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Large is beautiful – progress of HelioFocus 500 m² dish

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Abstract

System and component improvements and further development of the HelioFocus dish are described, which is the largest point-focusing concentrator worldwide. An overview of the innovative system is given and enhancements of concentrator, turn table, receiver and heat transfer are shown.
Testing of new components and assemblies was conducted at the prototype dish in Israel. A demonstration plant with eight units was erected in China and shall be extended in further steps. Another demonstration plant in Israel is under construction, and several more projects are being developed.

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1. Introduction

A large dish concentrator with 500 m² reflecting surface and an innovative Fresnel-like arrangement of 2-axes bent mirror facets was developed and a first prototype erected and tested in Israel in 2011 [1]. The technology has been further advanced in the meantime, demonstration projects were set up and commercial projects are under development.

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HelioFocus have developed the system since 2008 and take care for the design of receiver and the complete heat transmission and exchange technique, control system and integration into power plant processes.

sbp have designed the dish structure since conceptual stage, incl. optical analysis, drives and combination with receiver and hot air piping.

1.1. Applications

While the highly concentrating system is able to provide high to extremely high temperatures and can be used for a variety of processes including Brayton turbines or solar chemistry, boosting of conventional power plants is a main focus. Investigating many potential applications, boosting of combined cycle or coal power plants proved to be economically most attractive as it makes best use of the outstanding system properties. It can produce ultra-supercritical steam (USC; i.e >620 °C and beyond) and maintain stable output of steam temperature and steam pressure under changing solar conditions along the day. Depending on turbine data, an overall efficiency from solar to electric of >30 % can be achieved. Looking over the whole process, one dish provides approx. 125 kW of electrical power.

2. Structural system

The Orion dish is composed of the subassemblies concentrator and turn table, consisting of following main components:

Concentrator:

- 220 mirror facets (1.5 m x 1.5 m each)
- 15 purlins from circular hollow sections, carrying the mirrors
- Six cantilever arms from rectangular hollow sections, 18 m long
- A welded rigid rectangular torque box of circular hollow sections, 22.5 m long
- Four-leg receiver support mainly made of circular hollow sections

Turn table:

- Two main side beams, welded from plates,
- Front beam of rectangular hollow section
- Rear concrete beam
- Azimuth bearing and diagonals
- Four elevation bearings and support members
- Circular crane rail and bogies/wheels

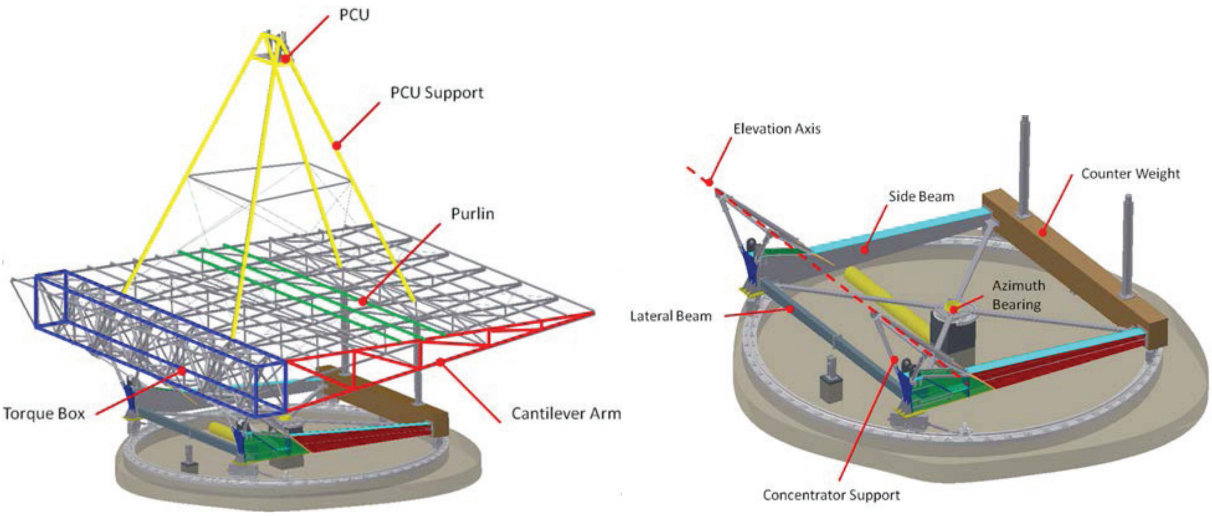

Fig. 1. System components (a) Concentrator; (b) Turn table.

The mirrors are mounted on the planar concentrator but individually tilted in a Fresnel-like manner such that the common focal point is at 14 m distance from the concentrator vertex. The PCU support carries the receiver which has its aperture at the focus.

For tracking towards the sun, the turn table rotates on the rail around the azimuth bearing (vertical azimuth axis) using 4 bogies, each of them equipped with double crane wheel blocks. The concentrator can be moved by hydraulically tilting it around the four elevation bearings (horizontal elevation axis).

