WHITEPAPER

Optimizing Accuracy in Concentrated **Solar Applications**

Concentrated solar power (CSP) and concentrator photovoltaic (CPV) technologies employ lenses and curved mirrors to focus large amounts of sunlight onto small areas for generating electricity. To maximize the degree of sunlight capture, solar tracking is utilized to adjust the optical components of CSP and CPV systems throughout the day, with the goal to maintain optimum positioning with the sun.

The efficiency at which CSP and CPV systems can generate electricity is directly dependent on the capacity of a solar tracker to attain the most precise alignment with the sun's positional shifts, enabling for sunlight to be accurately focused. Sensors play a key role by providing the necessary feedback as to whether or not correct positioning is achieved. If a system is slightly off-target, the sensor will provide the critical data that is needed to get back on track with the sun's cycle and the perfect rotation. As such, the choice in a sensor solution is an extremely important consideration.

OVERVIEW OF CONCENTRATING SOLAR APPLICATIONS

Although CSP and CPV applications are intrinsically different technologies, both utilize concentrated sunlight as a means for generating electricity. With CSP systems, concentrated sunlight is used to heat a heat-transfer fluid, which in turn creates steam that drives turbines for generating electricity. CPV systems function by focusing a large area of sunlight onto a small, highly efficient photovoltaic cell for creating electricity from that sunlight via the photovoltaic effect.

CSP and CPV systems can generate as much as 50% more energy over fixed-position systems

In contrast to fixed-position solar applications which are permanently orientated towards the general direction of the sun, CSP and CPV systems use solar tracking to optimize the angle of a photovoltaic panel and concentrate the lens or solar reflector throughout the day.

CSP and CPV systems can generate as much as 50% more energy over fixed-position systems and, depending on the application, incorporate either a single axis of rotation (parabolic trough and linear Fresnel mirror arrays) or two axes of rotation (central tower systems with heliostats, CPV systems, and dish/engine systems). While both types of rotations follow the elevation of the sun, systems with dual-axis trackers also track the azimuth.

Accuracy is the Limiting Factor

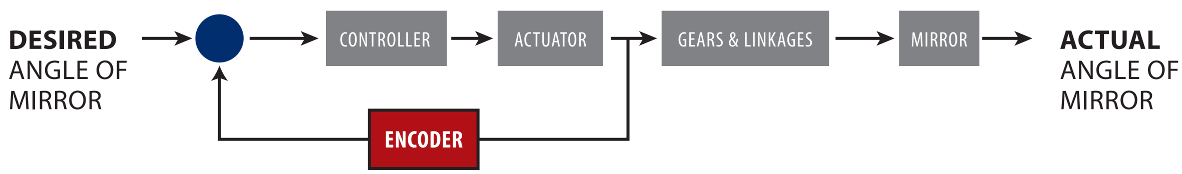
The main challenge for control engineers that manage CSP and CPV applications is to ensure that solar tracking systems are always on target in the most reliable and cost-effective way. Systems that are slightly inaccurate can result in significant drops in efficiency, substantially impacting solar performance. Depending on the size of the solar field, a tracking system that is off target by just a single degree can potentially cost millions of dollars each day in lost energy.

As with most tracking systems, accuracy is limited by the precision of the sensors used in each system. But beyond accuracy, a sensor also needs to be durable, reliable, and capable of long-term performance in extreme environments and harsh conditions.

A limited number of sensor options are available for single-axis solar trackers, as well as the elevation axis of dual-axis solar trackers.

Encoders

Traditionally, rotary encoders could be employed if using a motor with the solar tracking system. Linear encoders are also an option when utilized with a linear actuator. With both of these options, control software and algorithms are needed to translate the rotation of the motor or the distance extended by the actuator to the tilt angle of the mirror being controlled. Control checks are also required with encoder solutions to compensate for backlash or other irregularities in the system mechanics.

