ENVIRODISH AND EURODISH - SYSTEM AND STATUS

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Abstract – The EuroDish is an innovative 10 kW dish/Stirling system for decentralised power generation, developed by a German-Spanish consortium between 1998 and 2001. Currently the EnviroDish project is under way with the objective to prepare for market introduction of the EuroDish system. The EuroDish incorporates a newly developed 8.5 m diameter concentrator, made up of a sandwich shell from fibre glass reinforced plastic and the well proven and further improved SOLO Stirling 161 with 10 kW_{el} capacity. The tracking and control system was also revised and simplified, remote control capability is being realized. Two prototypes of this system were built in Spain for testing and continuous operation. Two more units were erected in Italy and India in 2002. Ways for cost reduction in small series manufacturing, erection and commissioning are investigated. Three so-called country reference units will be built in different countries to form a "showcase" for the technology in the future market and to collect experiences under different local conditions which are close to those in commercial applications.

1. INTRODUCTION

Schlaich Bergermann und Partner are developing dish/Stirling-systems since mid of the 80's. The stretched-metal-membrane principle has been used for the concentrators of these systems with 7.5 to 17 m diameter (Fig. 1) (Keck et al., Benz 1990, Schweitzer et al. 1992, Schiel et al. 1994, Baumüller et al. 1997, Keck et al. 1998). Even though having the advantage of good optical properties and high stiffness, the stretched membrane concentrators suffer from high expenses for transport and site assembly, where bulky special tools and expertise are required. This is acceptable when a significant number of systems is erected on one site, but the more typical case for first market introduction are single or few system installations.

From 1998 to 2001 a German-Spanish consortium developed a new dish/Stirling system, the EuroDish (Baumüller et al., 2001, Keck et al 2001, Schiel et al. 2001). The project was funded in part by the European Commission in the framework of the non nuclear energy program Joule III. Basing on the earlier systems, the main objective of the project was cost reduction for single system installation. Savings should be achieved in manufacturing and erection as well as for operation and maintenance. Therefore a main issue in the project was to find new solutions for the concentrator.

Beginning of 2002 the follow-up project EnviroDish has started, funded in part by the German Federal Environmental Ministry and carried out by a German consortium (Schlaich Bergermann und Partner, Stuttgart, SOLO Kleinmotoren GmbH, Sindelfingen, MERO GmbH & Co. KG, Würzburg, DLR-PSA, Almeria, Klein + Stekl GmbH, Stuttgart). The main objectives are the simplification and cost reduction of the newly developed concentrator, improvements at Stirling components, further integration of the control system, the optimisation of the erection procedures and the design of a stand-alone version of the system.

Fig. 1: Earlier dish/Stirling systems: upper 17 m/ 50 kW_{el} in Saudi-Arabia (TDSA), middle 7.5 m/9 kW_{el} in Almeria (DISTAL I), lower 8.5 m/9 kW_{el} in Almeria (DISTAL II).

2. DEVELOPMENT OF A NEW CONCENTRATOR

To overcome the high erection costs, a number of potential alternatives was defined and investigated in detail. An evaluation procedure was developed to compare the different designs, covering all relevant technical and economical criteria. Finally a completely new concentrator design was adopted. The innovative concentrator consists of a thin shell from a glass fibre reinforced resin sandwich, supported by a space frame ring truss. Similar to the stretched membrane, the 8.5 m diameter concentrator obtains high stiffness and low deadweight by profiting from the advantageous load bearing behavior of shell structures. To comply with the needs of transportation, the concentrator shell is divided into 12 identical segments that fit into a standard container and are assembled on the erection site. Each segment is joined to the ring truss at two points with a radius of 3.75 m.

Detailed structural analysis had to be carried out to optimize the concentrator shell and the ring truss in terms of stiffness under dead weight / wind load and material expenditures. To verify the simulation of the shell sandwich structure, comparisons were conducted with analytically resolvable sample models and with ANSYS calculations, which are admittedly a reference for composite structure modeling. The obtained results where in very good agreement with analytical calculations.

Two FE models were investigated: a single segment in the mounting position and the completed shell, consisting of 12 identical segments, with the supporting ring truss and mounted in the turntable. The single segment is supported on 3 mounting joints (Fig. 2). The admissible deflection under dead weight was identified to be less than 1 mm. This could finally be obtained with a sandwich cross section with 20 mm foam and two 1 mm reinforced plastic layers.

