How the T7 Absolute Inclinometer Reduces the Cost of Energy in Concentrated Solar Power Systems

Abstract

Concentrated solar power (CSP) and concentrated photovoltaic (CPV) methodologies generate electricity by focusing a large amount of sunlight onto a much smaller area. To maximize efficiency, the sunlight needs to be accurately focused. Being off by even a single degree could result in a significant drop in efficiency, and the biggest impact to the cost of delivering solar energy is efficiency. As with most systems, the accuracy is limited by the accuracy of the sensors used in that system. There are a number of different types of sensors that can be used in these systems. This paper discusses why an absolute inclinometer is the most effective sensor solution and why the US Digital T7 is superior to other inclinometers available today.

Concentrating Solar Systems Overview

Unlike traditional photovoltaic panels which are fixed in position and pointed in the general direction of the sun, concentrated solar power (CSP) and concentrated photovoltaic (CPV) methodologies focus a large amount of sunlight onto a much smaller area. In CSP systems, this focusing is used to create steam, which then drives a turbine to generate electricity. In the case of CPV systems, small but highly efficient PV cells are placed at the focal point to generate electricity directly.

Both CSP and CPV systems track the sun throughout the day to increase the total energy output. Such systems can see as much as a 40% increase in output as compared to fixed position systems. Depending on the application, the tracking systems can have either a single axis of rotation (parabolic trough and linear Fresnel mirror array) or two axes of rotation (central tower systems with heliostats, CPV, and dish/engine systems). So while both systems track the elevation of the sun, the systems with dual-axis trackers also need to track the azimuth.

To maximize efficiency, the sun needs to be accurately focused. Being off by even a single degree could result in a significant drop in efficiency, and the biggest impact to the cost of delivering solar energy is efficiency. Therefore, the primary concern of controls engineers working on such systems is how to ensure that their solar tracking system is always on target in a reliable and cost-effective way. As with most systems, the accuracy is limited by the accuracy of the sensors used in that system.

Opposing Requirements

As is the case of almost all complex systems, the solar tracker has conflicting requirements. The sensor used in the trackers has to be accurate. It also needs to withstand extreme weather conditions for twenty years or more with no maintenance required. At the same time, it needs to be low cost, which is in opposition to the previous two requirements. The challenge is to find the right sensor that will give the best balance of these requirements.

Inclinometers versus Encoders

For the single axis tracker and for the elevation axis of the dual-axis tracker there exist a few different options with regards to the kind of sensor that can be used. If a motor is used, a rotary encoder would be a possible solution. If a linear actuator is used, then a linear encoder can be used. With both solutions, the control software has to have an algorithm to translate the rotation of the motor or the distance extended by the actuator to the tilt angle of the mirror being controlled. There also have to be checks in place to compensate for backlash or other irregularities in the system mechanics. The simpler and truer feedback device would be an inclinometer.

The inclinometer measures the angle of tilt with respect to gravity. When it is mounted on the side of the mirror, the controller receives the actual position of the mirror. This angle is independent of the kind of actuator use in the system and any irregularities in the mechanics are transparent to the controller. The control software now becomes much simpler. There is also added confidence in the controller because the feedback signal is taken from the output of the control loop as opposed to from within the system.

