany*

<sup>3</sup> *Ruhr-Universität Bochum, Lehrstuhl für Massivbau, Universitätsstraße 150, 44801 Bochum, Germany*

<sup>4</sup> *Stanecker Betonfertigteilewerk GmbH, Robert-Bosch-Straße 17-19, 33178 Borcheln, Germany*

<sup>5</sup> *Solarlite CSP Technology GmbH, Duckwitz 10, 17179 Behren-Lübchin, Germany*

<sup>6</sup> *Pfeifer Seil- und Hebeteknik GmbH, Dr.-Karl-Lenz-Straße 66, D-87700 Memmingen*

<sup>7</sup> *Almecco GmbH, Claude Breda Str. 3, 06406 Bernburg, Germany*

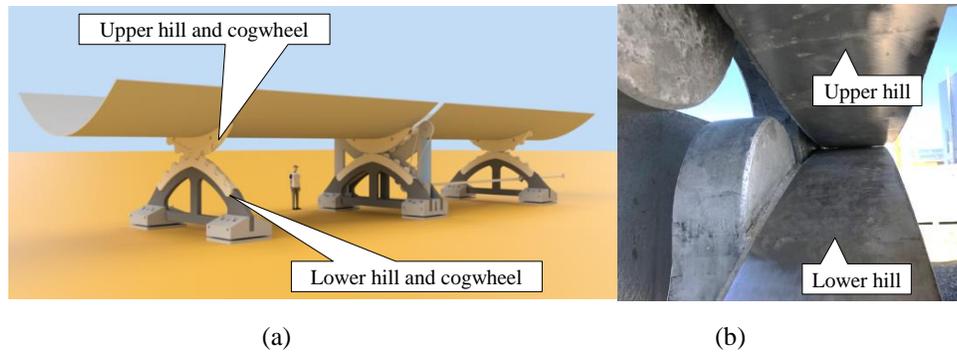
<sup>8</sup> *German Aerospace Centre, Institute of Solar Research, Plataforma Solar de Almería, Spain*

**Abstract.** Current parabolic trough collector development mainly aims at cost reduction. Within the project ConSol the goal was to reduce material and production costs by using high-performance concrete for the parabola shell itself and also for part of the tracking system. A high amount of manufacturing at the power plant site (“mobile factory”) by delivery of the raw materials and semi-finished products is foreseen, adding value to the local content. Within the project a collector prototype consisting of an extraordinary thin concrete shell was realised based on FEM calculations. The shell is moved via a novel sickle-shaped hill with a newly developed drive system. The collector’s shape was measured by photogrammetry and its optical performance deduced. A part of the ConSol project was dedicated to the improvement of a PVD coated mirror multilayer system on electrochemical polished aluminium strip substrate. With these new layer systems the reflective properties could be increased significantly. Finally, the costs of the system was summarised and cost benchmarks with existing collector technology.

## DESIGN

A choice at the beginning of the project was the use of a high performance concrete with very high flexural tensile strength of 18.2 MPa for the parabola material and a high Young’s modulus. Thereby, a non-cracked state and low deformations should be ensured. By a distributed drive system a torsion body, which would be difficult to be poured in concrete, could be avoided. Two solar collector elements (SCE) are connected to one drive unit (**FIGURE 1, a**). Due to the relatively high weight the parabola is not supported and turned via a bearing on a drive pylon, as typical for trough constructions, but rolls along a sickle-shaped hill with a thickness of 15 cm. It is formed in a way that the centre of gravity of the upper construction remains on the same horizontal level while the trough is tracked. To avoid sliding of the trough on the hill, cog wheels with a thickness of 8 cm at the side of the upper and lower hill are positioned. Hills and cog wheels were made of concrete (**FIGURE 1, b**) therefore, a special designed drive bearing was developed.

The movement is transferred via chains from a small engine between the pair of SCE. A pipe connecting the drive system of each SCE pair secures a parallel movement of the entire row even if one of the engines fails. The thickness of the parabola was calculated via FEM. A thickness between 5.5 cm in the middle and 3.5cm at the edge of the parabola has been realised, which would resist typical wind and other loads. Because of safety reasons the concrete had to be reinforced with steel.



