**Proceedings of Solar Forum 2001**
**Solar Energy: The Power to Choose**
**April 21-25, 2001, Washington, DC**

# EUROTROUGH DESIGN ISSUES AND PROTOTYPE TESTING AT PSA

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## ABSTRACT

A parabolic trough collector has been developed for various applications in the 200-400°C temperature range in solar fields up to the hundreds Megawatts range.

The design of a new support structure of the collector included concept studies, wind tunnel measurements, finite elements method (FEM) analyses and resulted in a structure with a central framework element. This torque box design will have lower weight and less deformation of the collector structure than the other designs considered. Therefore it will be possible in future to connect more collector elements on one drive which results in reduced total number of drives and interconnecting pipes, thus reducing the installation cost and thermal losses. In terms of the degree of material usage further weight reduction will be possible. The presented design has a significant potential for cost reduction, the most important goal of the EUROTROUGH project. The prototype has been set-up and is under testing at PSA (Plataforma Solar de Almería) for its thermal and mechanical properties.

## INTRODUCTION

Parabolic trough collectors have been the key element in the commercial application of concentrating solar thermal power plants in California. Although other concentrators promise higher concentration factors and higher system efficiencies the parabolic trough will continue paving the way for concentrating solar power. Considering this importance a European consortium has developed the next generation of a parabolic trough collector basing on the long experience of operation of LUZ collectors LS-2 and LS-3 in California.

The work targeted collector development for a wide range of applications in the 200-400°C-temperature range in solar fields up to the hundreds Megawatts range:

- Solar thermal electricity generation in co-generation plants
- Solar thermal process heat applications in a wide range of process steam
- Solar thermal sea-water desalination in MED processes

## STATE OF THE ART

The successful parabolic trough design in the 80s has been implemented in the Californian SEGS plants by LUZ, and the collectors still operate for grid-connected electricity production. The operating companies have worked thoroughly on improvement of operation and maintenance (Cohen et al., 1999). Features of the different collector types in terms of performance and durability became obvious.

The main characteristics of these collectors however establish the minimum requirements for a new generation of parabolic trough collectors.

Key elements of the existing technology are:

- support structure: steel frame-work structure with central torque tube or double V-trusses
- drive: gear drive, hydraulic drive
- tracking control: clock controlled, sun-sensor controlled
- reflector panels: parabolic mirrors, from glass or metal sheets

- absorber tubes (heat collection element = HCE): with evacuated glass envelope
- fluid: mineral oil, synthetic oil, water/steam

The components depend in part on the application, especially on the temperature range.

The EuroTrough project consortium gained through the thorough research on the existing parabolic trough collector designs an elaborate basis for the important design phase.

## EUROTROUGH DESIGN CONCEPT

The concept of the EUROTROUGH collector is basing on the boundary conditions mentioned above. Key characteristics are given in table 1.

TABLE 1: **EUROTROUGH** CHARACTERISTICS

| | |
|---|---|
| layout | parabolic trough collector |
| support structure | steel frame work, pre-galvanized, three variants; light weight, low torsion |
| collector length | 12 m per element; 100 - 150 m collector length |
| drive | hydraulic drive |
| max. wind speed | operation: 14 m/s, stow: 40 m/s |
| tracking control | clock + sun sensor, <2 mrad |
| parabola | $y = x^2/4f$ with f = 1.71 m |
| aperture width | 5.8 m |
| reflector | 4 glass facets |
| absorber tube | evacuated glass envelope, UVAC® or other, application dependent |
| fluid | oil, steam, application dependent |
| cost | < 200 Euro/$m^2$ |

Major effort was put on the design of the metallic collector support structure of the concentrator. Apart from survival of the structure, the stiffness of the collector is important to keep up collector performance with wind-loads during operation. This has been examined from two aspects:

- wind tunnel experiments for determination of the forces and moments
- Finite Element Method calculations (FEM) to determine collector deformation and estimate losses (spillage of radiation due to wind).