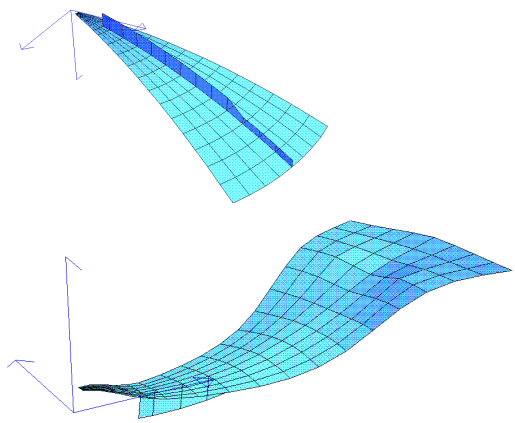

Fig. 2: FE model of single shell segment (left), deflections under gravity load (right).

In the first version the shell segments were stiffened by one resp. two integrated radial ribs on the segment backside. But, at the time when the segments are mounted to the ring truss and joined to each other continuously by gluing their radial edges, the stiffness increases by far since the structure then works as a shell. Thus the ribs are required only for the erection phase. Therefore the segment construction and the mounting procedure were modified: the stiffening ribs were omitted and the segments were supported by adjustable struts only during erection.

With the positive experiences of this approach, the procedure is currently being further developed. To reduce the expenses for adjustment of the struts and the segment contour control, precise stiffening ribs from aluminum sheets are temporarily attached to the segment front sides. After gluing the segment edges the ribs are removed. A rib prototype was built and first workshop tests have been carried out (Fig. 3).

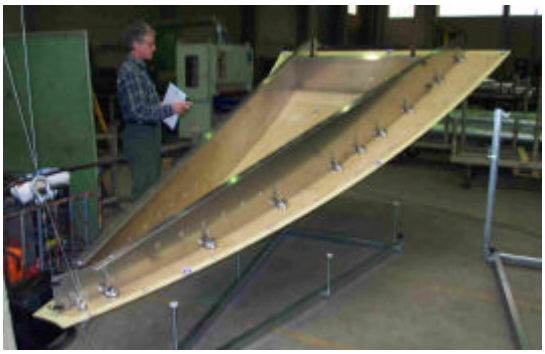

Fig. 3: Temporary stiffening rib under test.

The complete system including ring truss, concentrator and Stirling support and drive system was investigated under dead weight and wind loads in different concentrator elevation positions and wind directions. The target was to maintain full performance up to windspeeds of 10 m/s, power losses are admitted for windspeeds up to 15 m/s (Fig. 4).

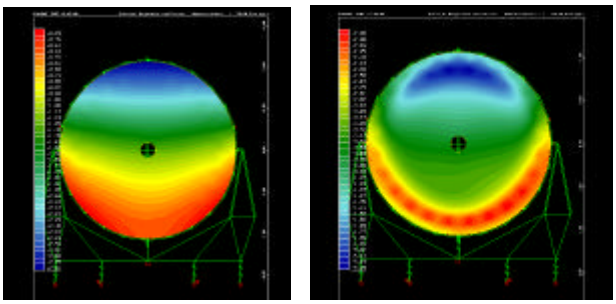

Fig. 4: Complete system: deflections under gravity load (left) and wind (right).

Due to the high demands in contour accuracy of the shell, high diligence was necessary for selection of appropriate materials, for the manufacturing tools and in the fabrication process. A high quality epoxy resin was used, the fibre glass is a regular E-glass type and is

applied in 3 layers, with the orientations 0°, 120° and 240° to obtain a quasi-isotropic behaviour. For the sandwich core a tempered PVC-foam was selected, which was crosswise slotted to allow for application on the convex mould.

The master pattern was made up of a wooden underframe and foam blocks glued to it, being milled with a 5-axis milling machine (Fig. 5). The segment manufacturing mould was laminated onto the master pattern. To obtain high long-term stability and high stiffness, the segments are heat treated in the mould, using an innovative integral heating system that consists of a layer of carbon fibres, laminated into the mould. The carbon fibres are electrically heated to 60 °C by applying a current source. Four heating zones with separate temperature control circuits ensure uniform and exact heating (Fig. 6).

Fig. 5: Manufacturing of segment master pattern: milled surface.

