

Torque in the Rotation Axis of a Parabolic Trough Solar Collector due to Wind Loads

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Abstract. Parabolic trough collector (PTC) solar plants are susceptible to episodes of high speed sustained wind or gusts, which can affect their performance due to aerodynamic loads on the collector. In some collector configurations, the axis of rotation of the collector is directly connected to the flexible joint of the collector, so that torque is also transmitted to the rotation and expansion assembly installed at the end of the solar collector assembly. To obtain accurate measurements of the effect of the wind on the axis of rotation of a PTC, a torque sensor and an inclinometer were mounted at the end of a PTC at the Plataforma Solar de Almería (PSA) (Spain). A series of tests were carried out with different wind speeds and directions to verify the performance of the measurement system in dealing with the structural deformation of PTCs due to wind loads.

Keywords: Parabolic Trough Collector, Wind, Aerodynamic Loads, Torque, Torsion

1. Introduction

Parabolic trough collector (PTC) solar power plants are typically located on large flat areas, often in arid or semi-arid regions, due to large direct normal irradiance (DNI) potential [1]. However, these systems are susceptible to episodes of high speed sustained winds or gusts, which can affect their performance. Due to the aerodynamic loads on the collector [2], wind episodes can cause a torque in the axis of rotation of the collector, which can lead to structural deformation of the collector [3] and therefore a reduction in optical performance. The effect of wind on the PTC depends on wind speed, wind direction and the duration of the wind gust.

In order to obtain accurate measurements of the effect of the wind on the rotation axis of a PTC, a torque sensor was installed at the end of a solar collector assembly installed in the HTF (Heat Transfer Fluid) test loop at the Plataforma Solar de Almería (PSA) (Spain). The PTC selected for the experiment has been in operation since 2011. In conjunction with the torque sensor, an inclinometer was installed to measure the angular deformation of the collector at the end where the complete measurement system was installed.

A test campaign was carried out over a period of approximately 3 months. During the test campaign, the torque of the collector was measured at different wind speeds and wind directions. In addition, during some of the tests, movement cycles of the collector were carried out to obtain measurements with different impacts on the collector. This work details the measurements obtained during the test campaign.

2. Methodology

As mentioned, this work is focused in measuring the torque induced by wind force on the rotation axis of a PTC. The PTC chosen to carry out the measurements is an URSSATrough semi-SCA (solar collector assembly) existing in the HTF test loop at the PSA. This PTC is oriented in an east-west direction and has a length, from the drive pylon, of 75 m; its parabola aperture width is 5.76 m [4]. The measurement devices were installed coupled to the rotation axis of the collector (see Figure 1), connected to the torque tube at the end of the collector, i.e. on the side opposite to drive pylon position. In this case, the rotation axis is connected to the swivel joint that connects the collector receiver tube to the HTF circuit return pipe. In this case, the torque measured on the rotation axis of the collector is transmitted to the swivel and is therefore the same as the torque on the swivel on this axis.

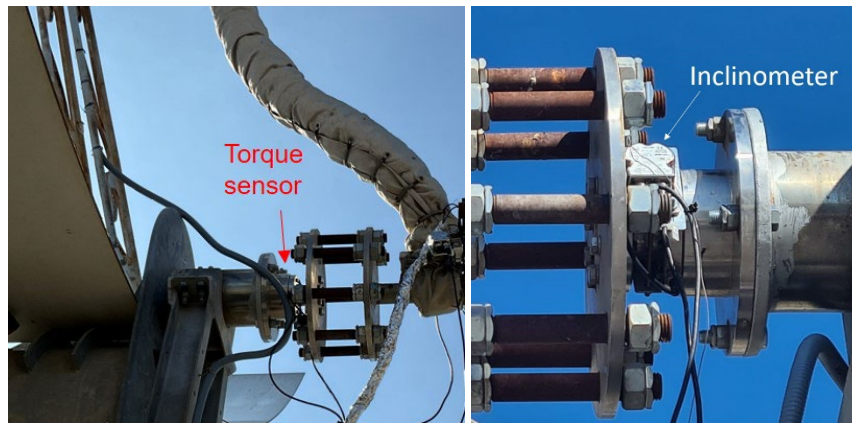


Figure 1. View of the experimental set-up to measure torque in the rotational axis of a PTC: (left) torque sensor; and (right) inclinometer coupled to the torque sensor

