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Construction method and optical characterization of parabolic solar modules for concentration systems

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Abstract

A process to build modular solar reflectors by using plane mirrors and a sandwich structure has been developed. We applied this process to manufacture parabolic modules that can be assembled in a parabolic dish of 5 m in diameter with the focus at 2.5 m. This paper discusses the evaluation of the light collection performances of a single parabolic module. The reflectance of the mirror material was characterized by means of a UV–Vis spectrophotometer, in the 250–1200 nm wavelength range, and of a pyrheliometer, with respect to a direct solar spectrum. The illumination profile of a module mounted on a sun-tracking system was tested by power density measurements in and out of the focal plane, and spots were compared with a theoretical one. In order to evaluate the high-flux solar energy arriving at the focus of a module, a flat-plate calorimeter was built. The study was carried out by measuring the energy absorbed by the water flow and the external losses due to convection. Based on an energy balance, the intercept factor and the overall optical efficiency of the collector were estimated.
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Keywords: Parabolic dish; Solar concentration; Solar modules manufacturing; High-flux measurement; Calorimetry

1. Introduction

Concentrating Solar Power (CSP) dishes use reflective parabolic modules, or approximations thereof, to concentrate sunlight onto a thermal receiver. The concentrated energy is absorbed as heat to drive a thermodynamic cycle and ultimately, to generate electricity. At the present time, solar dishes are very attractive thanks to their high concentration ratios and versatility (Poullikkas et al., 2010). High concentration ratios allow to contain the thermal losses and therefore to obtain high conversion efficiencies. Leading contenders use dish–Stirling systems with average geometric concentration ratios over 3000 suns (Andraka and Powell, 2008). Beyond this, conversion efficiencies strongly depend upon the optical properties of the reflective materials and the optical quality of the manufactured elements. Several deviations from perfection impact the optical performances of the reflectors, such as, surface waviness due to manufacturing process, shape errors of the module, structural distortions due to wind and gravity, alignment errors (Guven and Bannerot, 1985).

These errors firstly affect the intercept factor, which is defined as the ratio of the energy intercepted by the receiver to the energy reflected by the reflector itself (Sodha et al., 1984).

In this paper, an easy process for manufacturing modular solar collectors by shaping flat mirrors, with the goal of constructing a parabola as accurately as possible and with a high optical efficiency is presented. Silvered mirror was adopted as reflective material as it combines both high reflectance and good mechanical properties (Poullikkas et al., 2010). Compared with other mirror types, it is preferred for its high reflectance, good specularity, durability,

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and resistance to distortion from loads. Despite these advantages, glass is heavy and brittle, requiring massive structural support (SERI, 1985). Fiberglass was proven to be a good structural material with proven rigidity under severe weather conditions (Gill and Plunkett, 1997) and (NREL, 1998). Some of most promising results in the construction of solar concentrator mirror facets have been obtained with sandwich construction, where membranes such as metal or plastic sheets are bonded to the front and back of a core material, and glass mirrors are bonded to one of the membranes (Stone et al., 1993; Schertz et al., 1991). This construction has the advantage of high strength-to-weight ratios. Our manufacturing process is based on the sandwich approach using a PVC panel as a core material, with fiberglass as back membrane and glass as front membrane. The manufactured modules are sectors of a parabolic dish with a collecting aperture area of about 0.8 m^2; the full dish made of 24 sectors would have a diameter of 5 m, and a projection area of about 20 m^2. The selection of the modules shape was intended to use identical module in order to ease mass production whereas the aperture area of each module is relatively large to reduce surface discontinuities between a module and the adjacent one.

The principal aim of this work is to assess the optical performances of a manufactured parabolic module. After a brief description of the technology for a module's production, Section 2, in Section 3 the characterization of the mirror by means of reflectivity measurements is reported. The shape of the illumination profile of a single parabolic module obtained by power density measurements is then presented in Section 4. Finally, in Section 5, the measurement of high-flux solar power at the focus of a parabolic module is reported. To perform these measurements a flat plate calorimeter was built and then a thermal balance study was carried out. The main remarks of this works are given in the conclusions.

2. Manufacturing process

The paraboloidal surface corresponding to the full dish of 5 m in diameter is defined by the equations:

$$Z = a \cdot (x^2 + y^2) \tag{1}$$

$$(x^2 + y^2)^{\frac{1}{2}} \leqslant 2500 \tag{2}$$

with its vertex in $x = 0$, $y = 0$, $z = 0$, where $a = 10^{-4}$ mm^{-1}, x, y, z, are given in mm and the focal point is located at the position (0, 0, 2500 mm). The dish has been ideally divided in 24 identical basic sectors (modules) having common vertex, every sector having angular width of 15° and 0.818 m^2 nominal area normal to the z axis (net aperture area).

The process to manufacture the modules makes use of a mould made of resin. The lodging wall of the mould is convex and consists of a slice portion of a round paraboloid with upward-directed convexity. The mirror surface will acquire the shape of this wall, so great care must be applied in the refining of the mould. Each parabolic sector was manufactured by shaping a starting plane mirror and a support material in a unique process, resulting in a single composite piece with the desired curvature and continuous reflective surface.

The first step to produce a module is the arrangement of a flat 0.8 mm thick silvered mirror (FAST GLASS®) onto the mould, with reflective surface turned towards the convex wall. Afterward, structural layers are deposited above the mirror in the following order: a fiberglass layer, a PVC panel and another fiberglass layer. Shaped thin still plates were inserted in the PVC panel to add stiffness to the whole structure and to help the maintenance of the curvature over time.

The mould is then inserted inside a soft plastic bag connected to a rotary pump in order to create vacuum. When an adequate vacuum (3 mbar) is reached, the difference from internal and external pressure is used as uniform force which shapes the layers against the mould surface. The same difference of pressure is used to insufflate into the fiberglass matrix a thermosetting epoxy resin; for such purpose, the non-rigid container is placed in communication, through an inflow line, with a resin tank. The fluid resin, filling the non-rigid container, penetrates into the porous fiberglass and glues the stiff PVC layer to the mirror back-surface. The reduced pressure created inside the bag has the advantage of ensuring a gradual and uniformly distributed shaping of the mirror.

The parabolic sector is extracted from the mould when the hardening of the resin, that requires some hours after the end of the infusion, is completed. More details about the different steps of the process are described in the patent (Bettonte et al., 2007).

The manufacturing process satisfies two fundamental requirements for the concentration systems: the good optical quality of the resulting reflector and its reproducibility. In fact five out of six of the built sectors have shown the same optical characteristics, whereas the remainder has resulted faulty due to the breaking of the plastic bag during

Fig. 1. Solar collector composed by three parabolic modules mounted on the sun tracking system.

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