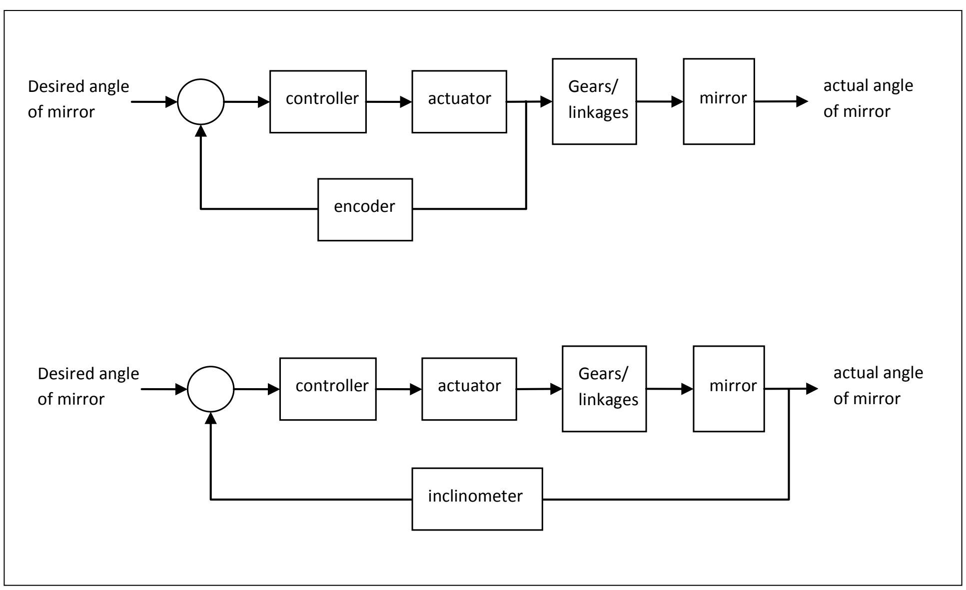

Figure 1 Feedback path for inclinometer versus encoder

High Accuracy Sensor

With an incremental inclinometer, the output represents a change in angle. An absolute inclinometer, however, reports the actual angle, such that the controller will know at all times the actual position of the mirror. Since the output is absolute there is not a time consuming home cycle at power up, even if the mirror was moved while power was interrupted.

The T7 is an absolute inclinometer. It has a resolution of 0.01° and is accurate to 0.1° for 0C to 70C. The chart below shows the measured accuracy for a typical T7. Note that in the controlled environment of a laboratory, the accuracy is much better than the specified value.

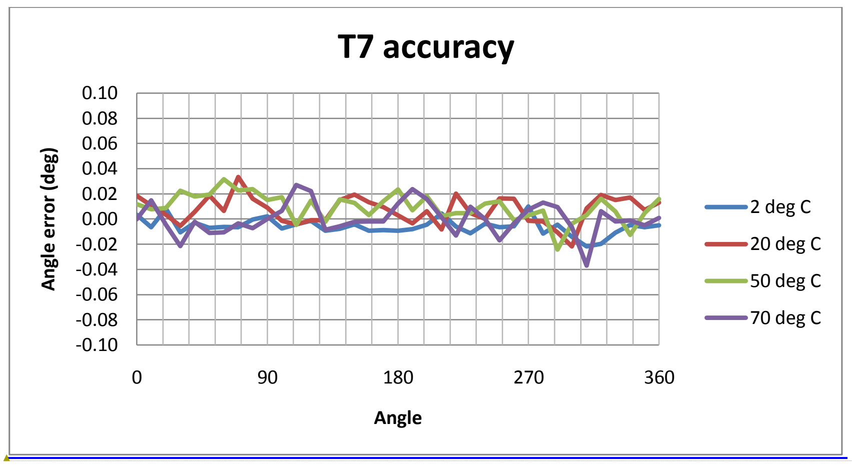

Figure 2 Accuracy of a typical T7

The chart shows that the T7 accuracy holds true over the full 360° range. Often, an inclinometer's accuracy is valid for only a limited range of angles. Because the T7 has no such limitation, its orientation when mounted is not critical since the reported angle can be configured via software after it is mounted. There is also no limitation on the range of movement of the tracker when using the T7.

High Resolution Sensor

Inclinometers are typically either a mechanical or solid state device. Mechanical inclinometers have some sort of weighted pendulum to reference gravity. So when the inclinometer is tilted, the pendulum swings down and the amount it swings is the angle output of the sensor. This pendulum would have to be damped and also would be mounted with bearings. As a result of

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the friction on the bearings, there is a limit on how small a movement the inclinometer can detect. This effect is called stiction and it limits the resolution and accuracy of the inclinometer.

Solid state inclinometers, like the T7, have no moving parts. Therefore, the T7 does not have any errors due to stiction. This makes it ideal for solar trackers where frequent small changes are made. For 0.1° movements, the differential error (DNL) is under 0.02°. During characterization of the T7 for movements of 0.1°, the differential error (DNL) was measured. The error was analyzed and a cumulative distribution showed that the DNL error is 0.01° with a 90% confidence interval. The maximum error is under 0.02°.