The torque sensor is a model AEP-MTRX2KNM005 and it was connected to a load cell model AEPETAD4111D24. It is a static torque sensor with measurement in both directions, double flange format, range 2000 Nm, class 0.05 and sensitivity 1 mV/V. The electronics of the load cell provide an accuracy of 0.02 %. An IFM Electronic model JN2200 inclinometer was installed in conjunction with the torque sensor. This is a 2-axis inclinometer with a measuring range of $\pm 180^\circ$, a resolution of 0.05° , an accuracy of $\leq \pm 0.5^\circ$ and a repeatability of $\leq \pm 0.1^\circ$.

In order to verify the performance of the measurement system in dealing with the structural deformation of PTCs due to wind loads, a series of tests were carried out with different wind speeds and directions. The tests were carried out in two series: one in which the collector moved cyclically through 180 degrees, and the other in which the collector remained stationary in the stow position.

The most common wind direction during the test period was SW, between 180° and 270° , with 0° being the north wind direction. This means that the wind had an oblique incidence on the aperture plane of the collector when it is in the stow position, hitting the reflective surface of the parabola and the back of the reflective surface being protected from the wind. To ensure that the values obtained are comparable, we have selected the tests with this wind direction, comparing the measurements in the stow position with the opposite one, at 180° , when the wind hits the back of the reflective surface and the whole structure. We have also included the results obtained when the wind blows in the direction of the axis of rotation of the collector, in this case with an easterly wind (around 90°).

As mentioned above, the deformation of the solar collector in the axis of rotation in each situation was measured by comparing the angle of rotation of the collector measured at the drive pylon with that measured at the other end using the inclinometer coupled to the torque sensor.

3. Results

The figures in this section show the raw torque data obtained during various days of operation. The data presented in these figures correspond to the following variables: wind direction, wind speed, torque, rotational position (AngleD) measured at the drive pylon position of the PTC, and rotational position (AngleT) measured by the inclinometer installed coupled to the torque sensor in the outlet of the PTC. The stow position corresponds to a rotation angle of -17° , where 0° is the collector position with the collector aperture facing south and 180° with the collector aperture facing north. Wind direction 0° corresponds to a north wind. Positive torques correspond to the direction of rotation of the collector from the stow position to the north and negative torques to rotations in the opposite direction.

In order to establish a reference for determining the influence of wind on torque measurements, some tests were developed with very low wind speeds, around 5 km/h. Figure 2 shows the data obtained over three days of operational, including the first and second day (top figures) and the last day (bottom figure) of the test campaign, to determine if there was any torque bias. This figure shows, for a wind speed of around 5 km/h, a torque of around -250 Nm to -300 Nm in the stow position and around 125 Nm to 175 Nm in the north position. These results don't show an evolution of the torque due to the execution in different days, so any significant bias during the tests can be discarded. At 180° , there is a difference of about 2.5° between the position measured in the drive pylon and at the torque sensor at the end of the collector, due to torsion of the structure by its own weight, structural design and lifetime.

