Design, Fabrication, and Testing of a Modular Concentrated Solar Power Trough System

Alexander Slocum[1], Ronald Campbell[1], Scott Ziegehgaen[2], William Miskoe[2], De Vita Lorenzo Ippolito[3], Nicola De Blasio[3]
[1]*Massachsetts Institute of Technology, USA*
[2]*Iron Dragon Corporation, USA*
[3]*ENI, Corporation, ITALY*
slocum@mit.edu

Abstract

Keywords: Concentrated solar power, parabolic trough, stiffened shell

Parabolic troughs to concentrate solar power and generate steam have been commercialized on an industrial scale for many decades; however, they are currently economical only as "peaker" plants, or to assist gas fired plants by preheating water for the boiler. Furthermore, they require immense flat land areas to be set-up. The SolaROI project seeks to reduce manufacturing, installation, and maintenance costs with a new design for the troughs that is based on using automotive and aircraft industry type manufacturing methods applied to a simplified trough structure and kinematics. Fundamentally we use the shape of the reflective surface itself as a major part of the structure, as opposed to having a separate structure to hold the reflective elements. Precision parabolic ribs are formed and then the flat reflective panels are attached As shown in Figure 1. Verifying Saint-Venant's principle, we found the required precision of the parabola is obtained when the ribs are less than 3 panel widths apart. In large scale application, 12m long segments would be driven individually and rotate about the collector tube so the trough overall can follow the contour of the land which saves installation costs and the environment underneath the troughs. Tests on a 4m long prototype module with 5.77m aperture indicate that it works as well as current troughs, but is significantly less costly to build and install.

1 Introduction

Concentrated Solar Power (CSP) is one part of a well balanced solar energy plan, and the simplicity and proven reliability of parabolic troughs make them particularly well suited for applications where CSP is to pre-heat water for a combined cycle plant [1].

Parabolic troughs are well-evolved and on a large scale generally follow the Euro-Trough concept of a truss-based torque tube from which are mounted ribs that support mirrors [2]. Most focus has been on developing metal or dielectric film mirrors to reduce cost and weight. Storage is also possible with trough based CSP plants [3,4]. Here we aim to show a design that is more aircraft-like than bridge-like to reduce Bill Of Materials (BOM) and assembly costs.

2 Machine Design Philosophy

An efficient structure to support bending loads is made by moving material away from the neutral axis, while enabling shear stresses to transfer the bending stress from compression to tension across the section. Torsional stiffness requires a closed section. Hence if a long line of troughs is to be actuated by a single actuator, a very torsionally stiff spine is needed; however, trough efficiency drops rapidly under windy conditions and thus we take the approach that many small low cost actuators along the length of a trough section can be more efficient. Specifically, if a section of trough, say 12 m long, is driven at each end, then there are no torsional loads, only bending, and a very different structural optimization criteria exists. Specifically, a thin shell with longitudinal and circumferential stiffeners can be designed. Furthermore, the shell acts as the reflective surface so in effect it satisfies two functional requirements at once.

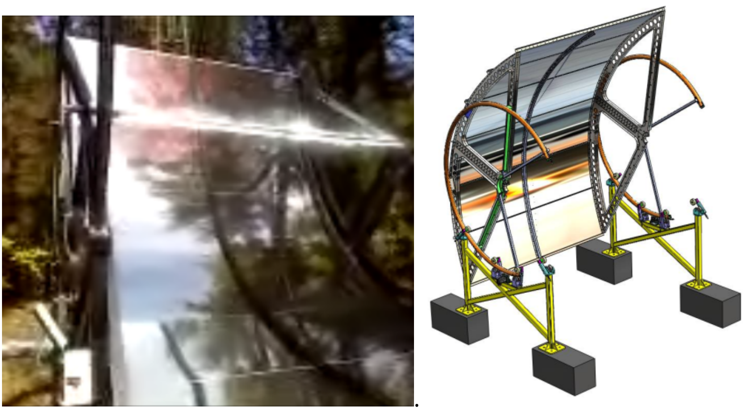

Figure 1: Prototype and solid model of 4m long 5.7m aperture parabolic trough

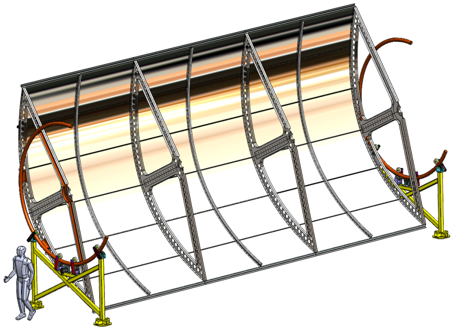

Figure 2: 12 m long 5.7 m aperture modular stiffened shell parabolic trough concept.

2. 1 Shape Deformation Tests

Deformation testing was carried out on the trough by rotating it through 90º and comparing deflections/sag at the two positions. The exterior of the trough was gridded for reference purposes. There were six rows, A through F, and nine equi-spaced points along each row, numbered from 0 to 8, left to right, looking from the trough exterior. During assembly, very taut strings were stretched along the trough to aid in precision alignment. The testing procedure was to rotate the trough to point vertically and measure the deflection, i.e. the distance between the string and the backside of the trough, at the points of the matrix. Then the trough was rotated by 90º to point horizontally and the measurements repeated. There is a correction factor for the sag of the string which was determined using a laser beam; it was determined to be about 3 units at the string center. In summary the 4 meter trough proved to be very stiff, well within the requirement of maintaining shape accuracy to 1 mm. Note each 1% shape error correlates roughly to a 1% loss in efficiency.

2.2 Optical Testing

Basic optical testing of the trough was accomplished by rotating the trough axis to optical vertical, then scanning the trough with a vertical (pendulum) laser beam, and observing where the reflected spot intercepted the receiver. The results were generally very good (VG) in terms of the reflected spot striking normally on the receiver tube. (Table 1.). On a sunny day the trough was focussed on the sun; within a fraction of a minute the paint burned off the receiver tube, the tube glowed in the IR (as picked up by the video camera), and the air-filled tube began to sag.

Table1: Parabolic shape accuracy tests by reflected laser spot

Optical reflection measurements Test 2 on November 30, 2010																	
Seq	Location	A	Al	Br	B	Bl	Cr	C	Cl	Dr	D	Dl	Er	E	El	Fr	F
1	West End	Cal			VG			VG			VG			VG			Cal
5	West End + 1m	VG-vsl	VG-vsl	VG	VG	VG	VG	VG	VG-vsh	VG	VG	VG	VG	VG-vsl	VG	VG	VG
4	Center - at rib	VG	VG	VG	VG	VG-vsh	VG-vsh	VG	VG	VG	VG	VG-vsl	VG-vsl	VG-vsl	VG-vsl	VG	VG
3	East End - 1 m	VG		VG	VG-vsh	VG	VG	VG	VG	VG	VG	low-gra	VG	VG	VG		VG
2	East End	Cal			VG			VG			VG			VG			Cal

3 Conclusions

The initial hypotheses appear to be correct:

1. A lower cost structure can be achieved using aircraft-type construction techniques (thin shell with stiffening ribs).
    a. Reduce cost and increase efficiency by moving the ribs to the backside of the surface panels.
2. Reflective surface film on top of structural shell makes a good mirror.
    a. Surface can be kept cleaner if vibration and vortices used to reduce dust accumulation on the surface.
3. The torsionally compliant trough can be accurately controlled using actuators on each end of the trough.
    a. The chain drive on the round ring is not as robust as we would like, but guides could be added to prevent chain derailment.
    b. A Eurotrough-type linkage should be considered, since automotive powered tailgate designs might be utilized for reduced cost.

References:

[1] Sargent & Lundy LLC, 2003. Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts (No. SR-550-34440). NREL.

[2] M. Geyer et-al., “EUROTROUGH - Parabolic Trough Collector Developed for Cost Efficient Solar Power Generation “, 11th Int. Symposium on Concentrating Solar Power and Chemical Energy Technologies, September 4-6, 2002, Zurich, Switzerland

[3] Herrmann, U., Kelly, B., Price, H., 2004. Two-tank molten salt storage for parabolic trough solar power plants. Energy 29, 883–893.

[4] Herrmann, U., Kelly, B., Price, H., 2004. Two-tank molten salt storage for parabolic trough solar power plants. Energy 29, 883–893.