**A CLOSED LOOP TRACKING SYSTEM FOR A LINEAR FRESNEL HYBRID PV/THERMAL MICRO-CONCENTRATOR SYSTEM**

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ABSTRACT: A key factor in maximising the lifetime energy yield of hybrid linear concentrator photovoltaic-thermal (CPV-T) technologies is the accuracy and reliability of the tracking system. CPV and CPV-T systems convert only the direct beam component of solar radiation, amounting to around 80% of global irradiation at suitable concentrator sites. This paper presents an overview, including key design features, of a novel linear Fresnel reflector-based optical and tracking system that is implemented in the ANU-Chromasun Micro-Concentrator (MCT). An environmentally sealed enclosure isolates all system components from the environment, allowing for a simplified, low-power tracking system that increases system lifetime energy yield, and improves the mean time between failures.

## 1 INTRODUCTION

The ANU-Chromasun Micro-Concentrator (MCT) aims to deliver linear hybrid CPV-T technology in a package that is suitable for the distributed rooftop solar energy market [1]. CPV technology offers marked reductions in silicon utilisation, but capitalising on this promise requires that the more complex balance of systems is implemented reliably and cost-effectively. Two major factors that contribute to efficiency losses in a CPV system are: (1) Optically imperfect reflectors, and (2) non-uniformities in illumination within and across cells.

The MCT system employs series-connected cell strings to build system voltage to a level that facilitates efficient integration with low-cost inverters. In such a configuration, avoiding illumination mismatch is important for maintaining maximum power output [2]. In traditional linear CPV systems, such as the ANU CHAPS system, the weight and composite structure of the mirrors make this very difficult to achieve. Illumination variations of up to 40% have been observed in practice [3]. Likewise, non uniform illumination across individual cells can have detrimental effects on performance by exacerbating localised series resistance effects. Even with well-tuned optics, the typical Gaussian distribution produced by Fresnel reflectors peaks the illumination at the focal centre.

The MCT has adopted a 'systems design' approach, in which these challenges are avoided, rather than being confronted directly. The most notable design consideration is the low form-factor enclosure shown in Figure 1. This enclosure seals all components from the surrounding environment and offers both aesthetic improvements and the freedom to implement novel approaches to replacing conventional system components.

For example, the linear Fresnel concentrators have been implemented using ultra light-weight, 97% efficient, front-surface reflectors. By eliminating the possibility of soiling or wind loading on the reflectors, additional conventional reinforcing infrastructure is no longer required. In addition, the receiver is mechanically decoupled from the optics, allowing for ultra light-weight, high-efficiency, front surface reflectors to be employed. This is particularly important for a hybrid receiver, where the total receiver weight is necessarily increased.

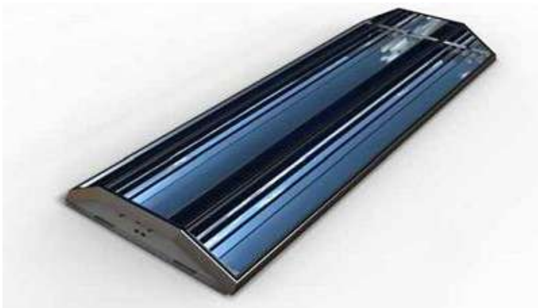

**Figure 1:** The MCT enclosure

Further, by totally eliminating the requirement to consider wind loading and soiling, a major source of complications for tracking systems, mirror design, and mirror materials have been avoided. This has allowed the employment of an array of independent ultra light-weight, 97% efficient, aluminium Fresnel reflectors. Free from any unbalanced internal mechanical stresses, or warping stresses induced by differential thermal expansion of composite structures, the reflectors are precisely tensioned at each end of the enclosure to provide sub-milliradian optical accuracy. As a consequence, the tracking system is in the position to concern itself with optical considerations alone, and is not subject to the environmental factors that contribute to the reduced mean time between failures (MTBF) suffered by conventional CPV and CPV-T systems.

The system operates at approximately 15X optical concentration, relaxing the system tracking requirements. Tracking accuracy requirements are further relaxed by the inclusion of secondary 'winglet' optics on the receiver extrusion, which increase the effective optical aperture.