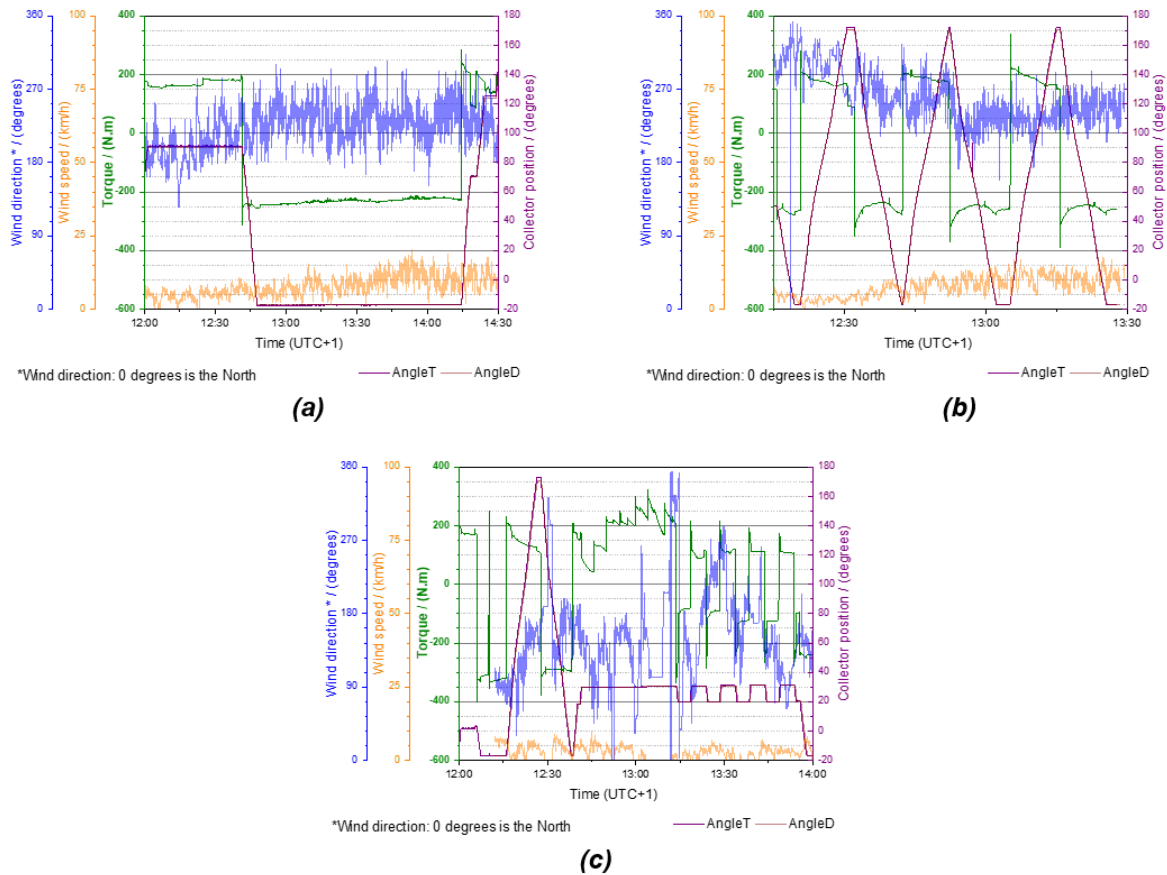


Figure 2. Raw experimental data of tests at low wind rate: (a) first day; (b) second day; and (c) last day

Figure 2 (a) and (b) show a torque of approximately -250 Nm in the stow position and approximately 175 Nm in the north position as the wind increases from 5 to 20 km/h with a

wind direction SW ($\sim 225^\circ$). At 180° there is a difference of around 2.5° between the position measured at the drive pylon and the one measured at the torque sensor at the end of the collector.

Figure 3 shows the case when the wind is in the same direction as the axis of rotation of the collector, in this case is east direction ($\sim 90^\circ$). The measured wind speed was in the range of 5 to 15 km/h. The torque measured at the stow position was around -300 Nm and in the north position was around 100 to 150 Nm. In the 180° position, the figures show a difference of about 1.5° between the position measured at the drive pylon and the one at the torque sensor at the end of the collector.