3. System enhancements

With the prototype system, novel approaches were developed for the system solution and also for most of the components – a challenging task. The prototype in Dimona could prove all design targets and has in some points even exceeded expectations. However, as first of its kind, there were many lessons to be learned during design, manufacturing and testing of the prototype unit. Based on these experiences, fields for improvement were identified on system level and for a number of components of concentrator, turn table, receiver, air piping and other parts of the unit. Shortcomings of existing solutions were investigated, improved components were worked out and a completely new design was developed.

3.1. Dish

The mirror pattern in the prototype dish, approximating a circular area, is the optically most efficient one. However, the required effort for the supporting steel structure is less than optimum since the edges of the structure are not equipped with mirrors. A techno-economic analysis showed that a square mirror pattern, with reduced overall size (24 x 24.5 m instead of 26.5 x 25 m) - and optically less efficient edge mirrors - saves considerably more steel and thus cost than the equivalent of the slightly reduced overall performance makes up.

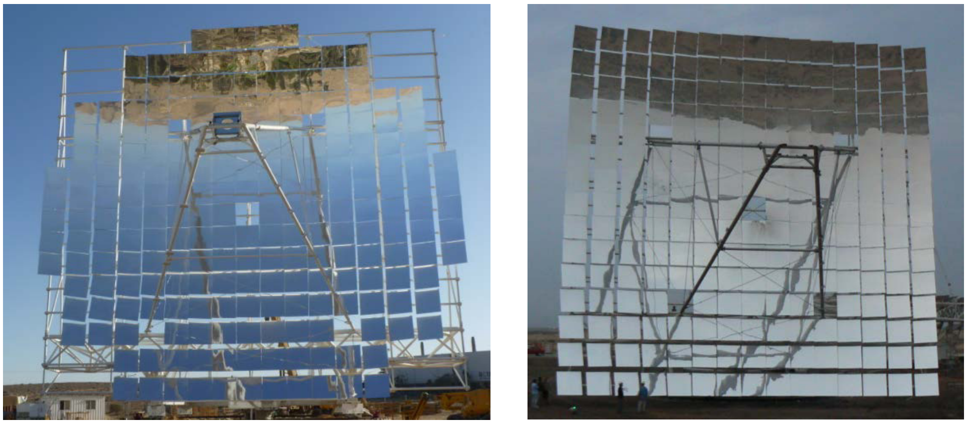

Fig. 2. Mirror pattern (a) Prototype; (b) Orion dish.

For a more exact determination of wind loads, being an important factor for a large structure, the wind tunnel testing done for the prototype was extended to an array of dishes. While wind shading reduces loads for many combinations of dish azimuth and elevation position and wind direction, there are cases where unfavorable aerodynamic effects from neighboring units increase wind loads.

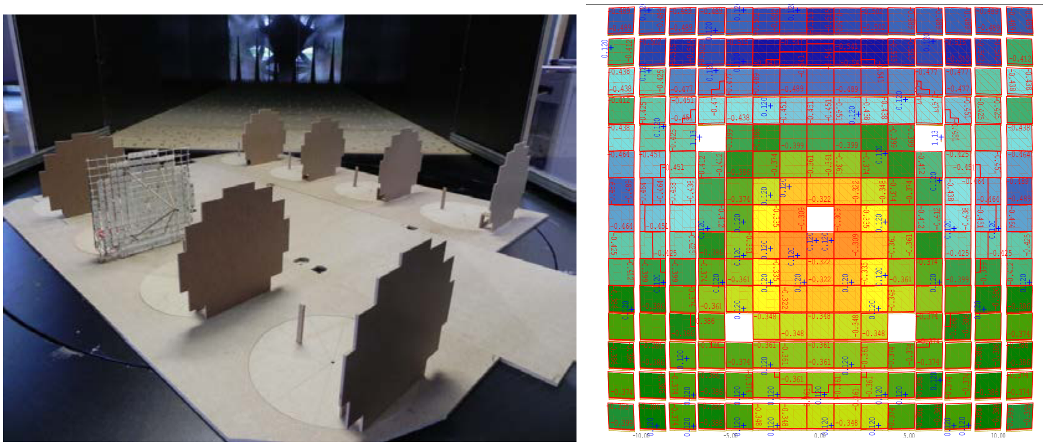

Fig. 3. (a) Array wind tunnel model; (b) Example of wind pressure distribution on mirror facets.

Structural analysis was continuously accompanied by optical analysis. For this end, ray tracing was performed, based on the deformed geometry and provided key optical and performance characteristics like radiative power intercepted by the receiver aperture for different elevation angles. Focal point drift by deadweight induced structure deformation was compensated by closed loop maximization through elevation angle correction (in the same way as the real system controls do).

The static principle of the mirror supporting structure was maintained: this consists of a stiff and rigid torque box as the “backbone”, framework cantilever arms (6 instead of 7 due to overall size reduction) attached to it and purlins with the mirror facets, running parallel to the torque box.

