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Cite as: AIP Conference Proceedings **2445**, 120019 (2022); https://doi.org/10.1063/5.0086923
Published Online: 12 May 2022

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Low-Cost Movable Heliostat

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Abstract. Movable heliostats avoid the rail systems of rotating heliostat fields. They can be realized cost effectively by modifying low-cost carousel type heliostats. The cost for the modifications is estimated and compared to the savings resulting from the higher efficiency.

INTRODUCTION

The heliostat fields of solar tower power plants are usually stationary although this reduces their efficiency. The cosine loss is significantly lower for heliostat fields rotating around the tower with the azimuthal velocity of the sun (Fig. 1). Furthermore, higher concentration ratios can be achieved due to less astigmatism. Ruiz et. al [1] determined that for rotating heliostat fields the number of required heliostats could be reduced by 14 %. Therefore, several concepts of rotating heliostat fields have been proposed (e.g. [2] [3] [4]). However, no cost effective solution was found so far. Most concepts are based on rail systems on which the heliostats run. For the rear part of the field, the length of the rails between the heliostats has to be comparably long which leads to high specific cost. Therefore, a concept of a movable heliostat without rail system is presented. The tracks of the heliostats are not fixed, which allows for a denser heliostat field at noon/in summer with further increased efficiency due to the reduced intercept losses. Furthermore, moveable heliostats could facilitate their installation, cleaning, and maintenance since they move to their field position by themselves and could also run autonomously to cleaning and maintenance stations.

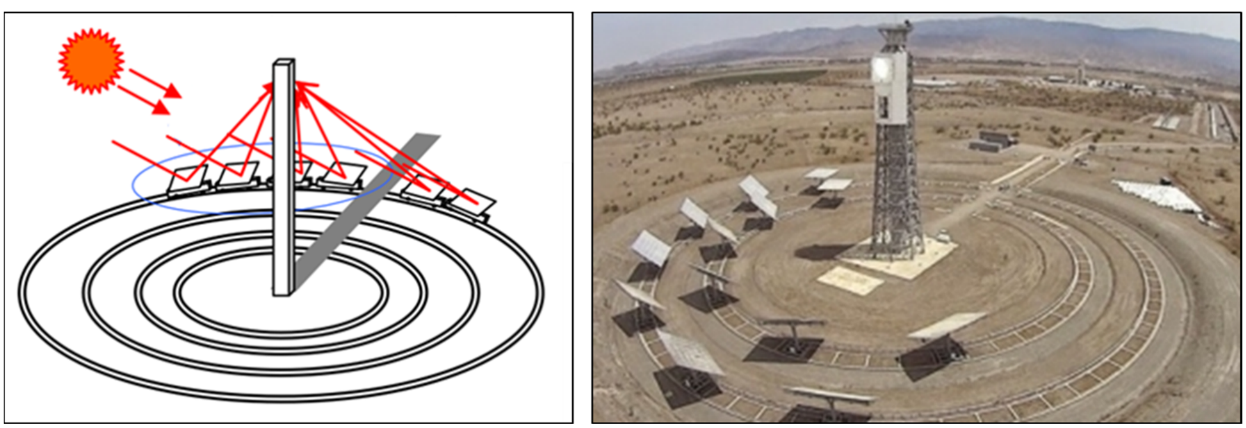
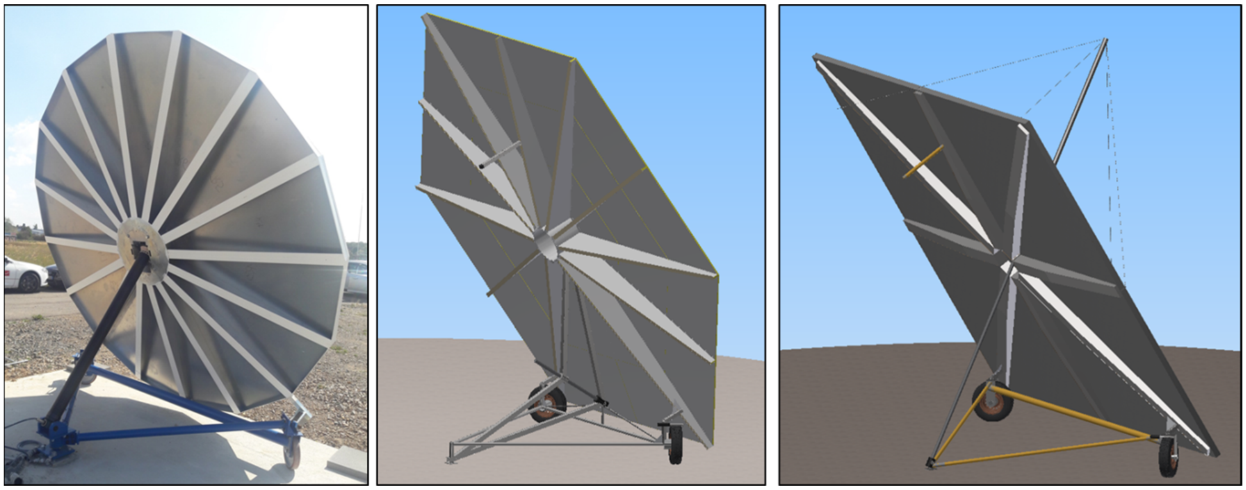