## 2 THE CHROMASUN MICRO-CONCENTRATOR

At the low concentration levels delivered by the MCT optical system, coupled with the high length to width ratio, the need for dual-axis tracking is avoided, and a single-axis, closed-loop tracking system is employed. An array of parallel reflectors are driven by a low cost, low-power consumption stepper motor at each end. The motors are independently tracked, based on feedback provided from solid-state sensors located at each end of the receiver. This configuration allows for a corrective 'twist' to be applied to the reflector arrays to compensate for any minor misalignments and defects produced during manufacture and assembly. This improves the reliability of production systems so as to produce a high level of illumination uniformity across the receiver length. The light-weight mirrors present a dramatically reduced load on the tracking system, thereby minimising the parasitic power losses.

The single-axis approach vastly simplifies construction when compared with the dual-axis tracking systems demanded by high-concentration CPV systems. At the operating concentration ratio, a theoretical maximum acceptance angle of over 3º is expected [4]. Furthermore, the expected daily yield is increased, especially in the early and late hours of the day.

## 3 TRACKING SYSTEM DESIGN

A unique feature of linear Fresnel concentrator systems is that the system may be designed such that the reflectors all rotate at the same angular velocity while tracking. Fresnel reflector systems are granted this ability by the fact that the focal length of the system does not vary with changes in the azimuthal angle. The practical result of this feature is that it allows the mirrors to be ganged together for actuation while maintaining proper focus at the receiver, as shown in Figure 2 below.

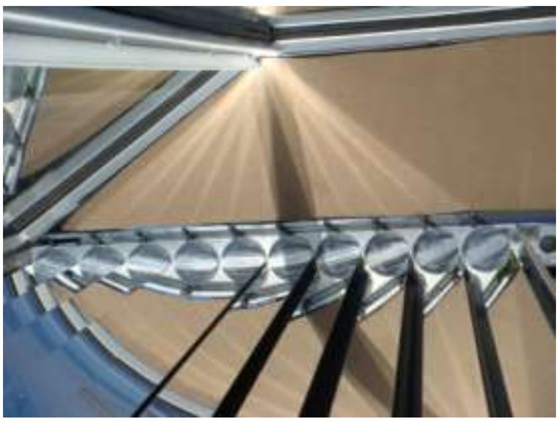

**Figure 2:** A close-up view of the Fresnel mirror array showing the focal characteristics of a prototype unit.

The elements of the mirror array are ganged together at each end by a two-bar linkage system that is controlled by a zero-backlash linear stepper motor. The linear stepper motor drives the "major" link, a horizontal linear slider which transfers linear motion to the ten smaller links, referred to as the "minor" links. The minor links are directly connected to the mirror mounts, close to the perimeter of the mirror hubs. The mirror hub is identical across all elements in the mirror array, however the point at which the link makes connection to the mirror hub is unique for each mirror pair.

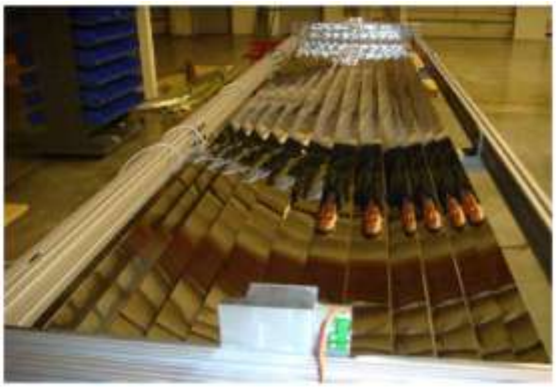

**Figure 3:** Fresnel mirror array showing the smooth optical characteristics of the ultra-lightweight mirror elements.

The tracking system was designed to utilise ultra-lightweight reflectors that can be positioned precisely, enabling the centre of gravity of the reflective elements to be situated directly along the axis of rotation. This design feature avoids the common characteristic in concentrator tracking system design where the centre of gravity of reflective elements shifts about the horizontal pivot axis. The changing location of the centre of gravity affects the direction of the backlash of the actuation gearing, resulting in a decrease in tracking accuracy. Furthermore, the unbalanced torques produce warping of the structure, which has an additional detrimental effect on focus and light flux distribution. In contrast, the result for the MCT is that backlash is minimised to close to zero, and there are no variable torques at any point on the radial excursion of the mirror assemblies; both features subsequently contributing to improved tracking accuracy.