### 1. Wind Tunnel Evaluation

In a first step detailed wind tunnel tests have been conducted for getting a reliable database for the expected wind loads at different locations in the collector field. Figure 1 shows the experimental set up of the wind tunnel test. Bending and torsion forces have been determined in these experiments. Horizontal forces and pitching moments have been evaluated for different wind speed and direction, different collector positions in the field and various elevations of the collector. The evaluation of the wind tunnel measurements confirmed that the solar collector field of a full size plant could be divided into three different wind loading zones: The shadowed inner field area with approximately 95% of the total Solar Collector Elements (SCE), the transient area (close to the edges of the field) with about 2.5% and the high wind loaded edges and rim areas where about 2.5% of the total SCE are located. Due to these different wind loads the collector structure is designed in accordance to these different wind zones. A solar collector field will have three different types of collector structures (a high wind loaded, a medium wind loaded and a regular structure) depending on where the SCE is located in the field. The cost of a complete Solar Collector Field will be dictated by the cost of the regular SCE located in the shadowed field area. Due to this result the next step in finalizing the design was concentrated on the SCE structure in the shadowed field area.

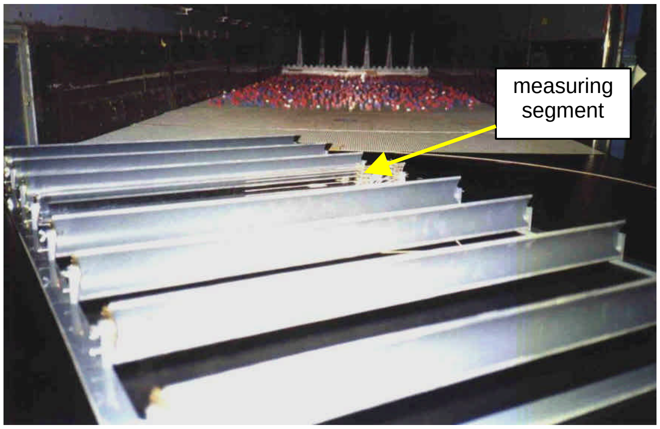


Figure 1: Experimental set-up of the wind tunnel test. Cp values have been measured at different positions of the collector element, different locations in the field and various pitching angles of the SCE as well as different wind directions.

### 2. Structural Analysis

Detailed FEM investigations on the structural behavior under different load cases (dead load, wind loads under different pitching angles of the collector and different wind directions) for different designs were performed for obtaining results on the expected deformation of the structure under different operation conditions. From these results the expected optical performance of the new collector design was derived. A lot of effort was spent on evaluating the optical performance of the new collector design:

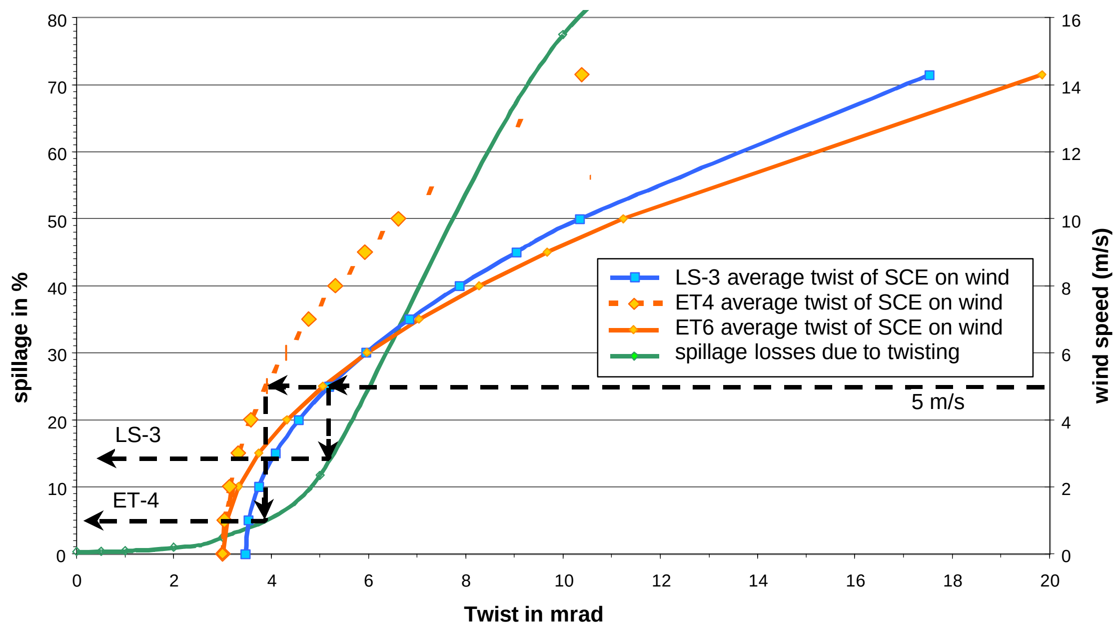


Figure 2: Analysis of angular twist and radiation spillage as result of wind load on the Solar Collector Assembly for EuroTrough collector with 100 and 150 m (ET4, ET6), and the reference collector (LS-3).