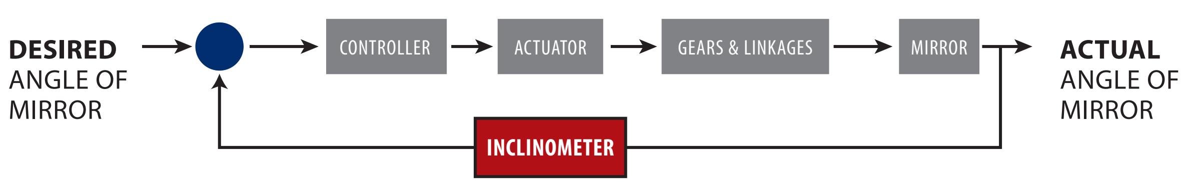


Inclinometers

In more recent years, inclinometers have begun to largely replace encoders as the most viable and cost-effective sensor technology solution. Offering the capacity for simpler and truer feedback, an inclinometer measures the angle of tilt with respect to gravity and provides the ability to adjust a CSP or CPV system to the optimal angle for maximizing output.

Inclinometers help correct any accuracy losses that can occur as a result of gearing imperfections or mechanical errors in the tracking system. By calibrating the optimal alignment and expected efficiency, inclinometers allow for fine adjustments to achieve precise synchronization with the sun's cycle.

When an inclinometer is mounted on the side of a mirror, the controller receives the actual position of the mirror. This angle is independent of the actuator and any irregularities in the mechanics are directly evident to the controller. The logistics of this configuration enable a high degree of confidence in the controller as the feedback signal is taken from the output of the control loop, as opposed to from within the system.



Advantages of absolute solid-state inclinometers

While different types of inclinometers are available, absolute solid-state inclinometers have shown to be the most effective option for use with solar tracking systems including CSP and CPV applications.

Inclinometers are typically mechanical or absolute devices. Mechanical inclinometers utilize a weighted pendulum to reference gravity. When the inclinometer is tilted, the pendulum shifts based on the amount of tilt, providing the angle output of the sensor. Pendulums need to be damped and mounted with bearings. As a result of friction on the bearings, there is a limit as to how small a movement a mechanical inclinometer can actually detect. This effect, called stiction, limits the resolution and accuracy of the inclinometer. Mechanical inclinometers are also susceptible to problems associated with dirt, grit, and other minuscule materials that can accumulate in the working parts, potentially leading to inaccuracies.

As opposed to mechanical inclinometers, absolute inclinometers have no mechanized or moving parts, and therefore are not prone to errors resulting from stiction. Absolute inclinometers are also sealed, which provides protection against environmental factors, eliminating potential problems from outside materials.

By reporting the actual angle, absolute inclinometers provide feedback that is the most advantageous because the controller is always aware of the actual position of the mirror. Additionally, since the output is absolute, there is not a time and energy consuming home cycle at power up, even if the mirror was moved while power was interrupted.

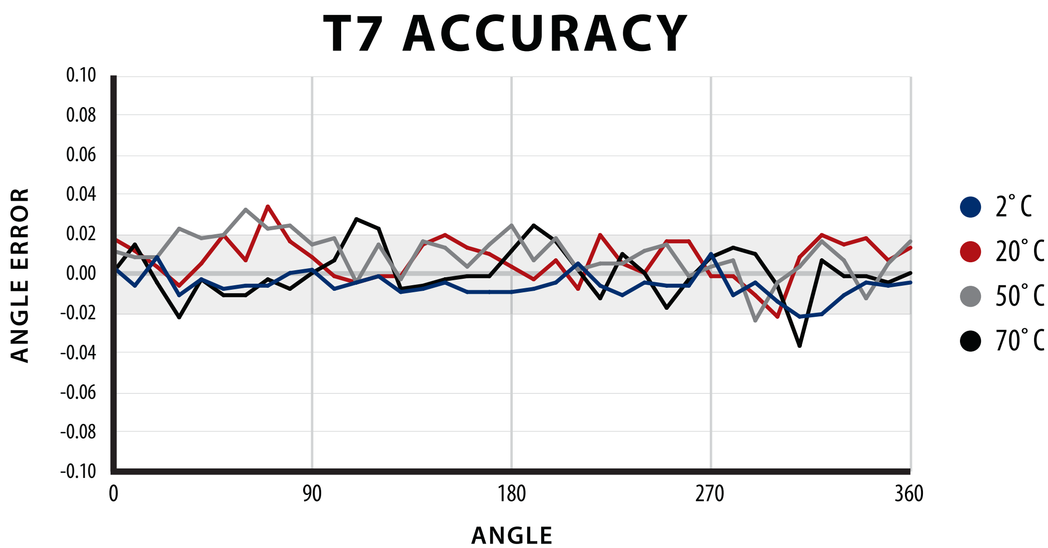
T7 ABSOLUTE INCLINOMETER: **INNOVATION IN ACCURACY**

The T7 Absolute Inclinometer from US Digital® represents a breakthrough in high-accuracy, sensor technology for solar tracking systems and CSP and CPV applications. Providing the capacity to accurately sense tilt angles over a full 360° range in a single axis, the T7 incorporates a resolution of 0.01° and is accurate to 0.1° in temperatures ranging from 0°C to 70°C.