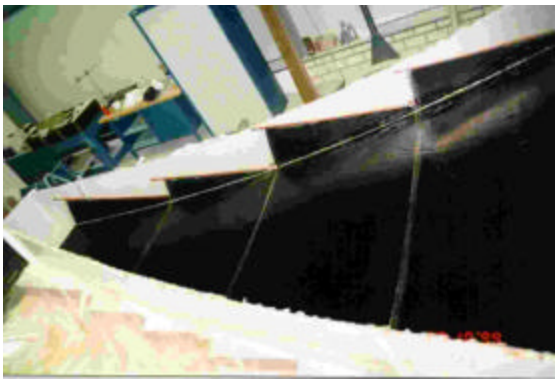

Fig. 6: Manufacturing of segment mould: carbon fibre heating elements.

As the heat treatment generally tends to generate distortions and thus hampers keeping the contour tolerances, part of the concentrators were manufactured without heat treatment. Since no post-curing variations were observed, heat treatment is regarded dispensable.

The shell segments are manufactured under vacuum consolidation. After laminating and heat treating, the stiffening ribs and mounting consoles are glued onto the segment backsides (Fig. 7). In a last step the front sides are equipped with thin glass mirrors (0.9 mm) to obtain a durable surface with high reflectivity (94 %, solar weighted, air mass 1.5) (Fig. 8).

Fig. 7: Segment fabrication: application of rib and mounting consoles.

Fig. 8: Segment fabrication: attaching thin glass mirrors.

3. TRACKING SYSTEM

The azimuthal concentrator suspension with turn table was maintained from the DISTAL II system. The turn table is a space frame construction rolling with 6 wheels directly on the ring-shaped foundation (Fig. 9). The azimuth bearing (vertical axis) is located in the turntable resp. foundation center, the concentrator is suspended at the elevation bearings (horizontal axis).

Fig. 9: EuroDish tracking system: turn table (left), drive unit (right).

The drives are based on the principle of large lever arms, introducing the wind forces to the gears and motors via drive arcs with 9 m diameter, which allows for the use of small, lightweight and commonly available gears. The drive arcs are equipped with simple prestressed roller chains. The drive units use standard steel rollers, spur gears and low cost servo motors.

4. RE-DESIGN OF THE STIRLING POWER CONVERSION UNIT

The SOLO 161 Stirling (Fig. 10) has been approved in the DISTAL II units as well as in applications at Sandia National Laboratories and is the most mature and reliable engine in the 10 kW class today (Baumüller et al 1997, 2001). Thus only improvements and redesign of components (solar receiver, cavity, cooling system) had to be carried out.

For the proven tube solar receiver (Fig. 11) measures were taken to reduce costs. By now, joining of the 78 tubes from Inconel 625 to the manifolds as well as the manifold parts together is done by vacuum brazing.

Different receiver cavities have been developed and tested: one version was designed with the front part made up of a water-cooled aluminum cylinder, for the rear section ceramic fibers were completely packed into sheet metal (Fig. 12). This design proved to be reliable and cost effective. Nevertheless, the cold surface absorbs a considerable fraction of the useful heat and thus reduces system performance.

To overcome this disadvantage, an innovative ceramic cavity is under development. It is based on a vacuum molded pulp from high temperature silicate ceramic. With a new way for attaching the ceramic block to the metallic cavity housing, the problem of vibration induced abrasion seems to be resolved. The performance gain was up to 1.5 kW of net power above the water cooled version.

Fig. 10: SOLO 161 solar Stirling.

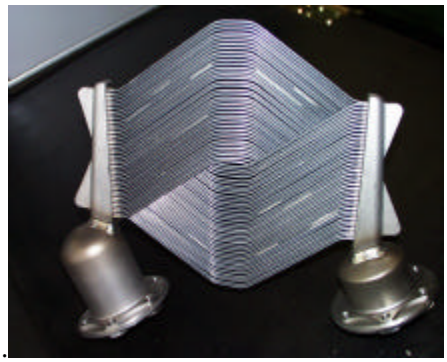

Fig. 11: Vacuum brazed receiver.

Fig. 12: Water-cooled cavity (left), rear section (right).

Variants of the cooling system were investigated and built to reduce the high assembly costs for tubing of the radiators while maintaining performance. Also, different types of radiators were tested.

5. COST EFFECTIVE CONTROL SYSTEM AND REMOTE CONTROL

The EuroDish control concept was proven in the DISTAL II systems. It allows for fully automatic system operation. Its kernel is a control PC running under Windows NT, located in the operator room or locally in a cabinet at the dish, which communicates with up to 16 dish/Stirling systems via a rugged industrial field bus. The sun position is calculated by the PC control software, obtaining exact time from a GPS receiver or an Internet time server. Positioning commands are sent to the drive control in the local cabinet at every dish.

