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On-Sun Alignment of a Concentrated Solar Parabolic Dish Located in Abu Dhabi, UAE

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Abstract. Improper alignment is one of the key parameters that affect the performance of a concentrated solar parabolic dish (SPD). The receiver must have a flux distribution that is as uniform as feasible for an SPD to operate at its optimum performance. The aim of this research is to align a SPD from *ZED Solar* [1], which is recently installed at Khalifa University's Masdar Institute Solar Platform in Abu Dhabi, United Arab Emirates. This dish's future application involves integration with a photo-electrochemical hydrogen production reactor, which demands a multi-aimpoint alignment approach for optimal performance. To facilitate this alignment, the sunspots of all facets are initially aligned within a 200 mm diameter circle around the focal point using the on-sun alignment method. During the alignment, the dish was placed in sun-tracking mode, with all facets covered except the one being aligned. The reflection of the facet on the target was observed using a camera. The facet was adjusted until the aimpoint was oriented in the optimal position. The average time to align one facet, including cleaning, loosening the front nuts, and replacing the covers, was found to be around 15 minutes. The complexity of the bolt mounts, rust on the bolts, and the use of a manlift contributed to the prolonged alignment process. Despite these challenges, the on-sun alignment method proved to be an accurate way of aligning the facets of a concentrated SPD.

Keywords: Concentrated Solar Parabolic Dish, Alignment, On-Sun Alignment Method, Hydrogen Production, Optical Efficiency

1. Introduction

Energy is an ingredient of developed states and developing countries rely on fossil fuels for energy harvesting. The overreliance on fossil fuels for energy production is a critical issue for the world. In 2022, fossil fuels, including gas, oil, and coal, accounted for a staggering 76.72% of the world's energy consumption, while only 23.28% came from clean and low in CO_2 emissions energy sources [2]. This disproportionate dependence on fossil fuels has a significant and detrimental impact on the environment, with the electricity and heat sectors being the primary contributors to greenhouse gas emissions.

Industries are the largest consumers of heat energy on a global scale. The heat energy demand of the industry is on the rise and a 1.7% annual growth in demand is expected until 2030 [3]. Notably, almost half of the energy utilized in the industry is for high-temperature applications (>450ºC) [4]. Concentrated Solar Thermal (CST) systems are poised as a potential solution to sustainably generate such energy. The CST systems can be divided into point and line focus collectors. The point focus collectors are the solar power tower (SPT) and the solar parabolic dish (SPD) while the line focus collectors are parabolic trough collectors (PTC) and linear Fresnel collectors (LFC) [5].

This study is focused on concentrated SPD system. The performance of a concentrated SPD system is evaluated by optical and thermodynamic metrics. Optical performance metrics include optical efficiency and solar concentration ratio, whereas thermodynamic performance metrics include absorption efficiency, ideal thermodynamic conversion efficiency, and receiver thermal efficiency [6, 7]. The optical performance metrics are dependent on the concentrated solar flux distribution, which is influenced by several optical errors [8]. These errors can lead to energy loss, aperture size variations, and excessive peak flux values. The optical errors are tracking errors, alignment errors, facet defects (shape and waviness), and gravitational structural deflections [9].

Improper alignment, also known as mirror installation error, is one of the key parameters that affect the performance of a concentrated SPD [10]. The receiver must have a flux distribution that is as uniform as feasible for an SPD to operate at its optimum performance, which needs proper alignment of the mirrors or facets. A perfect alignment of a dish means that the concentrated radiation is focused at one point in the focal plane before diverging in the direction of the reception plane. This is an ideal starting point when aligning a dish. The four important requirements for aligning the concentrated solar parabolic dish are presented by Diver [11] and Ren et al. [12]. The requirements are as follows: (1) it must be simple to execute and set up; (2) it must be quick; (3) it must not require complicated or expensive instruments; and (4) it must permit alignment at any time of the day and without removing the receiver.