The height of the support structure, i.e. of torque box and cantilever arms, was also explored in a techno-economic optimization and reduced for 20 %.

Analyzing the prototype detail construction, it was found that, besides of some member section improvements, structure nodes make up a too high proportion in overall mass; especially with the torque box. As a result from several designs investigated, most of the nodes were changed from welded plates to an enhanced kind of direct welding of hollow sections. This allowed for a 30 % reduction of the concentrator mass compared to the prototype.

The turn table was also analyzed to identify reduction potential. Turntable main dimensions have a strong impact in steel mass and it could be shown that some reduction of size outweighs the effect from increased moments due to wind. By this, the steel rail and foundation, on which the turntable rotates, could also be reduced in diameter.

Overall, a steel mass reduction of more than 20 % could be achieved.

The optical quality of the slumped square glass mirrors was not completely satisfactorily with the prototype. However, mirror optics has a strong and direct impact on the overall performance; therefore considerable effort was put in optimization of the fabrication process. Even if there is still potential for further improvement, the effort resulted in substantial improvement of the optical quality.

3.2. Drives and control system

The hydraulic drive system was optimized while preserving the highly innovative concept for azimuth and elevation movement. In azimuth, a hydraulic pilgrim step system was applied first in the prototype and showed very good performance and reliability, proving this a very cost-effective solution to transmit high forces.

While the reduced rails diameter compensated wind load reductions from the smaller dish contour, thus not allowing for reduction of components, the lower concentrator dead weight resulted in stroke reduction of the two large hydraulic cylinders for the elevation movement.

Detail improvements were worked out for the proven hydraulic system. The hydraulic storage is not a low-cost component but its advantages in providing high power for fast dish movement and reduction of maximum electrical power demand outweigh its cost, thus it has been maintained.

Relocation of the hydraulic power unit and storage (located on ground besides the dish with the prototype) to the turn table allowed for some simplifications and cost savings by reducing pipe length and omitting flexible hoses to accommodate for azimuth movement of the turn table.

The control system was further developed and an integrated SCADA software solution created. This is a powerful and flexible basis, allowing for support of multiple field configurations and well suited for integration to power plant control systems through standardized interfaces.

3.3. Receiver and heat transfer system

A volumetric receiver is applied to absorb solar radiation and transmit the energy to the heat transfer fluid. It is capable of generating pressurized hot air at up to 1000 °C with efficiency of >90%.

Both the receiver on system level as well as many components of the receiver were enhanced to further improve performance, reduce cost and increase service life. Especially the highly complex air flow through the receiver, which is key for understanding and optimizing this demanding subsystem, was analyzed and optimized.

The receiver design at HF was supported by sbp through a sophisticated ray tracing analysis, conducted with NREL's SolTrace. The receiver interior with glass dome, absorber and other components was modeled in detail. Flux density on the glass dome as well as on the geometrically complex absorber were simulated and energy flow were calculated. These data were used as an input for CFD analysis (computational fluid dynamics).

Considerable effort was undertaken to reduce cost of the annulus air pipes, conducting cold air to the receiver and hot air back, and of the swivel joints used to accommodate the biaxial dish motion. Also, the air-water/steam heat exchanger was subject of ongoing development.

4. Projects

4.1. Prototype

The first prototype at Rotem Industrial Park near Dimona, Israel, was operated to collect operational experience with the innovative system. It was also used for testing many modified or new components like mirrors, control system, receiver and air piping. Significant performance improvements could be achieved with these activities.

4.2. Orion project

The demonstration project Orion near Wuhai, Inner Mongolia/China consists of 8 dishes, corresponding to 1 MW_e, has been developed for the Chinese power producer TAIQING Solar Thermal Power Co. For the first time, a group of dishes will be operated together, and collecting energy via hot air piping will be demonstrated. Furthermore, operation will happen under harsh environmental conditions (frost to below -30 °C).

Plant construction is finished, moving to commissioning stage and full operation during Q1 2015 (the extremely hard winter doesn't allow for continuous work).

Fig. 4. Orion plant near Wuhai, Inner Mongolia.

4.3. Stardust project

Four dish systems are under construction at the combined power plant of Ramat Hovav site in Israel, demonstrating boosting application. The generated steam will be fed into a power plant for the first time and thus form an important step in system development for boosting of conventional fossil power plants.

4.4. Further projects

The demo plant near Wuhai will be further expanded to 10 MW_e and 200 MW_e. A 600 MW_e coal-fired conventional power plant will be erected at this site, the 200MW_e solar field will be used to boost the plant and save considerable amount of coal.

Several more projects for plants up to >100 MW_e are under development in China, Israel and other countries.

References

[1] T. Keck et al, "The HelioFocus Large Dish Prototype", Proceedings of SolarPACES 2012 Conference, 11-14 September 2012, Marrakech, Morocco