To reduce the number of discrete components in the control cabinet, a so-called motion controller was developed. It is a microprocessor board located in the cabinet and has several tasks. The main function is to carry out the positioning commands from the control PC. Therefore it is equipped with a field bus interface to the control PC and serial interfaces to the servo motor controllers of azimuth and elevation axis as well as to an operator terminal. Additionally a number of further functions were implemented like hardware watchdog and safety detrack handling, manual drive operation and weather data acquisition. The motion controller board was extensively tested, it is available in an improved and mature second version (Fig. 13).

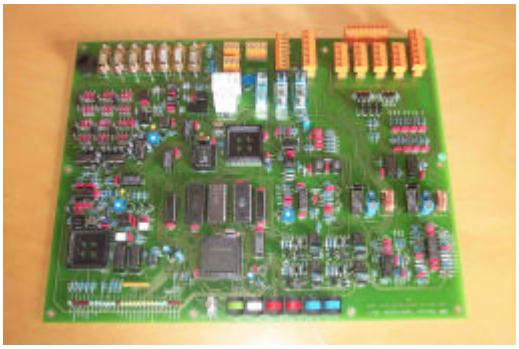

Fig. 13: Motion controller board.

The major part of the Stirling engine control is also executed in the PC. Via the field bus interface it communicates with the local Stirling controller, a microprocessor board that serves as an intelligent I/O terminal, reading sensor data and operating the gas valves, alternator contactor etc.

The capability for remote access is a important new feature currently being implemented into the EuroDish control system. A new control system concept was created therefore, realization is under work. The Data Acquisition System, which is independent from the control system up to now, will be integrated in the new concept, saving hardware costs and making all data available.

Via the www it will be possible to read system status informations and online measurement data as well as stored operational data and state and error logs. This allows for a continuous operational supervision and preventive maintenance even at remote applications where service personnel isn't permanently available. In the case of failures the maintenance personnel gets informations on the sequence of the incidence and can prepare for the required corrective action. Furthermore the data collected enlarge the operational experiences and thus improve the basis for further system development.

As a side effect, runtime statistics and selected online data can be opened to the public through the www.

6. SYSTEM INSTALLATION, OPERATION AND PERFORMANCE

Within the EuroDish project, two prototypes were erected on the Plataforma Solar de Almeria by end of 2000 and early summer 2001 (Fig. 14, Fig. 15). After commissioning and a test operation phase the units are operated continuously since February 2002.

The optical quality of the dishes was verified with the DLR flux mapping system (Fig. 16). The results of these measurements confirmed the precision of the shell. A maximum normalized flux density of 1280 W/cm² (Insolation 1000 W/m²) was recorded, the flux distribution in the receiver plane shows satisfying uniformity.

Fig. 14: EuroDish systems in Almeria.

Fig. 15: Assembled concentrator (top), handling of shell segments (bottom).

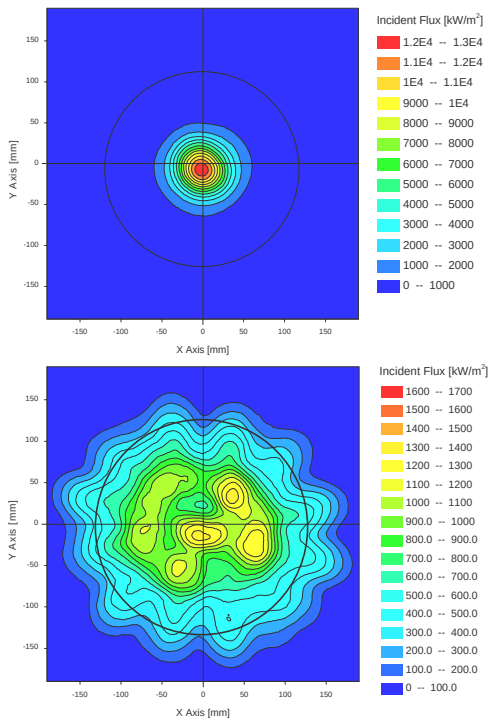

Fig. 16: Flux density distribution in the focal (top) and receiver (bottom) plane.

Typical daily performance characteristics are shown in Fig. 17. As a result of the limitations of the dish optical quality, the performance still lies below the desired values. In the near future the systems will be converted to use Hydrogen as working gas instead of Helium. It is expected to achieve the desired values then.