The aim of this research study is to align the SPD from *ZED Solar* [1], which is recently installed at Khalifa University's Masdar Institute Solar Platform (KUMISP) in Abu Dhabi, United Arab Emirates (UAE). It is pertinent to mention that the SPD was not operational at KUMISP, and it was undergoing its initial alignment process. The dish under investigation has a diameter and a focal length of 9 meters and 5.2 meters respectively. The *ZED Solar* dish comprises thirty mirrors (facets) arranged in a parabolic configuration on a monopile. The rated reflectivity of mirrors is 96.1% [13]. This dish's future application involves a photo-electrochemical hydrogen production reactor, which demands a multi-aimpoint alignment approach for optimal performance. To facilitate this alignment, the sunspots of all facets are initially aligned within a 200 mm diameter circle around the focal point. Subsequent alignment improvements will be introduced via a multi-aimpoint strategy. This study details the alignment methodology and its outcomes.

2. Literature Review

Over the years, various alignment techniques have been developed for the alignment of concentrated SPDs. These alignment techniques include laser alignment [14], distant light source alignment [15], near light source (2-f) alignment [15], digital image radiometer (DIR) alignment system [16], on-sun alignment [15], color-look-back alignment method [10], color 2-f alignment method [17], and fringe reflection method [18]. The advantages and disadvantages of various alignment methods are listed in Table 1. The initial alignment of the *ZED Solar* dish was performed using on-sun alignment method, aiming to position the sunspots of all facets within a circle of 200 mm diameter around the focal point. It is important to mention that the alignment of the dish for the hydrogen production unit falls outside the scope of this study.

The on-sun alignment method involves a series of steps to ensure precise alignment of the SPD. Initially, all facets of the dish are covered except for the one undergoing alignment. A target is then positioned at the focal plane of the dish to capture the reflection of the aligned facet. Subsequently, the dish is activated in tracking mode to accurately position it towards the sun. Then, the reflection of the facet on the target is observed, either visually or by measuring the temperature distribution using thermocouples. Finally, the facet is adjusted until the aim-point is optimally oriented. It's worth noting that while this method offers alignment precision, its accuracy may be impacted by factors such as non-uniform visual inspection or thermocouple response [15]. For further details on alternative methods, interested readers can refer to the specified references.

Table 1. *Advantages and disadvantages of various alignment methods.*

Method	Advantages	Disadvantages	Ref.
Laser Alignment	Fast Simple instruments Alignment is possible at small distance	Alignment is possible only at zero-degrees elevation	[14]
Distant Light Source	Simple instruments	Slow Alignment is possible only at zero-degrees elevation Minimum distance of 100 m is needed	[15]
Near Light Source (2-f)	Fast Simple instruments Alignment is possible at small distance	Alignment is possible only at zero-degrees elevation	[15]
Digital Image Radiometer	Very accurate Alignment is possible at small distance	Slow Complex instruments Alignment is possible only at zero-degrees elevation	[16]
On-Sun	Fast Simple instruments Alignment is possible at any elevation angle Alignment is possible at small distance	Dish moves during alignment Moderately accurate	[15]
Color-Look-Back	Simple instruments	Slow Alignment is possible only at zero-degrees elevation Distance of 100 m is needed	[10]
Color 2-f	Fast Alignment is possible at any elevation angle Alignment is possible at small distance	Complex instruments Moderately accurate	[17]
Fringe Reflection	Fast Alignment at any elevation angle Alignment is possible at small distance Very accurate	Complex instruments	[18]

3. Methodology

The alignment strategy, methodology, and accuracy are dependent upon the receiver placed at the concentrated SPD. Thus, it is crucial to determine the alignment goal and desired accuracy before initiating the alignment procedure. To facilitate the alignment of the dish for the hydrogen production unit, it was decided to align the sunspot of all facets in a circle with a diameter of 200 mm around the focal point.

3.1. Equipment used for Alignment

Special fabric covers with mild steel structures that had the exact shape of the facets were used for covering the facets of the *ZED Solar* dish. A picture of the *ZED Solar* dish with covered facets can be seen in Figure 1(a). To observe the reflection of each facet individually at the focal plane, a lightweight aluminum structure with a 10 mm aluminum plate was secured at the counterweight using three screws drilled into the cement. Figure 1(b) shows the picture of the target installed at the counterweight. To provide feedback to the adjustment engineers, a Complementary Metal-Oxide-Semiconductor (CMOS) camera (Basler acA1920-155um) with a lens (Nikon 18-35 mm f/3.5-4.5D IF-ED) and a neutral density (ND) filter was mounted on the boom of the dish as depicted in Figure 1(c). Additionally, a sample picture of the target with the camera is presented in Figure 1(d) to aid in illustrating the process.