**FIGURE 1.** Drawing of pair of SCE with drive system in the middle (a) and details of hill and cog wheel (b)

## RESULTS

### Experiences in Production and Handling

A pair of SCE with drive system was erected (**FIGURE 2**). The SCE could be tracked well by the drive system. The tolerances between upper and lower cog wheel allowed the SCE to slip for short distances on the hills. This slipping induced dynamic forces on the parabola structure which may be the reason for cracks occurring above the end of the sickle carrying it. These cracks can be avoided by reducing peak loads at the ends of the sickles through patches distributing the load on the parabola structure.



**FIGURE 2.** Pair of SCE with drive system in the middle

### Development of mirrors based on aluminium coil

A part of the ConSol project was dedicated to the improvement of PVD coated mirror multilayer system on electrochemical polished aluminium strip substrate. This reflector material offers the advantage of flexibility so that

it can be applied to any geometry. The pretreated aluminium coils with a width of 1250 mm are coated on an industrial air-to-air PVD strip coater, ensuring a cost efficient mass production of the material.

Before the start of the project mirror systems on aluminium substrate were already available but these systems were based on a multilayer mirror systems with an high purity aluminium mirror layer. These PVD layer systems were additionally protected against environmental impact by a sol-gel based protection coating. These layer systems were tested in the foregoing Alumir project. The result of the project was, that the reflectance of these mirrors was too low and the environmental stability was not sufficient compared to glass mirrors.

For the speedcoll project PVD multilayer systems with a high purity silver reflection layer were developed. To protect the silver against environmental impact the silver layer was packed between special silver protective layers and additional new sol-gel protective top coatings were developed.

First, different possible layer systems were simulated and optimised by an optical design software. Suitable layer systems were deposited on the industrial strip coater. These new layer systems were optically characterised and tested in different degradation tests to select the best layer system.

With these new layer systems the reflective properties could be increased significantly. Now the reflective properties are nearly on the level of glass mirrors (see **TABLE 1**).

**TABLE 1.** Comparison of reflective properties

material	$\rho_{s,h}([280,2500],8^\circ,h)$	$\rho_{\lambda,h}(660nm,8^\circ,h)$	$\rho_{\lambda,s}(660nm,15^\circ,12.5mrad)$
1mm glass mirror	0.956	0.965	0.965
4mm glass mirror	0.944	0.957	0.950
ConSol mirror system	0.964	0.975	0.923
Alumir mirror system	0.897	0.906	0.826

The best layer system shows good environmental stability in the Alumir 10year „Desert“ test. The solar weighted, specular reflectivity decreased only by 2.9 ppt. This means the project target was fulfilled.

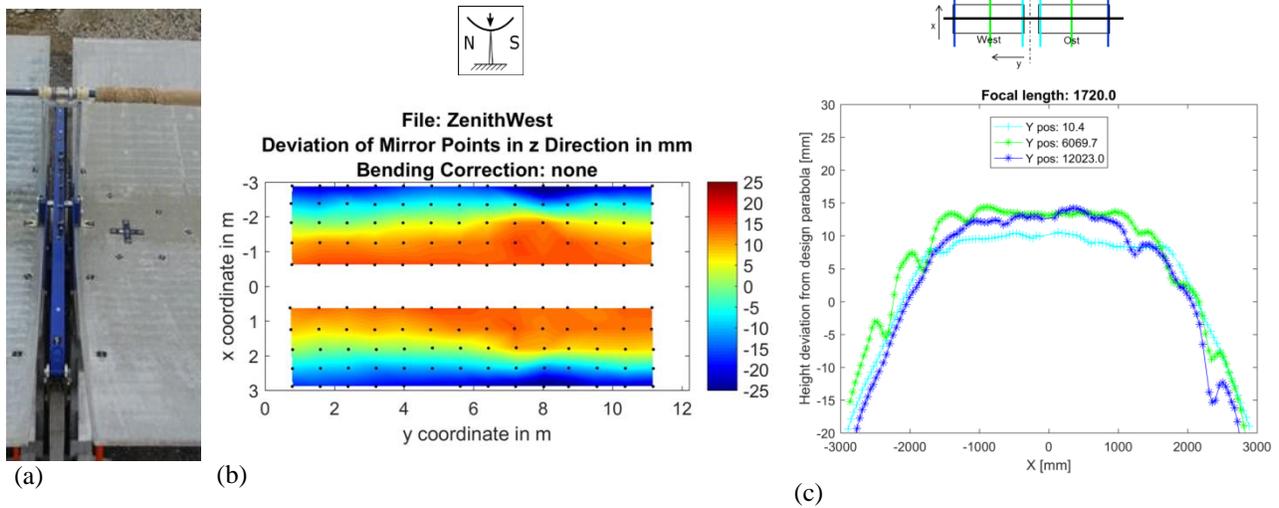
Nevertheless, the environmental stability is still not high enough compared to glass mirrors.