FIGURE 1. Rotating heliostat fields [4] [5]

SolarPACES 2020
AIP Conf. Proc. 2445, 120019-1–120019-6; https://doi.org/10.1063/5.0086923
Published by AIP Publishing. 978-0-7354-4195-8/$30.00

HELIOSTAT BASIC CONCEPT

Carousel type heliostats are well suitable to be adapted for movability since they already run on the ground. At SolarPACES 2017, a carousel heliostat concept of extraordinary low cost was presented [6]. A first prototype of reduced scale was built and tested [7] (Fig 2 (a)). With additional innovations in detail, the cost can be further significantly reduced (Fig. 2 (b) and (c)) [8]. The heliostats require wireless energy supply and control [9] to be able to move freely on the site.



(a) (b) (c)

FIGURE 2. 8 m² carousel heliostat prototype [7] (a), 50 m² heliostat with scissor elevation drive [8] (b), 44 m² heliostat with further modifications for cost reduction [8] (c)

CHASSIS

Two Steered Wheels

The heliostat's carousel can be modified for movability by replacing the central bearing with a third wheel and by adding a steering mechanism to each of the other two wheels (Fig. 3). Regarding cost of the mechanics and to keep the control simple, it would be favorable to have only one wheel steered. However, no solution with only one steered wheel was found because of the following boundary conditions that have to be fulfilled at once:

- The two not steered wheels have to be on one axis of rotation to avoid slippage in direction of the wheel's axes.
- The bearings of the concentrator and of the elevation drive have to be close to the wheels to avoid high bending forces on the connecting tubes of the carousel.
- The lower edge of the concentrator has to be about tangential to the circular pathways of the heliostat.

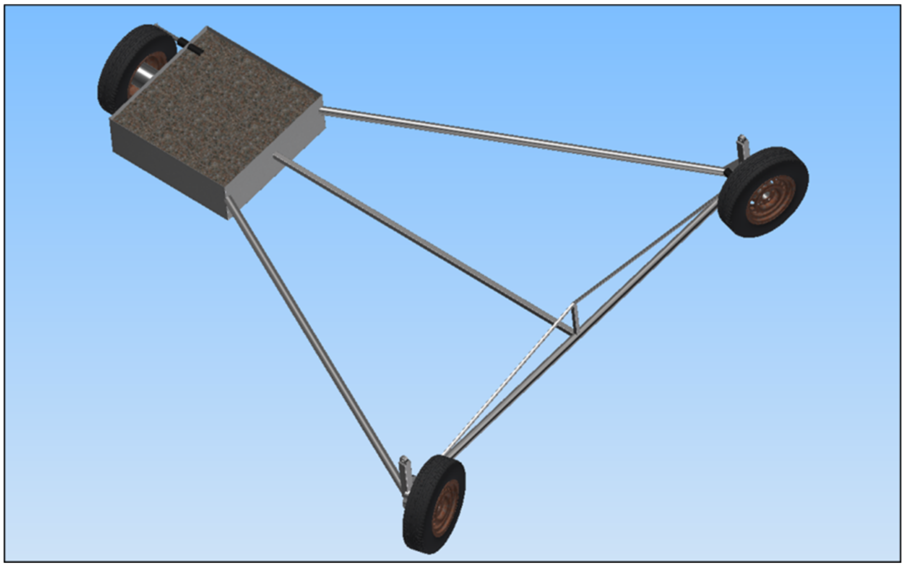


FIGURE 3. Chassis with one driven and two steered wheels and with counter weight

In principle, these modifications would be sufficient to realize the required azimuthal movement. However, towards noon, the elevation of the sun is higher and the heliostat rows could be closer to reduce the intercept losses. The variable field density would lead to non-circular pathways of the heliostats. As a consequence, the angle between the heliostat's carriage and the sun would vary in the course of the day which would require an additional mechanism for slight rotation of the concentrator.

Three Omnidirectional Wheels

An additional mechanism for rotating the concentrator could be avoided if the heliostat as a whole would be able to rotate about its central vertical axis. This would also increase its maneuverability. With omnidirectional wheels this would be possible (Fig.4) [10] [11] [12] [13]. A precondition would be low cost omnidirectional wheels that are able to run on only stabilized ground.