(a) (b) (c) (d)

Figure 1*. The components used in the on-sun alignment of the ZED Solar dish: (a) ZED Solar dish with facets covered, (b) target placed at the focal plane to observe the reflection of the mirrors, (c) camera equipped with lens and ND filter to visualize the mirror spot, and (d) captured image of the target using the camera.*

3.2. Steps of On-Sun Alignment Method

The *ZED Solar* dish comprises two rings - the inner and outer ring - with a total of thirty facets. The outer ring consisted of 15 facets, numbered sequentially from 1 to 15 in a clockwise direction. Similarly, the inner ring comprised 15 facets, numbered from 16 to 30, also in a clockwise direction. Each facet is attached to the spokes using four bolt mounts. All bolt mounts are identical, and there is a nut on each side of the facet. The front nut is used to lock the position of the facet, while the back nut holds it in place due to gravity.

The alignment team consisted of three engineers. Two of them used a manlift to access and adjust the back nuts of the bolt mounts, while the third engineer provided feedback by monitoring the live feed from the camera. The alignment process was carried out in the following steps:

- The first step involved cleaning the facets using a cleaning mop and a high-pressure water pump with a gun. A manlift was used to access the facets at higher elevations in the outer ring, and for the inner ring facets, the spokes of the dish were used as a ladder.
- In the second step, the locking nuts positioned on the front side of the facets were intentionally loosened to enable control of facet movement through the back nuts.
- Once the facets were cleaned and the locking nuts were loosened, the dish was put into tracking mode to observe the reflection of the facets on the target. A picture of the dish in tracking mode with the alignment setup is presented in Figure 2(a).
- After activating the tracking mode, the reflection of the facet was observed in the live feed from the camera, which was operated from the control room located next to the dish.
- The back nuts of the facets were adjusted to align the facet based on the feedback from the engineer monitoring the camera feed.
- Once the facet was aligned, the locking nuts were tightened, and the adjusted facet was covered again with fabric covers.
- After that, the next facet to be aligned was uncovered as shown in Figure 2(b).
- The procedure was repeated for all facets until the sunspot was aligned in the region of interest.

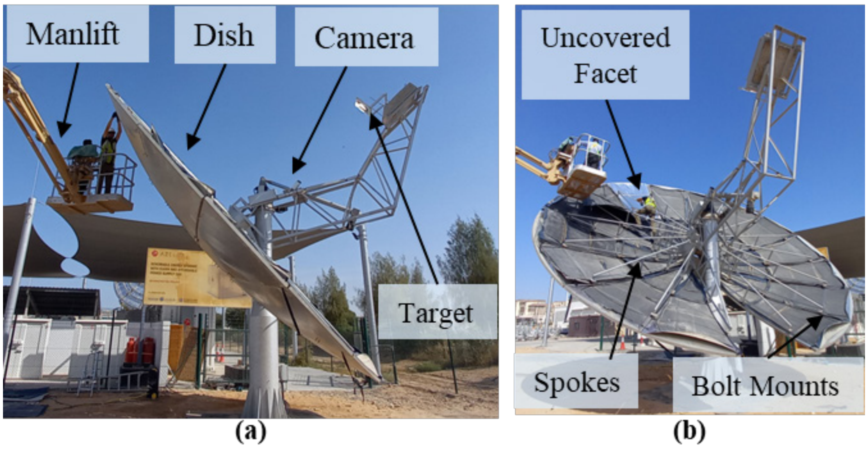

Figure 2. *(a) Adjusting the nuts from the back of the facet while the dish is in tracking mode. The picture also shows the manlift, camera, and target with a sunspot. (b) Adjusting the nuts from the front of the uncovered facet.*

4. Results and Discussion

This section delivers vital findings from the alignment of the *ZED Solar* dish accomplished through the on-sun alignment method. First, the results of the alignment process are explained followed by the results of time consumed during the alignment process. Lastly, this section delves into the challenges encountered and offers prospective recommendations for future alignment efforts.