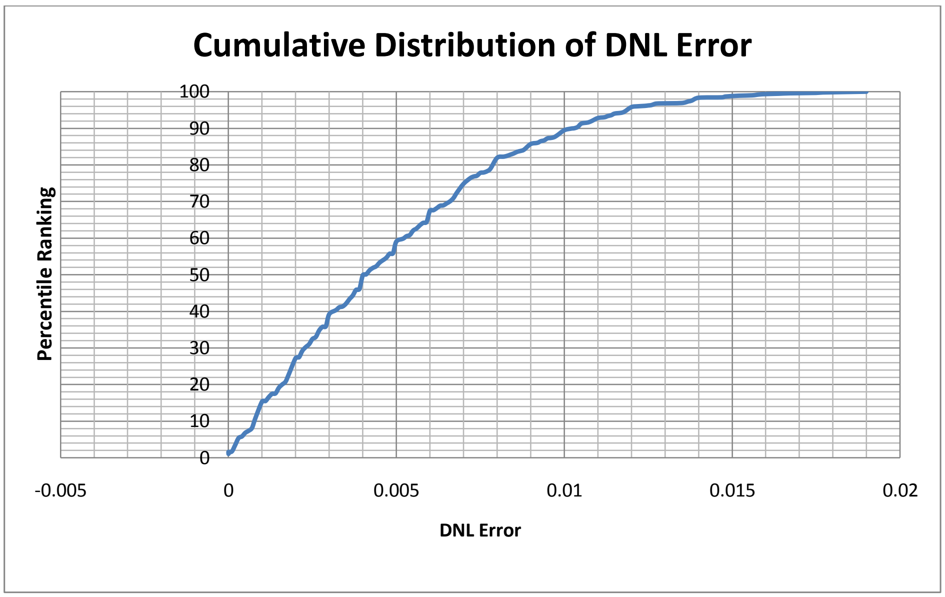

Figure 3 Cumulative Distribution of DNL Error

T7 Stability

While some are better than others, most solid state inclinometers drift over time. The T7 on the other hand has exceptionally low drift. Several T7s have been permanently mounted and show no measurable drift during life testing. This means that the control engineer can trust that when the T7 position reading changes, it is due to the system moving, and not some internal error in the sensor.

Reliability in Adverse Weather

The ideal location for CSP and CPV power plants is in hot desert regions, where there is plenty of unused barren land and abundant solar energy. However, the desert also means a wide range of temperatures: below freezing at night to extremely high temperatures during the day. The T7 has an IP rating of 67.

Low Cost of Installation

Another big advantage of the T7 is that it is very easy to mount. There isn't a need for any special coupling or other fancy mounting to a drive shaft. The T7 can be easily mounted on the side of a parabolic trough or a mirror with four screws or bolts. This decreases material and labor cost during installation. There doesn't have to be any assumptions made about the mechanics of the system in the control software and no extra algorithms are needed to convert motor speed or linear actuator displacement to angle of the mirror. Also any slippage or backlash that occurs will not affect the reading of the T7, thus ensuring that the tracker is always on target.

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

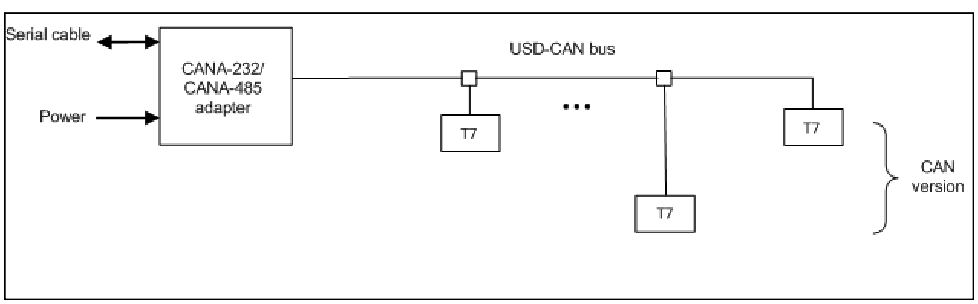

Figure 4 T7 Network

Conclusion

As mentioned earlier, the challenge that a control engineer faces is to find the right sensor that will maximize the tracker accuracy and longevity, while ensuring that the price is low. There are advantages and disadvantages to any sensor that is ultimately chosen for the system. However, for solar trackers, inclinometers have the features needed to make that technology stand out. And in all cases, the combination of high accuracy, high reliability, ease of installation and use makes the T7 the ideal inclinometer to drive down the cost of solar energy in concentrated solar power systems.

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