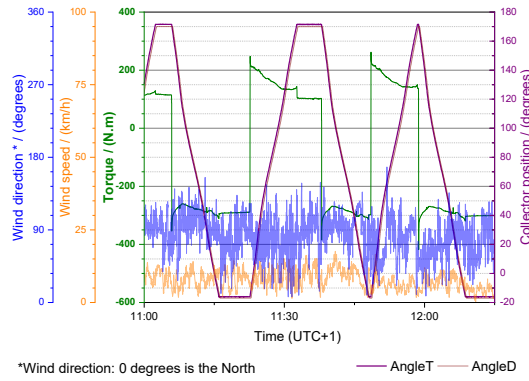
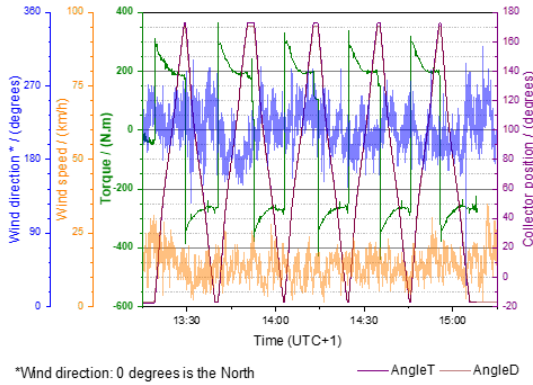
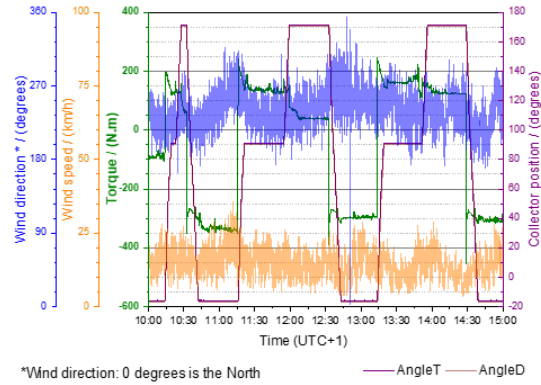


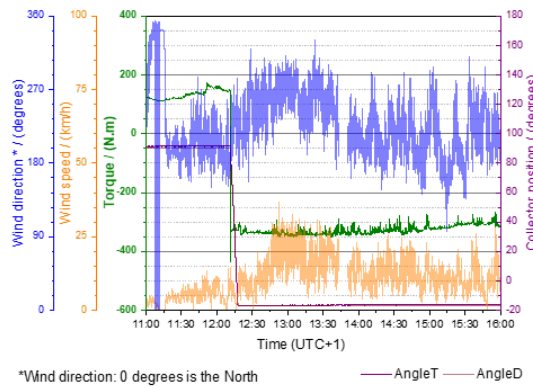
Figure 3. Raw experimental data of tests with wind with east direction



(a)



(b)



(c)

Figure 4. Raw experimental data of tests at medium wind rate

The results for wind speeds increasing from 15 to 25 km/h with the wind direction SW ($\sim 225^\circ$) are shown Figure 4. These results show a torque of about -250 Nm to -350 Nm in the stow position and about 100 Nm to 200 Nm in the north position. At 180° position the figures show a difference of about 2.5° between the position measured at the drive pylon and the one at the torque sensor at the end of the collector.

Finally, Figure 5 shows data obtained during two different days of operation with high wind speed, with peaks above 60 km/h and SW direction ($\sim 225^\circ$). The torque measured in the stow position is in the high range of -350 Nm to 300 Nm and for the north position in the range of -50 Nm to 100 Nm. These wide ranges are due to the rapid gusts of wind. For the 180° position, there is a difference of approximately 2.3° between the position measured in the drive pylon and the one at the torque sensor at the end of the collector.