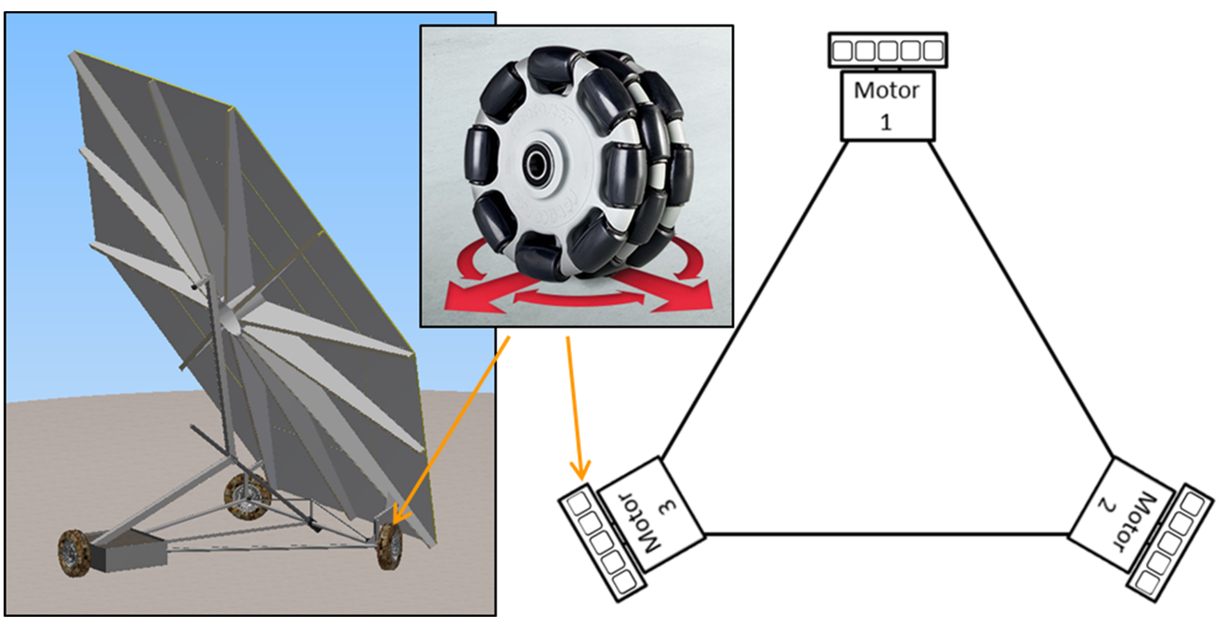


FIGURE 4. Chassis with omnidirectional wheels (sketch of omnidirectional wheel [14])

Wind Protection

To prevent the heliostat from being tipped over by wind, a counter weight is needed additionally to the weight of the wheel, motor, and batteries (Fig. 3). It can be realized at low cost by using a container filled with material available on site, like stones or sand. Due to the total weight of the heliostat, probably no anchoring in stow position is required.

CLOSED-LOOP CONTROL

The heliostats may run directly on stabilized soil. The unevenness of the ground and possible slippage are compensated by the closed-loop control. The control is based on a camera chip with fish-eye optics placed on the concentrator of each heliostat [6] [7]. The control strategy for a heliostat with two steered wheels (Fig. 5, left and bottom right) could comprise the following steps:

- The daily pathways are defined by the steering angle of the two steered wheels.
- The horizontal distance between the camera images of the sun and of the receiver l_y (Fig. 5, top right) depends on the heliostat position within the heliostat field and stays quasi constant in the course of the day for circular pathways [4]. For non-circular pathways, l_y is a function of time and can be calculated. The correct distance l_y is adjusted by the speed of the driven wheel.
- In principle, the normal of the concentrator is correctly aligned when the midpoint between the images of the sun and of the receiver (green X) is at the position of the midpoint of the complete camera image (blue X) (Fig. 5, top right) [8]. The task of the control system is to minimize the vertical distance between these two points Δz using the elevation drive and the horizontal distance by adjusting of the azimuth drive speed. For non-circular pathways, Δy is additionally adjusted by the mechanism for slight rotation of the concentrator.