Computer modeling of the optical performance was done with ray tracing of the structure deformed due to bending and twisting, evaluation of tracking error, deformation and misalignment of the absorber tube.

Different operating wind velocities from 3 to 14 m/s (causes different induced twisting moments on the structure) were investigated in order to estimate the influence of a windier site on optical system performance.

For comparing the obtained results with the data and experience gained in the US and on the Plataforma Solar de Almería with other collector designs the same FEM analysis was also performed for those structures. Three design variants have been worked out and compared to each other by detailed FEM calculations, and cost approximates.

## RESULTS

Based on these studies a so-called torque-box design has been selected as the most promising concept. The torque-box design proves to allow less deformation of the collector structure due to dead weight and wind loading than the other designs. This reduces torsion and bending of the structure during operation and results in increased optical performance and wind resistance. An extension of the number of SCEs per drive unit from today 8 (100m) to 12 (150m) is feasible. This decreases the total number of required drives for a collector field as well as the number of interconnecting pipes and will have a positive impact on the total collector cost.

The actual EUROTROUGH collector support structure design is shown in figure 3. It is composed of a rectangular torque box with mirror support arms. The rotational axis is in the center of gravity, a few millimeters above the torque box.

The central element of the box design is a 12-m long steel space-frame structure having a squared cross section that holds the support arms for the parabolic mirror facets. The torque box is much simpler than the LS-3 space frame structure. The box is built out of only 4 different steel parts. This will lead to an easy manufacturing and will decrease required efforts and thus cost for assembling and erection on site. Transportation requirements have been optimized for maximum packing.

The design comprises mirror supports that make use of the glass facets as static structural element, but at the same time reduce the forces onto the glass sheets by a factor of three. This promises less glass breakage with highest wind speeds.

Due to an improved design of the drive pylon the Solar Collector Assembly could be mounted on an inclined site (3%). Thus cost for site preparation will be reduced.

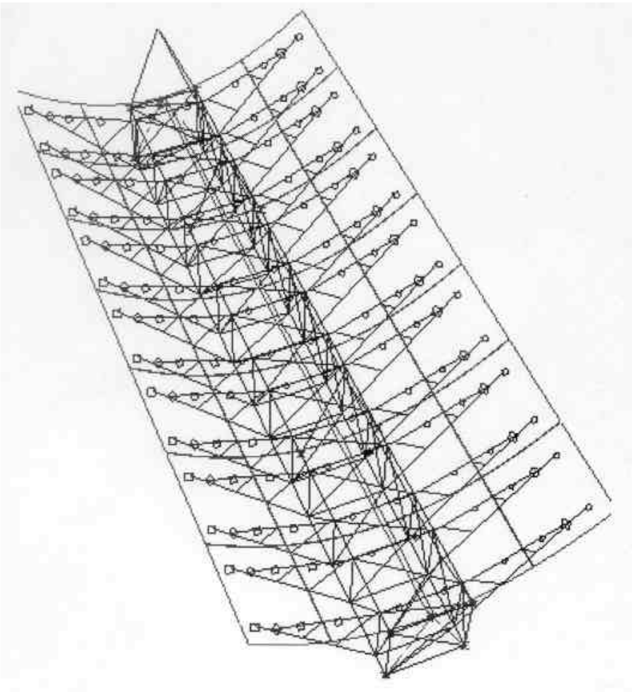

Figure 3: Sketch of the EUROTROUGH collector torque-box design: Central element is a steel construction which absorbs torsion and bending forces. The reflector panels are supported with attached arms, using a type of fixation to reduce breakage.