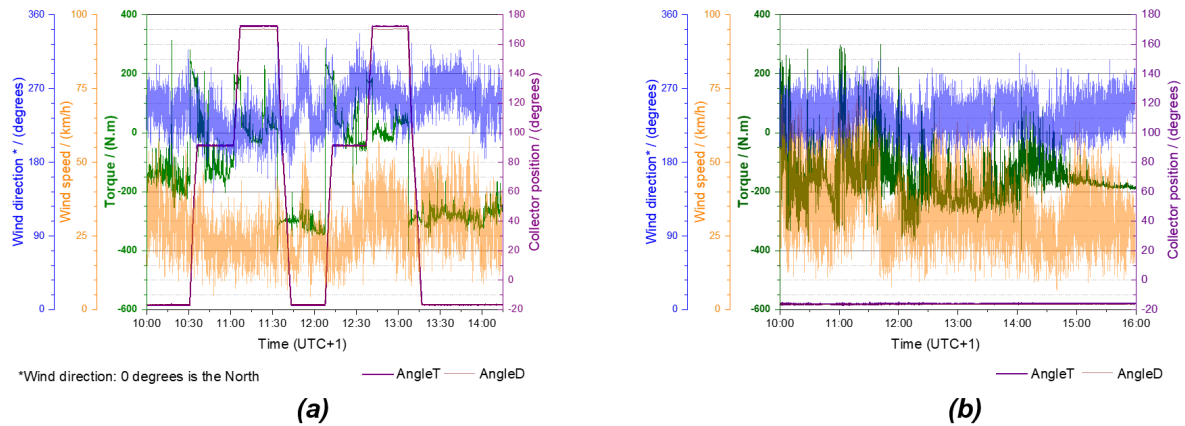


Figure 5. Raw experimental data of tests at high wind rate

4. Conclusions

A resume of the results is shown in Table 1.

Table 1. Resume of measurements for the different wind speed and directions

Wind speed (km/h)	Wind direction	Position	Torque (Nm)	Torsion ($^\circ$)
5	-	Stow	-300 to -250	0
5	-	North	125 to 175	2.5
5 – 20	SW ($\sim 225^\circ$)	Stow	~ -250	0
5 – 20	SW ($\sim 225^\circ$)	North	~ 175	2.5
5 – 15	E ($\sim 90^\circ$)	Stow	~ -300	0
5 – 15	E ($\sim 90^\circ$)	North	100 to 150	1.5
15 – 25	SW ($\sim 225^\circ$)	Stow	-350 to -250	0
15 – 25	SW ($\sim 225^\circ$)	North	100 to 200	2.5
10 – 60	SW ($\sim 225^\circ$)	Stow	-350 to 300	0
10 – 60	SW ($\sim 225^\circ$)	North	-50 to 100	2.3

These results show that for the SW wind direction ($\sim 225^\circ$) there is no significant effect of wind speed on the torque for the stow position for wind speeds below 25 km/h, this is with the wind hitting by the reflective side of the parabola. When the collector aperture is facing north, i.e. with the wind hitting the back of the reflectors, there is also no significant difference, being slightly lower at high speeds because the shape of the parabola causes a lift force that counteracts its weight and relieves torsion.

When the wind gusts are stronger, even reaching 60 km/h, the measured torque amplitudes increase significantly with the wind speed. The amplitude of the torque oscillations is much higher in the case of collector in the stow position, i.e. collector aperture facing south, than in the case collector aperture facing due to the sail effect that occurs in parabolic surface. Torque differences have been measured from -329 Nm to 283 Nm in 10 seconds and from -318 Nm to 285 Nm in 3 seconds or from 285 Nm to -299 Nm in 1 second, which means many large and rapid torque changes in a very short time. This can affect the durability of the structural components of the collector and its solar tracking mechanism as well, in this case, the swivel joint to which the collector rotation axis is connected.

Future tests will focus on completing the study with more operational data and studying the influence of the wind speed on the torsion of the analyzed PTC when the collector aperture is facing the zenith or other positions different to those facing north or south. These tests allow to understand how wind influences the torsion experienced by the collector, so that this can be taken into account in the collector's design by reinforcing those parts that are most susceptible to high winds and in the operating strategies to identify the wind directions that cause the most dangerous loads and thus avoid them in high winds.

Data availability statement

Datasets of the results presented in this article are available through Zenodo at the following link: <https://doi.org/10.5281/zenodo.13354540>

Author contributions

Conceptualization, R.L.M., L.V.; Resources: R.L.M., L.V., C.A.C.; Methodology, R.L.M., L.V.; Data curation, R.L.M., L.V.; Validation, R.L.M., L.V.; Writing – original draft, R.L.M.; Writing – review & editing, L.V., C.A.C..

Competing interests

The authors declare that they have no competing interests.

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