4.1. Alignment

To move the sunspot downwards, the back nuts of the c and d bolt mounts, as shown in Figure 3(a), were tightened, and vice versa to move it upwards. Similarly, to move the sunspot to the right, the back nuts of the a and d bolt mounts were tightened, and vice versa to move it to the left. It was observed that the sunspot moved 8 cm for each degree of facet movement in either the elevation or azimuth direction. Figure 3 provides a visual representation of the alignment process for one of the facets.

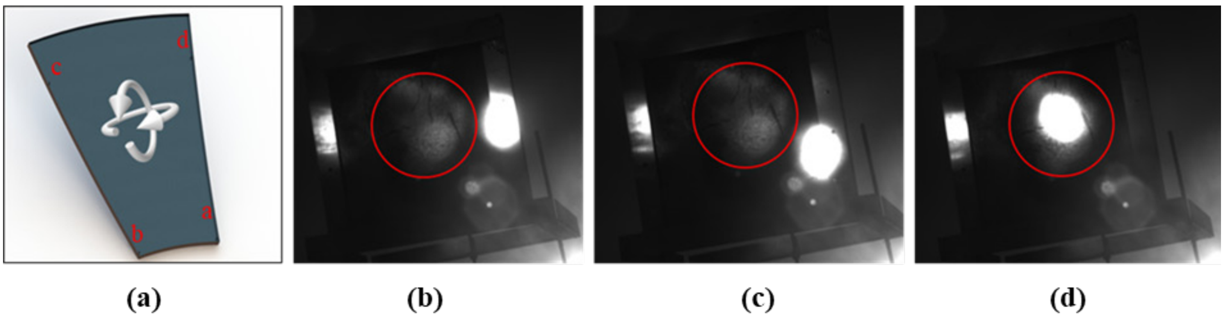

Figure 3. *These pictures illustrate the alignment process of a facet, where (a) presents a schematic of the facet, (b) shows the initial sunspot outside the region of interest, (c) displays the new sunspot after tightening the back nuts of mounts a and b, and (d) exhibits the final sunspot located within the region of interest.*

A detailed computer aided design (CAD) model of the facet with labelled bolt mounts is shown in Figure 3(a). Upon uncovering the facet, it was observed that the sunspot was in the bottom right corner, outside the pre-defined region of interest as shown by the red circle in Figure 3(b). The objective was to move the sunspot into the region of interest by adjusting the back nuts of the facet mounts. To achieve this, the adjustment engineers tightened the back nuts of mounts a and b, resulting in an upward shift of the sunspot, as seen in Figure 3(c). Finally, the adjustment engineers tightened the back nuts of mounts b and c, moving the sunspot to the left and achieving proper alignment, as depicted in Figure 3(d). The same procedure was applied to align all facets.

It should be noted that some facets did not initially have a sunspot on the target and required alignment through a trial-and-error process. In these cases, the sunspot was moved only in one direction (either horizontal or vertical) until it was successfully aligned with the target. Once the sunspot was on the target, the standard alignment procedure was used to finalize the facet's adjustment.

4.2. Time Consumption

A plot of time taken by individual facets during the alignment is presented in Figure 4. It is important to highlight that the alignment of the facets was conducted in a random sequence, primarily based on their accessibility. The average time to align one facet, including cleaning, loosening the front nuts, and replacing the covers, was found to be around 15 minutes. The minimum time, 10 minutes, was taken by facet no 26 whereas the maximum time, 20 minutes, was taken by facet no 20.

In the alignment process of the outer ring, facets positioned closer to the ground, specifically facets 1, 2, 3, 13, 14, and 15, were accessible easily and thus required less time to align. Conversely, facets situated higher, such as facets 5 through 11, demanded more time due to the necessity of using a manlift to reach their bolt mounts.

A similar pattern was observed in the inner ring alignment. Facets 16, 17, 29, and 30 were aligned more quickly as their bolt mounts were easily accessible. In contrast, facets away from the ground required additional time. In certain cases, alignment time was further extended due to the complexity of the bolt mounts and the presence of rust on the bolts. The use of a manlift to reach the higher facets also contributed to the prolonged alignment process.