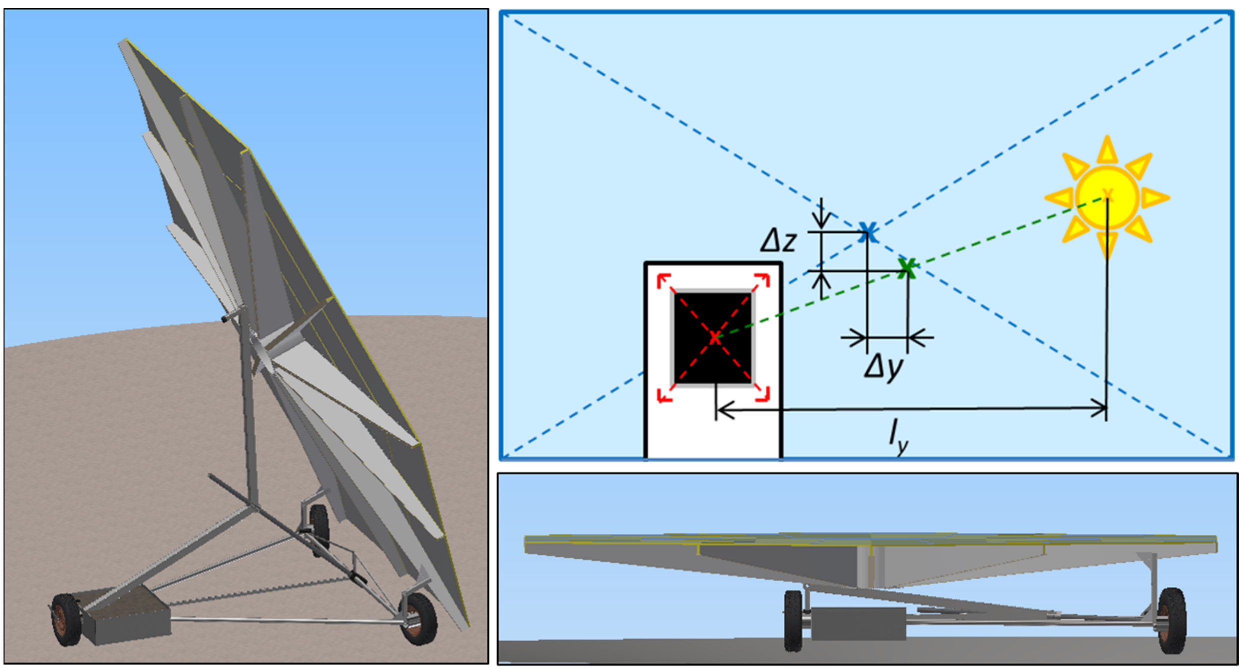


FIGURE 5. Sketch of 50 m² movable heliostat with two steered wheels in operation (left) and in stow position (bottom right); sketch of the tracking camera's image (top right, without the deformations of the fish eye optics), the control keeps l_y constant (for circular pathways) and minimizes Δy and Δz

COST ESTIMATIONS

Table 1 gives a rough cost estimation for the movable heliostat with two steered wheels compared to a stationary one. Additional cost result from the adaptions of the chassis of the azimuth drive as described above. Since the heliostats run from west to east in the course of the day (for the northern hemisphere), a three-time larger terrain is assumed. For this terrain the soil has to be levelled and stabilized. Energy is needed not only to rotate the concentrator about the elevation and azimuth axes but also to move it in the field. Therefore, the energy demand and the cost for photovoltaic modules and batteries is increased. The additional costs for the required rotatable receiver and for the land are not considered.

TABLE 1. Modifications and estimated cost for 10'000 movable heliostats of 50 m² with two steered wheels compared to stationary heliostats (additional cost for rotatable receiver and for land not considered)

Component	**Modifications**	**Stationary ($/m²) [8]**	**Movable ($/m²)**	**Cost Increase**
Concentrator		28	28	0 %
Azimuth drive	Two steered wheels, counter weight, mechanism for slight concentrator rotation	7	12	70 %
Elevation drive		7	7	0 %
Levelling and ground stabilization	Three times larger heliostat field size	4.5	11	140 %
Control and energy supply	Adapted control, higher energy demand	11.5	17	50 %
Fabrication/assembly/profit		13	16	20 %
Total		71 $/m²	**91 $/m²**	**30 %**

SUMMARY AND OUTLOOK

Compared to conventional T-type heliostats, an overall cost reduction seems to be possible. However, when compared to a stationary heliostat of same carousel type [8], the aforementioned solution with two steered wheels leads to about 30% higher cost (Table 1). Furthermore, a rotatable receiver would be necessary and a larger terrain for the heliostats to run on with additional extra land cost. Since the possible reduction of the number of heliostats is only about 14% [1], rotating heliostat fields would not be cost effective yet. Further cost reductions would be required. This could be only possible with low-cost solutions of the following points:

- Omnidirectional wheels to avoid mechanism for slight concentrator rotation and which are able to run on only stabilized ground
- Energy supply (PV + batteries)
- Rotatable receiver
- Site with low land cost that can be easily leveled and for which the soil can be stabilized at low cost

ACKNOWLEDGMENTS

The investigations are partly funded by the Federal Ministry for Economic Affairs and Energy (SAHEL project, 0324301).

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