One of the objectives of the design was weight reduction as compared to the LS-3 collector structure. The following table shows weight figures for the EuroTrough Collector Element:

TABLE 2: EUROTROUGH SOLAR COLLECTOR ELEMENT WEIGHTS:

| EuroTrough Collector Component | | **strong SCE** | **“field” SCE** |
|---|---|---|---|
| Glass mirrors | kg | 747 | 747 |
| HCE (incl. oil) | kg | 73 | 73 |
| Torque box | kg | 597 | 597 |
| End Plates | kg | 186 | 130 |
| Cantilever Arms | kg | 384 | 231 |
| HCE supports | kg | 113 | 90 |
| Torque Transfer | kg | 32 | 32 |
| Total weight steel structure only | kg | 1,312 | 1,080 |
| Specific weight steel only | kg/m² | 19.0 | 15.6 |
| Total weight incl. mirrors and HCE | kg | 2,132 | 1,900 |
| Specific weight kg/m² | kg/m² | 30.9 | 27.5 |

The accuracy of the concentrator is achieved by a combination of prefabrication with jig mounting on site. The majority of the structural parts is produced with steel construction tolerances. The accuracy for the mirror supports is introduced with 6 drillings in each of the cantilever arms. Two of them serve for positioning and keep available for later alignments. The other four holes are used for the mirror support brackets and define the position of the parabola with a relatively simple erection jig.

An important objective was the cost reduction of parabolic trough collectors. The weight of the steel structure has been reduced about 14% as compared to the available design of the LS-3 collector. Additional cost reduction in the order of another 10 % is assumed by reduction of the variety of parts and by more compact transport. Series production cost of the total collector installation below 200 Euro(€) per square meter of aperture is anticipated.

## PROTOTYPE TESTING AT PSA

The construction and workshop drawings have been finished and the first prototype collector has been mounted in a strong version (for high wind load) at PSA, see figures 4 and 5. The collector is set-up in east-west direction and with careful temperature sensor installation for improved testing capabilities. Due to budget limitations only half a collector (drive pylon with collector elements to one side only) has been prepared (figure 5).

Figure 4: View of the EUROTROUGH support structure taken during mirror assembly.

Figure 5: The EUROTROUGH collector prototype tested at PSA has currently four, later six collector elements to one side of the hydraulic drive.

The test program for the prototype includes initial thermal performance tests with synthetic oil up to 390°C. Further tests aim at optical and mechanical evaluation of the collector.

## OUTLOOK

As wind influence is highly transient and difficult to measure with the thermal output, stress and acceleration sensors as well as angular encoders on several pylons are foreseen.

Additional outcome from the prototype development phase goes towards economic fabrication technologies for mass production.

Performance data from the testing and other recent project information will be available in Internet (www.eurotrough.com).

Basing on the current design with lower cost and higher performance of the parabolic trough collector, a next step towards better competition of solar power with conventional fossil technologies has been achieved.

Like in other European project work on trough collectors, e.g. direct steam generation, the project aims at further cost reduction and market penetration for near term future.

Worldwide interest in solar thermal technology is the driving force for the ongoing work on the parabolic trough collector design. The design is available for interested license takers. The main challenges for the EUROTROUGH technology are electricity generation, and process heat in a wide temperature range, including desalination.

## ACKNOWLEDGMENTS

Financial support of the European Commission (JOR3 CT98 0231) and the consortium partners is gratefully acknowledged.

The presented work has been performed by the EUROTROUGH consortium partners Instalaciones Abengoa, S.A. (INABENSA), Schlaich Bergermann und Partner (SBP), Fichtner Solar GmbH, FLABEG Solar International, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), and Centre for Renewable Energy Sources (CRES).

## REFERENCES

Cohen, G., Kearney, D., Price, H. (1999) "Performance history and future costs of parabolic trough solar electric systems", *9th Int. Symposium on Solar Thermal Concentrating Technologies*, Odeillo, France, June 1998, J. Phys . IV France 9 PR3 pp. 169-179.

Esteban, A.; Lüpfert, E. (2001) "Final Report EuroTrough project JOR3-CT98-0231", public version.

Pilkington Solar (1996) "Status Report on Solar Thermal Power Plants - Experience, Prospects and Recommendations to Overcome Market Barriers of Parabolic Trough Collector Power Plant Technology." Cologne 1996. ISBN 3-9804901-0-6.