For mounting the mirror material an adhesive tape with a special foam layer was laminated onto the special treated backside of the aluminium strip. So it is possible to easily glue the mirror material directly on the concrete parabola shell.

## Photogrammetry

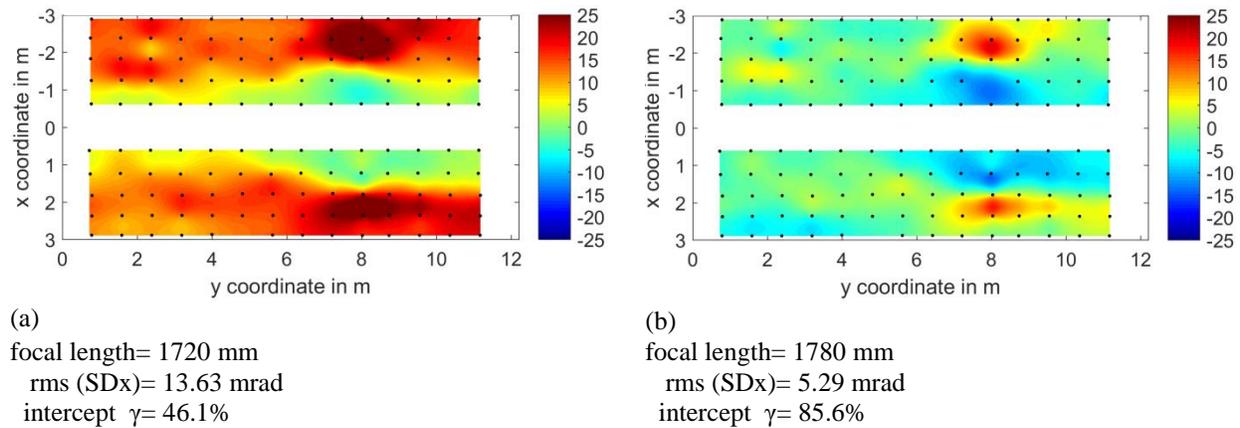
The shape accuracy of parabolic troughs, the positioning of the receivers as well as structural deformations due to dead-load can be assessed by means of close range photogrammetry. To this end, the prototype structure was equipped with coded and non-coded retroreflective targets (see **FIGURE 3 (a)**) and measurements were taken in zenith and close to horizon position of the collector. The analysis yields the 3D coordinates at the target points that are then interpolated and evaluated for shape accuracy and deformation.

The height deviation of the mirror points in zenith position shows a considerable and systematic widening of the parabolic crosssection that is illustrated in **FIGURE 3 (b)** and **(c)** for the west SCE: In comparison to the design parabola the concentrator shell is too high in the region of the vertex and too low towards the edges. This translates to large local and systematic slope deviations  $SD_x$  shown in **FIGURE 4 (a)** that in turn lead to a large fraction of the incident sun light missing the receiver, resulting in a low intercept factor of only 46%. The measurement results obtained in horizon position essentially show the same effects but are not detailed here. Height and slope deviations in y-direction are typically less critical for parabolic trough collectors. In the present case they were well within the tolerable range and thus not dealt with in detail here.



**FIGURE 3.** (a) Prototype collector with PG targets before applying the reflector material  
 (b) Height deviation of mirror points (West SCE in zenith position)  
 (c) High resolution height deviation of the parabola at selected location (West SCE in zenith position)

As the effective focal length of the concentrator is thus systematically increased compared to the design, this can be compensated by adjusting the receiver position. Optimum optical results are achieved by an upshift of the receiver by about 60 mm resulting in a focal length of 1780 mm instead of 1720 mm. **FIGURE 4 (b)** clearly shows the benefits of this measure matching the focus to the prevailing slope: The SCE intercept increases to 85.6%.



**FIGURE 4.** Results of slope deviation in mrad in x direction (direction of the parabola) for the West SCE in zenith position  
 (a) at design receiver position  
 (b) with corrected receiver position - positive values indicate a reflection of the rays above the focal line

The widening of the concentrator shell may result from the impression taken during casting (using a mould with a parabolic cross-section), creep, setting and shrinking processes during curing of the concrete as well as in the deformation due to own weight. The deformation analysis (not presented in this paper) comparing measurement results in zenith and horizon position clearly indicates that the latter is an issue for the current prototype.

