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Large monolithic curved panels and cylindrical torque tubes for concentrated solar power parabolic trough systems

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Abstract
Concentrated Solar Power (CSP) plants based on parabolic troughs require a large number of modular trough segments connected end-to-end to form typically 100 meter sections which are connected to form Solar Collector Arrays (SCA). Each trough segment is composed of a large number of parts and is supported by pylons. To minimize part count and pylon foundation requirements, a design is presented for the direct implementation of long SCAs, on the order of 100 m long, where each SCA is supported by as few as two pylons. The central requirement is the implementation of large apertures that maintain precise optical focussing under all operational conditions and loads (mainly wind). Very stiff and low cost structures are required, implying high structural efficiency at low cost and minimal amounts of materials.

Keywords: Concentrated Solar Power, CSP, parabolic trough

Long "Backbone Tube Racks" (BTRs) are manufactured on site as structures for the racking (mounting) of modular "Sandwich Panel Reflectors" (SPRs). The BTRs are made with a modular spiral welding pipe mill set up on site, as typically hundreds of 100m long SCAs are needed for a Concentrated Solar Power (CSP) plant. High precision rack mounts on the spiral welded tubes are obtained by machining reference-mounting surfaces for the SPRs using a laser guided portable milling machine. The fact that the stiffness of a tube in bending and torsion is proportional to the cube of its diameter is crucial to the design.

The parabolic SPRs have an aperture of about seven meters. The sandwich panels have two outer metal skins, separated by a lightweight core. The SPR would be formed against a precise front-fixture for optical accuracy. A backside fixture forms precision mounting surfaces located with respect to the front side parabolic optical surface. Reflective film or curved glass panels are attached to the parabolic surface. Convenient panel widths are a (sub-)multiple of the length of the optical receiving tubes, such as two or four meters. Sandwich panels, by analogy with I-beams, offer a very high ratio of the moment of inertia (in two dimensions) to the mass of the materials. The stiffness of a sandwich panel is proportional to the square of its overall thickness, again providing high structural efficiency at low cost. These modular SPRs can be mounted onto each backbone by bonding so no adjustment is ever needed.

A 100m long backbone tube would typically be about 1.2m diameter with 20mm wall thickness, and be mounted on two pylons located to minimize bending deformations. As the evacuated receiving tubes come in standard 4m lengths, the BTR is sized such that the differential deflection across any 4m chordal segment of the BTR is less than about 1 mm in order to cause less than 1% loss in efficiency. Actuators to rotate the trough in the presence of strong winds also create a significant radial loads, and thus should be located at the support pylons to avoid causing any bending loads on the BTR. An interesting result is that the best location for the sun sensor for servo control of trough position is not necessarily collocated with the actuator.

A detailed feasibility study of SPR-BTR CSP systems is presented. First, a parametric study for the design of an optimized sandwich panel is formulated, and the results are validated by finite element analysis. The sandwich panel stiffness inherently enables wide aperture parabolic reflectors, for example seven meters or greater.

An optical efficiency analysis is formulated to provide the basis for the structural optimization of the system. The design goal is to accurately position the SPRs as they are installed on the BTR, and then maintain accurate focussing on the receiver under all conditions of gravity and wind. When the SPRs are pointing at or near the zenith, gravity effects dominate; when the SPRs are pointed to or near the horizon, wind effects can dominate. Three types of optical errors caused by deviations from the ideal parabolic cylindrical reflecting surface are analysed. "Droop" occurs when the outer portions (transverse direction) of the SPR deflect and defocusing results. "Sag" happens when the BTR deflects between supporting pylons, again leading to defocusing. "Twist" exists when the BTR twists away from the point of actuation due to the combined forces of gravity and wind. The analysis demonstrates how the very high strength and stiffness of the SPR-BTR structure enables low optical errors at minimal cost.

The third section of the paper treats the over-all optimization of an SPR-BTR system, depending upon various assumptions about the cost of materials and components. An optimization metric, which relates optical efficiency and cost in a single objective, is established. Various parametric studies are conducted, varying such critical parameters as BTR diameter and wall thickness and the number and spacing of the pylons.

The optimization surface is rather broad, but BTR lengths of over 100 meters are found to be optimal.

An important consideration is that the two key components of the design are being produced in increasingly higher quantities. The volume of sandwich panels used in both residential and increasingly commercial applications, called Structural Insulated Panels, has soared in recent years. And the pipeline industry has been adept at producing long tubes (for pipes) for many decades, and recently Keystone Tower Systems has perfected a modular transportable tube mill for in-situ manufacture of large diameter long wind turbine towers.

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