The systems are working fully automatic, 7 days per week. In the meantime a technical availability of 90-95 % has been achieved.

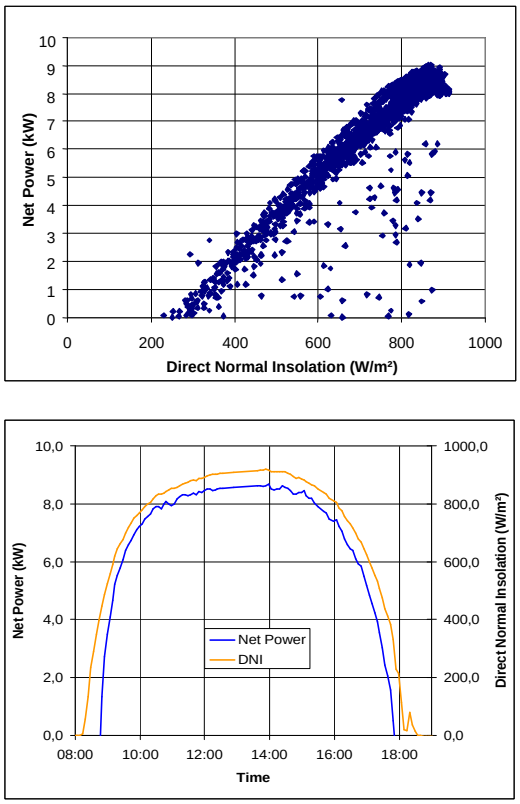

Fig. 17: Daily measurement data (top), power vs. insolation characteristics (bottom).

7. NEW PROJECTS AND OUTLOOK

In co-operation with Karnataka Energy Management Services Ltd (KEMS), a EuroDish system was erected in at the Vellore Institute of Technology (VIT) in Vellore, South India in March 2002 and commissioned in July 2002. The unit is under test operation since then (Fig. 18).

In June 2002 another system was built at the Centro Elettrotecnico Sperimentale Italiano (CESI) in Milan. It was commissioned in July 2002 and is operated since then (Fig. 19).

Within the EnviroDish project, one important objective is to collect more experiences with system erection and operation under different boundary conditions which are close to those of real applications. Furthermore the system and technology shall be demonstrated in countries with potential markets.

For this target, in the present project three so-called country reference units will be established. Attention shall be attracted in these countries at suitable sites and clients. Suitable potential customers for this stage are utilities, R&D organizations, country distributors etc.

As a next step to market introduction an array with 50 dish/Stirling systems is aimed for. With such a field extensive operational experiences can be gained in short-term. At the same time due to the number of systems to be built, series manufacturing will be started and the related cost reduction measures realized.

Fig. 18: EuroDish system in Vellore, India.

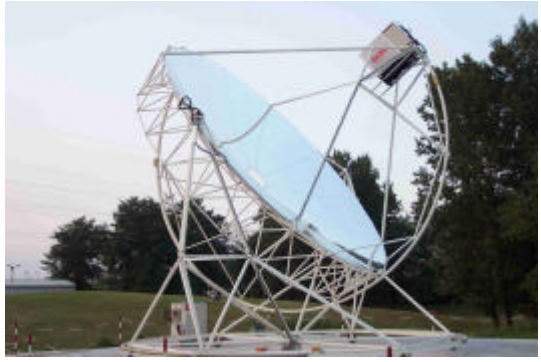

Fig. 19: EuroDish system in Milan, Italy.

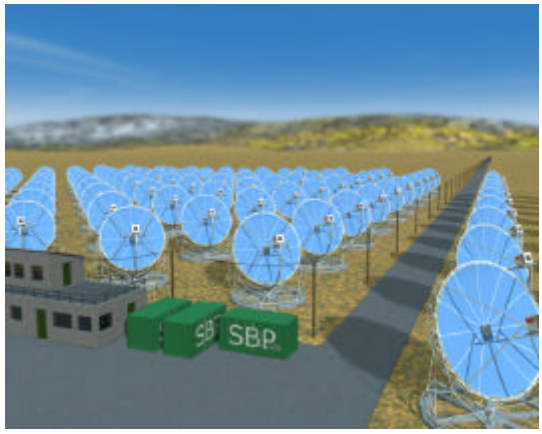

Fig. 20: View of future dish/Stirling array.

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