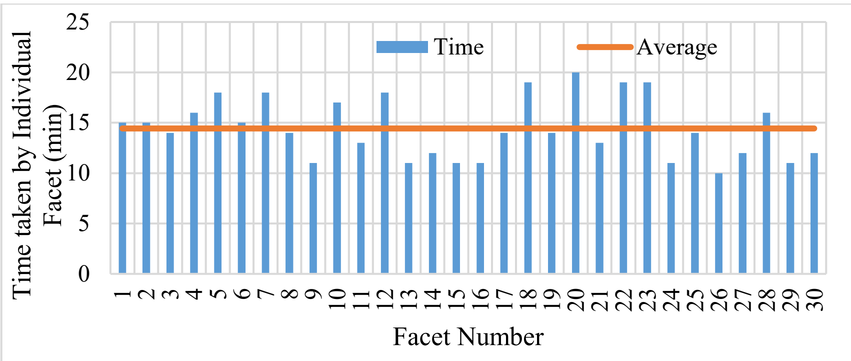

Figure 4. *Time taken by individual facets during alignment.*

Despite these challenges, the on-sun alignment method proved to be an accurate way of aligning the facets of a concentrated SPD. The main drawback is the time-consuming nature of the procedure due to the need to climb on the moving dish to lock the front nuts and change the facet covers. Overall, the alignment process was successful, and the results demonstrate the feasibility of using the on-sun alignment method for concentrated SPDs.

4.3. Challenges and Future Recommendations

The primary challenges encountered during the alignment process were linked to the intricacy of the bolt mounts, rust accumulation on the bolts, and the necessity for a manlift. The bolt mounts, characterized by the presence of two nuts on each side of the facet, required the initial loosening of the front (locking) nut for facet adjustment. Accessibility to these front-side nuts proved particularly challenging, resulting in prolonged overall alignment time.

The precision of the on-sun alignment method depends on the efficacy of the feedback process, which can be managed manually, utilizing thermocouples, or implemented through image processing. In this research, manual oversight was employed for camera feedback. Nevertheless, the potential for a significant enhancement in method accuracy exists through the implementation of image processing to detect the sunspot's position. Moreover, scaling up the on-sun method for aligning many dishes poses another challenge.

In the future, the *ZED Solar* dish will be utilized for a photo-electrochemical hydrogen production reactor, necessitating the deployment of a multi-aimpoint alignment strategy. A dedicated target, considering the theoretical reflection of each facet and prepared through Ray-tracing, will be employed. The on-sun alignment technique, enhanced by image processing, will facilitate the alignment of *ZED Solar* dish facets.

5. Conclusion

The aim of this study was to align the facets of the *ZED* Solar dish within a 200 mm diameter circle centred around the focal point. The on-sun alignment method was adopted for the initial alignment of the *ZED* Solar Dish. Throughout the alignment process, special fabric covers were employed to cover all facets and the dish was placed in tracking mode. Reflections from the facets were observed on a lightweight aluminum plate. A CMOS camera equipped with a lens and an ND filter was affixed to the dish's boom to observe the sunspots. Adjustments to the sunspot within the region of interest were made using the front and bottom nuts of the mount bolts. It was observed that the sunspot moved 8 cm for each degree of facet movement in either the elevation or azimuth direction. On average, it took approximately 15 minutes to align one facet, encompassing cleaning, loosening the front nuts, and replacing the covers. The primary challenges encountered during the alignment process were associated with the intricacy of the bolt mounts, bolt rust accumulation, and the need for a manlift. Despite these challenges, the on-sun alignment method emerged as a reliable and accurate approach for aligning the facets of a concentrated SPD.

Data availability statement

The authors declare that no data were generated in the current study, and therefore, there are no data sets or supplementary materials to disclose.

Author contributions

- Muhammad Abdullah: Experimentation, Writing – review & editing
- Brenda Hernandez Corona: Writing – review & editing
- Dr. Nicolas Lopez Ferber: Writing – review & editing
- Dr. Mathieu Martins: Resources, Experimentation, Writing – review & editing
- Dr. Nicolas Calvet: Conceptualization, Writing – review & editing.

Competing interests

The authors declare that they have no competing interests to disclose.

References

[1] ZED Solar. "ZED Solar Pakistan." https://zedsolar.com/ (accessed 26/04, 2024).

[2] Our World in Data. "Global primary energy consumption by source." https://ourworldindata.org/energy (accessed 10/10, 2023).