The remaining slope peculiarities in **FIGURE 4 (b)** and their origins were not investigated in detail as the casting mould was not available for inspection at the time of measurement anymore. In series production they would have to be eliminated, however.

## Cost Analyses

As a part of cost benchmarking, a CSP plant with the size of Andasol 1 was evaluated. All plant components except the solar collector (solar collector assembly) are considered to be the same as Andasol plant. Even some of the core components like vacuum receiver and REPA are standard components i.e. 70 mm standard oil receiver and 2.5" ball joints. An intensive cost analysis was performed for the 510,000 m<sup>2</sup> solar field where prices for the ConSol collector components were obtained/developed. Receiver and REPA prices were adopted from Andasol publication, concrete parts and structural steel adopted from market standard price and supplier of Nanodur. Pfeifer quoted the tracking system price and Almeco quoted solar mirrors respectively. From the cost breakdown shown in **TABLE 2** it can be seen that the concrete parts and tracking system hold the major share of the collector cost. The whole solar collector field is estimated on the basis of operating with thermal oil HTF up to 393 °C. The costs for the components have been calculated thoroughly including the production facilities for a power plant.

**TABLE 2.** Cost overview

Component	Costs in €/m <sup>2</sup>
Foundations, sickles, cog wheels and parabola	87
Mirror and adhesive tape	19
Steel components	16
REPA	4
Tracking	23
Receivers	30 (680€/unit)

The position foundations etc. includes site preparation, assembly tent, jigs, storage area, trailers for transporting SCE within the field, cranes for lifting and tools. A concept for the construction of a high number of SCE for power plants has been developed very thoroughly (**FIGURE 5**).



## SUMMARY

In the ConSol project, various techniques adapted to a concrete collector structure were developed and implemented. It was possible to develop a parabola with a thickness of 3.5 cm to 5.5 cm and an aperture width of 5.77 m and 12 m length, which was also built as a prototype. It is tracked on a rolling hill, whereby the centre of gravity remains above the point of support.

One linear tracking unit drives 2 collector modules each. The motors are connected to each other via a pipe ensuring that if one motor fails, all modules continue to be aligned and tracked.

The solar weighted, specular reflectance of a silver mirror on aluminium coil substrate could be strongly improved compared to similar materials previously commercially available. The solar-weighted hemispherical reflectance could be raised to 96.4 % exceeding values of state of the art glass mirrors. The mirror has a slightly lower specularity of 0.947 which results in a specular reflectance (at 660 nm) of 92,3%.

Based on the developments, the costs for a solar field of 510,000 m<sup>2</sup> collector aperture surface were determined. Reduced costs for economies of scale were included and the costs for the means of production were calculated in detail. The specific price per square meter is 261 €/m<sup>2</sup> compared to 242 €/m<sup>2</sup> for the Andasol power plants for completely installed solar fields including collectors, field piping, electrical engineering, control etc. . .

Studies on slimmer concrete structures have shown that it is possible to reduce the weight of the collector shell and rolling hills by approx. 50 %. This would reduce the material costs for these components from 76 €/m<sup>2</sup> to 38 €/m<sup>2</sup> and the specific collector field costs to 223 €/m<sup>2</sup>.

The expected annual yields of a collector were determined based on the results of the photogrammetry of the two collector modules built. The calculations show that the LEC (Levelised Costs of Electricity) for a power plant with Andasol layout with the investments and the efficiency of the ConSol collector are around 21.93 €/ct/kWh. In comparison, the LEC of the Andasol reference power plant is 19.0 €/ct/kWh.

The project was successfully completed with the construction of a prototype showing the functionality of the concept. A photogrammetric measurement has shown that the shell has widened after casting, so that due to the deviation of the collector slope the intercept value is 86%, taking into account an upward shift of the receiver. Possible causes for this can lie in the impression taken during casting, in creep, setting and shrinking processes during curing of the concrete as well as in the deformation due to own weight due to a lack of rigidity. At least in parts, the shape deviation can be compensated for by appropriate compensation in the mould.

## ACKNOWLEDGMENTS

The findings have been gained in the frame of the project “ConSol” which has been funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag.