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Development and Testing of a Power Trough System Using a Structurally-Efficient, High-Performance, Large-Aperture Concentrator With Thin Glass Reflector and Focal Point Rotation

Conference Paper
NREL/CP-550-39208
November 2005

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Presented at the 2005 DOE Solar Energy Technologies Program Review Meeting
November 7–10, 2005
Denver, Colorado

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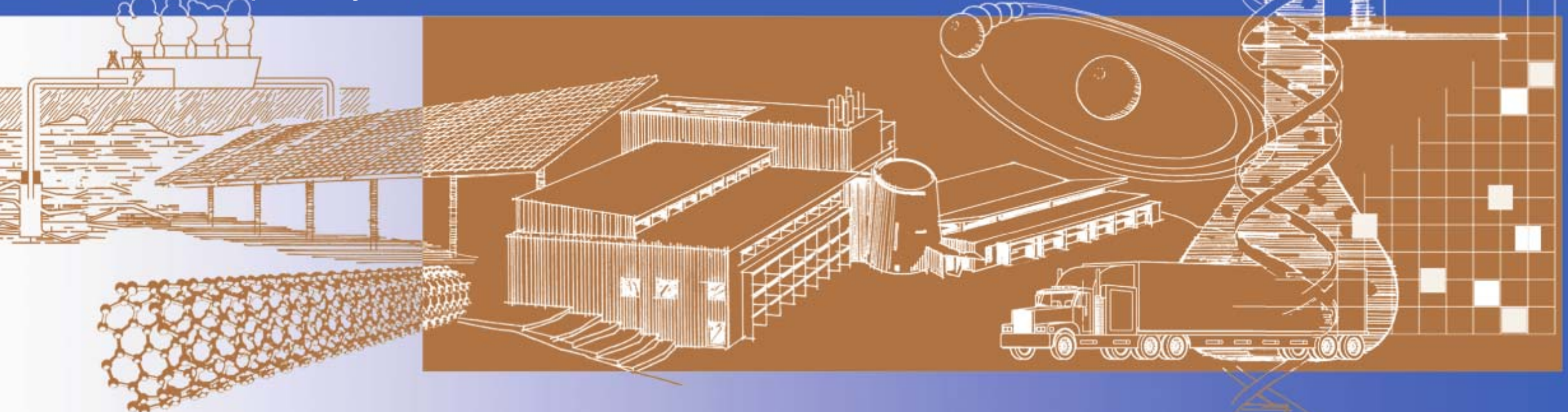

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Development and Testing of a Power Trough System Using a Structurally-Efficient, High-Performance, Large-Aperture Concentrator With Thin Glass Reflector and Focal Point Rotation

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ABSTRACT

Industrial Solar Technology has assembled a team of experts to develop a large-aperture parabolic trough for the electric power market that moves beyond cost and operating limitations of 1980's designs based on sagged glass reflectors. IST's structurally efficient space frame design will require nearly 50% less material per square meter than a Solel LS-2 concentrator and the new trough will rotate around the focal point. This feature eliminates flexhoses that increase pump power, installation and maintenance costs. IST aims to deliver a concentrator module costing less than $100 per square meter that can produce temperatures up to 400 C. The IST concentrator is ideally suited for application of front surface film reflectors and ensures that US corporations will manufacture major components, except for the high temperature receivers.

1. Objectives

The Focal Point Power (FPPT) program aims are:

- A large aperture trough using silver reflector and evacuated receiver (HCE) delivering 400 deg C
- A robust collector structure deployable in long rows
- Elimination of flexhose or multiple ball-joint connections between receivers and transfer piping by rotating around the focal point.
- Concentrators deployable at less than $100 per square meter of aperture area.
- Maximum US content

These objectives are consistent with Department of Energy's Solar Program Multi-Year Technical Plan to reduce the cost of utility-scale parabolic trough collector fields from about $250/m2 to $125/m2. IST's new concentrator will use nearly 50% less material than the current LS-2 design, plus it will reduce system maintenance and operating costs. The IST program effort aims to lower trough concentrator cost by approximately half from about $200/m2 to $100/m2

2. Technical Approach

Existing trough designs are variations on Luz (see Figure 1) technology developed in the 1980's that used heavy sagged glass produced outside the US, rear torque tubes and multiple flexible connections. In contrast, the FPPT is built around IST's proven IST-PT concentrator whereby the reflector is an integral part of the structure. The concentrator is the torsional and beam element (see Figure 2). The technical approach is to benchmark this proven design from a structural, optical and Design For Manufacturing Assembly (DFMA) perspective, then use this data to build a concentrator module almost four times the aperture area.

The contract is divided into two phases. Phase I is funded and the IST team is six months into a 12-month schedule. A summary of the project tasks is:

Phase I

- Build updated IST concentrator with steel front lattice and silvered reflectors.
- Optically characterize module using VSHOT.
- Perform analytical and finite element structural analysis of existing trough design and reconcile with test data.
- Apply DFMA techniques to manufacture and deployment of baseline concentrator.
- Design large-aperture module based on Finite Element Analysis (FEA).
- Engineer mechanical systems to allow focal point rotation
- Design module drive system and controls.

Phase II

- Develop parts list, fabrication tools and procedures
- Cost analysis of FPPT design
- Fabricate one or two prototypes for VSHOT testing
- Deploy FPPT system for optical and thermal testing at NREL.

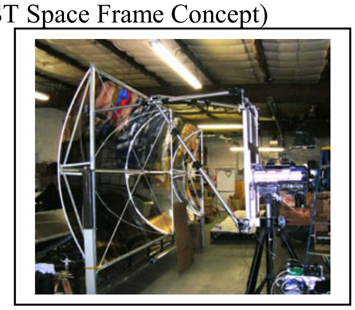
3. Results and Accomplishments

3.1 Optical Benchmarking

IST built two modules that were an upgraded version of its 20 ft x 7.5 ft IST PT-1 concentrator module. The upgrades included a steel front lattice for increased strength, and features to improve optical accuracy. The first module has a Reflectech silver film. This module is shown in Figure 2 undergoing VSHOT characterization by NREL. A

(Fig. 1: Torque Tube Troughs)

(Fig. 2 Optical Characterization of the IST Space Frame Concept)



second module with a Naugatuck thin glass reflector is scheduled for test October 25, 2005.

VSHOT testing demonstrated the uniformity of the module along its entire length. The flat rims of the parabola had the greatest error. The overall rms slope error was measured as 4.5 mrad. Such accuracy will result in a high intercept factor and an efficient concentrator.

3.2 Structural Analysis

J R Harris Co. personnel developed analytical and FEA structural models of the IST-PT that showed good agreement with test data. The models correctly predicted buckling failure of the concentrator under torsional loads and revealed design limitations. IST will build another module for structural testing that is modified to achieve greater strength, as predicted by the structural analysis, while incorporating the results of DFMA analysis. This experience and structural models incorporating wind data inputs derived from the work of Hosoya and Peterka are guiding the FPPT design.

The focal point rotation criterion, and the need to use available materials, including evacuated tubes were principle design drivers. Compared to standard troughs with rim angles of about 70 degrees, focal point rotation will increase the angle to 90-95 degrees and deepen the trough. The resulting FPPT is optically more accurate at the modest cost of requiring more reflector surface for a given aperture. Structurally, a deep and wide trough built to IST's design has a large moment of inertia. Compared to the IST-PT, this increase in strength is balanced against increased beam and torsional loadings and exposure to wind velocities greater at increased height above the ground. Preliminary designs have established a FPPT 12.1 m long using three evacuated receivers per module. The design goal is to link four modules per half-row for a total row length of 100 m.

3.3 Mechanics of Focal Point Rotation

Focal point rotation must address the following: 300 mm of receiver expansion; vertical translation of the receiver; relative motion between piping and the concentrator; and large bearings that must withstand concentrated flux while allowing focusing of individual concentrators. The solution to the problem involves independently supporting the HCE's and the concentrator. The concentrator support bearings have a large annulus to allow the passage of the HCE. However, the loads on these bearings, except at the drive pylon, are small since the rotational moment is passed between modules at the corners of the lattice. A radiation shield protects the bearings from solar flux and the vacuum HCE ensures there is little internal heating. The joints between HCE's are not at the concentrator support bearing and HCE support is from the vertex of the parabola.

A solution that allows rotation and translation of the receiver is to fix the HCE's to the concentrator using supports that allow axial movement only. A single joint at the end of each row accommodates rotational movement. Under such a limited degree of motion, such joints should be much more reliable and cause less pressure drop than a ball joint system used to displace a flexhose.

3.4 DFMA and Control System

DFMA analysis demonstrated weaknesses in fabrication, transportation and deployment of the baseline module. The lessons learned, together with structural improvements, will be incorporated into a redesigned IST-PT module and into the FPPT design. Outside vendors have been sought as a means of reducing manufacturing costs through automation. Apart from the HCE's, for which there is no alternative, the entire FPPT can be sourced and manufactured in the US.

IST is upgrading hardware and software components of its control system to convert to the new-generation CR1000 manufactured by Campbell Scientific. Additional attributes include radio communication, adding an observational camera and integrating the software with PLC protocols.

4. Conclusions

The baseline IST trough has been benchmarked as a basis of the FPPT design. The conceptual design of most system components is complete. The characteristics of the FPPT are described below. The FEA model will soon yield results. After further refinement, details of the FPPT will emerge together with the load data needed to finish the design of the support bearings and to move ahead on the design of the drive system. The mechanics of rotating the receiver are being refined. Phase I is on schedule. Phase II will test the validity of the designs by fabricating prototypes for testing and evaluation while delivering cost data.

Table 1. Attributes of FPPT

Rim angle	91.7 degrees
Focal length	1016 mm
Concentration ratio	19
Overall module length	12.1 m
Aperture width	4.19 m
Net aperture area	~ 50 m^2
Drive area	~ 400 m^2
Three Schott HCE's per module	4060 mm long
Estimated module weight	700 kg (14 kg/m^2)

ACKNOWLEDGEMENTS

The NREL work was performed under Midwest Research Institute National Renewable Energy Laboratory Division, Subcontract NAT-5-44440-02. Participants in the IST design team include Jim Harris & Fred Rutz, J R Harris & Co., Doug Werner, Douglas Engineering, Ben Auslaender, Quality and Technology Partners and Carlo La Porta, Capital Sun Group.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2005

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Development and Testing of a Power Trough System Using a Structurally-Efficient, High-Performance, Large-Aperture Concentrator With Thin Glass Reflector and Focal Point Rotation

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
E.K. May and R. Forristall

5d. PROJECT NUMBER
NREL/CP-550-39208

5e. TASK NUMBER
CP06.1001

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-550-39208

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

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15. SUBJECT TERMS
Photovoltaics; solar; power trough; concentrator; PV; NREL

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		19b. TELEPONE NUMBER *(Include area code)*