In contrast to inclinometers that are accurate only for a limited range of angles, the T7 has no such limitation. Therefore, the orientation of the T7 is not critical when mounted, since the reported angle can be later configured via software. No assumptions are necessary in regards to the mechanics of the system in the control software and extra algorithms are not needed to convert motor speed or linear actuator displacement to the angle of the mirror. Additionally, there is no limitation on the range of a tracker's movement when paired with the T7.

High Resolution Sensor

With no moving parts, the T7 is a silicone-based device that calculates tilt angle (inclination) by sensing the acceleration from absolute accelerometers integrated into a monolithic chip. The T7 has no risk of stiction, which would otherwise restrict the resolution and accuracy of the inclinometer, and is thus ideal for solar tracker systems where frequent and small changes are necessary. During characterization of the T7 for movements of 0.1°, the maximum differential error (DNL) was measured at under 0.02°. After the error was analyzed, a cumulative distribution revealed that the DNL error was 0.01° with a 90% confidence interval. This pinpoint mathematical accuracy is what makes the T7 so efficient in solar applications.



Enhanced Stability

Although most absolute inclinometers tend to drift over time, the T7 has demonstrated exceptionally low drift. Several T7s have been permanently mounted on tracking systems and have shown no measurable drift during life testing. Any slippage or backlash that occurs will not affect the reading of the T7, thus ensuring that the tracker is always on target.

Because of its proven and robust stability, control engineers can trust that when the T7's position reading changes, the reason is due to shifts in the system and not an internal sensor error.

The T7 incorporates a resolution of 0.01° and is accurate to 0.1° in temperatures ranging from 0°C to 70°C

Low Installation Costs

The T7 is also easy to install and can be quickly mounted on the side of a parabolic trough or a mirror with only four screws or bolts, minimizing material and labor costs during installation.

Multiple T7s can be daisy-chained together to a single controller, reducing the amount and complexity of wiring involved. Up to 64 T7s can be networked on a single cable that can extend up to 700 feet in length. USD-CAN, RS485 and RS232 interface versions are available.

Reliability in Adverse Environments

Many CSP and CPV power plants are located in hot desert regions where miles of unused barren land and abundant solar energy are available. However, these environments are also adverse and characterized by extreme temperatures ranges, including hot and freezing weather.

The T7 incorporates a robust design and is specifically engineered for durable performance in these climates. With an IP68 rating, the T7 is effectively sealed against dust and other potentially harmful elements, enabling for long-lasting operation in harsh conditions.

CONCLUSION

Control engineers are faced with the challenge of maximizing the performance of CSP and CPV systems while controlling costs. The biggest factor to the cost of delivering solar energy is efficiency, and being off target by just a single degree can have a significant impact. Having an effective sensor solution is critical to maximize the accuracy of the solar tracker.

Inclinometers offer distinct advantages related to cost-efficiency and the ability to provide simplified and truer feedback.

The T7 Absolute Inclinometer combines optimal accuracy and high reliability with stability and ease of installation, increasing the efficiency of solar energy in concentrated solar power systems.

For product specifications or more information on how the T7 Absolute Inclinometer can enhance the accuracy of your solar tracking system, please visit **usdigital.com/T7**.

ABOUT US DIGITAL

With over a million off-the-shelf configurations, plus any number of custom product offerings, US Digital® has delivered quality in motion since 1980. US Digital offers stellar service, delivering motion control solutions best suited to each unique need. Automated systems, continuous improvement protocols and stringent testing ensures we bring quality to every product manufactured.

Located in Vancouver, Washington, our vertically integrated facility and personalized service provides customers with industry lead times significantly shorter than the competition, offering same-day fulfillment on most orders.

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