## 4 TRACKING SYSTEM CONSTRUCTION

The MCT system was designed to meet a target operational lifetime of 20 years. The linear stepper motor for controlling the motion of the reflective elements meets automotive grade requirements and is rated for operation up to 120 °C. The motor components are rated for 0.5 million cycles, mechanically and electrically. However, over the anticipated 20 year operational lifetime of the MCT, the motor will cycle only 7,300 times, excluding uncommon occurrences when the system tracking returns to its stow position and initialises a new tracking cycle.

The manufacturing process selected for the "minor" links is a conventional and highly repeatable process where components are stamped from sheet metal. Bearings used at each end of the mirror hubs reduce the force required to rotate the mirrors to only 15N. This small load reduces the strain placed on the motor and reduces overall wear in the actuator assembly, improving mean time between failure and reduces the risk of motor backlash.

## 5 TRACKING SYSTEM FEATURES

The majority of conventional solar concentrators utilise an open-loop tracking system, i.e. feedback is provided to the tracking system by external components. For example, a maximum power point tracker may provide the feedback signal for a PV system. In contrast, the MCT uses a closed loop tracking system. This system ensures the MCT is continuously operating at optimal system output.

Solid state temperature sensors located on each edge of the receiver provide the feedback signal used in the closed loop tracking system. The image of the concentrated solar radiation is focussed to be equal distance between the sensors by minimising the measured temperature differential between the sensors. The sensitivity of the temperature sensors is sufficient to allow the system to maintain focus even in times of quite low direct irradiation.

An additional sensor directly monitors DNI so that the MCT can detect brief periods of interrupted sunlight, for example cloudy periods, and switch to “NOSUN” mode, so that the MCT maintains tracking without needing to initialise a new tracking cycle. In these periods the tracking system will continue to track at a rate defined by the angular velocity of the mirrors for the 15 minutes prior to the sunlight interruption, converted into the appropriate linear steps taken by the motor.

Each mirror pair in the mirror array are rolled to their optimum focal length to produce a broad Gaussian distribution of light intensity across the receiver. The lateral flux uniformity is further improved by the secondary “winglet” reflective elements that are incorporated into the receiver. Rather than attempt to reduce or eliminate the astigmatic effects introduced across the width of the mirror elements, they are actively incorporated into the design to further improve flux uniformity.

Future development of the tracking system of the MCT tracking system may include expanding the closed loop tracking system so that external signals are also accepted, such as the previously mentioned maximum power point tracker. However, the implementation of such a system will require significant development to operate efficiently and reliably while combining external inputs into the existing closed loop tracking system. In addition, such development would require the tracking system for the PV system to be substantially different from the system developed for the thermal only concentrator.

## 6 CONCLUSION

The MCT system is the result of a collaboration between Chromasun and the ANU. It is a unique implementation of CPV-T technology that is suitable for a broad range of domestic and commercial applications. The system has a high NDI conversion efficiency, a robust and fully enclosed optical system, a reliable and accurate tracking system, and a ‘roof-top friendly’ design. The novel design of the tracking system has resulted in increased reliability of system components, while simultaneously improving flux uniformity at the receiver. The system has been designed to operate efficiently and reliably over an operational lifetime of 20 years. Reductions in the Levelised Cost of Energy (LCOE) have been aggressively pursued. Examples of savings include reducing and simplifying material and component requirements, simplifying manufacturing processes, and utilising established manufacturing techniques. Additional characterisation and testing of the tracking and optical components of the MCT system is continuing.

## 7 ACKNOWLEDGEMENTS

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## 8. REFERENCES

[1] V. Everett et al, “Improving the Efficiency of Linear Concentrator Receiver Systems”, Solar09, the 47th Annual ANZSES Conference, Townsville, Australia, 2009.

[2] A. Blakers, “Silicon Concentrator Solar Cells”, from Luque A., and Andreev, V. eds, Concentrator Photovoltaics, Springer, 2007

[3] J. Coventry, “Performance of a concentrating photovoltaic/thermal solar collector”, Solar Energy, **78**, 2005, pp. 211-222

[4] S. Kurtz, “Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry”, NREL Technical Report, Nov. 2009