[3] C. K. Ho, "The Future of Concentrating Solar Power," 2020. [Online]. Available: https://www.osti.gov/servlets/purl/1826448

[4] T. Mancini et al., "Dish-Stirling Systems: An Overview of Development and Status," Journal of Solar Energy Engineering, vol. 125, no. 2, pp. 135-151, 2003, doi: https://doi.org/10.1115/1.1562634.

[5] P. Davenport, J. Martinek, and Z. Ma, "Analysis of Concentrating Solar Thermal System to Support Thermochemical Energy Storage or Solar Fuel Generation Processes," ASME 2019 13th International Conference on Energy Sustainability, no. V001T03A005, 2019, doi: https://doi.org/10.1115/ES2019-3871.

[6] K. Lovegrove and W. S. Csiro, "1 - Introduction to concentrating solar power (CSP) technology," Concentrating Solar Power Technology, pp. 3-15, 2012/01/01/ 2012, doi: https://doi.org/10.1533/9780857096173.1.3.

[7] K. Lovegrove and J. Pye, "Chapter 2 - Fundamental principles of concentrating solar power systems," Concentrating Solar Power Technology (Second Edition), pp. 19-71, 2021/01/01/ 2021, doi: https://doi.org/10.1016/B978-0-12-819970-1.00013-X.

[8] S. Ulmer, T. März, C. Prahl, W. Reinalter, and B. Belhomme, "Automated high resolution measurement of heliostat slope errors," Solar Energy, vol. 85, no. 4, pp. 681-687, 2011/04/01/ 2011, doi: https://doi.org/10.1016/j.solener.2010.01.010.

[9] C. E. Andraka, J. Yellowhair, and B. D. Iverson, "A Parametric Study of the Impact of Various Error Contributions on the Flux Distribution of a Solar Dish Concentrator," ASME 2010 4th International Conference on Energy Sustainability, Volume 2, pp. 565-580, 2010, doi: https://doi.org/10.1115/ES2010-90242.

[10] C. E. Andraka, R. B. Diver, and K. S. Rawlinson, "Improved Alignment Technique for Dish Concentrators," ASME 2003 International Solar Energy Conference, pp. 625-635, 2003, doi: https://doi.org/10.1115/ISEC2003-44088.

[11] R. B. Diver, "Mirror alignment and focus of point-focus solar concentrators," Sandia National Labs., Albuquerque, NM (United States), 1995.

[12] L. Ren, X. Wei, Z. Lu, W. Yu, W. Xu, and Z. Shen, "A review of available methods for the alignment of mirror facets of solar concentrator in solar thermal power system," Renewable and Sustainable Energy Reviews, vol. 32, pp. 76-83, 2014/04/01/ 2014, doi: https://doi.org/10.1016/j.rser.2013.12.006.

[13] ZED Solar. Solar Concentrating Dish - User Manual, 2012.

[14] R. B. Diver, D. E. E. Carlson, F. J. Macdonald, and E. A. Fletcher, "A New High-Temperature Solar Research Furnace," Journal of Solar Energy Engineering, vol. 105, no. 3, pp. 288-293, 1983, doi: https://doi.org/10.1115/1.3266380.

[15] R. B. Diver, "Mirror alignment techniques for point-focus solar concentrators," (in English), 1992, doi: https://doi.org/10.2172/7233191.

[16] J. Blackmon and K. Stone, "Application of the digital image radiometer to optical measurement and alignment of space and terrestrial solar power systems," in the 28 th Intersociety Energy Conversion Engineering Conference, Atlanta, GA, USA, 08/08-13/93, 1993, pp. 563-570.

[17] B. J. Steffen, C. E. Andraka, and R. B. Diver, "Development and Characterization of a Color 2F Alignment Method for the Advanced Dish Development System," ASME 2003 International Solar Energy Conference, pp. 657-663, 2003, doi: https://doi.org/10.1115/ISEC2003-44239.

[18] C. E. Andraka et al., "AIMFAST: Initial Dish System Alignments Results Using Fringe Reflection Methods," in ASME 2011 5th International Conference on Energy Sustainability, 2011, vol. Parts A, B, and C, pp. 695-704, doi: https://doi.org/10.1115/ES2011-54453.