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3rd Generation Rim Drive Heliostat with Monolithic Sandwich Panel

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Abstract. The improvements of the mechanical structure of the current rim drive heliostat generation with chain drive system and monolithic sandwich structure is described. The improvements of the mechanical structure result in increased torsional stiffness of the pylon, reduced manufacturing effort, increased life time of the chain gears, and better access to the drives. Dynamic wind loads were determined by loading a transient finite element model with pressure distribution time series gained by wind tunnel tests. Due to the rims, the heliostat shows significantly better dynamic behavior than conventional heliostats without rims.

INTRODUCTION

To make solar tower power plants competitive the cost especially of the heliostats must be reduced. In the past, many investigations have been made to reduce cost in construction, operation, and maintenance of heliostat fields. At rim drive heliostats, the accuracy requirements and the wind loads on the drive units are comparably low because of the long lever arms of the rims which significantly reduces the the demand for strong mechanical structure and precision of the drives compared to conventional heliostats. Previous developments of a rim drive heliostat have been presented in [1], [2] and [3]. Here, investigations of the dynamic wind load behavior and the improvements of the 3rd rim drive heliostat generation are presented (Fig. 1).

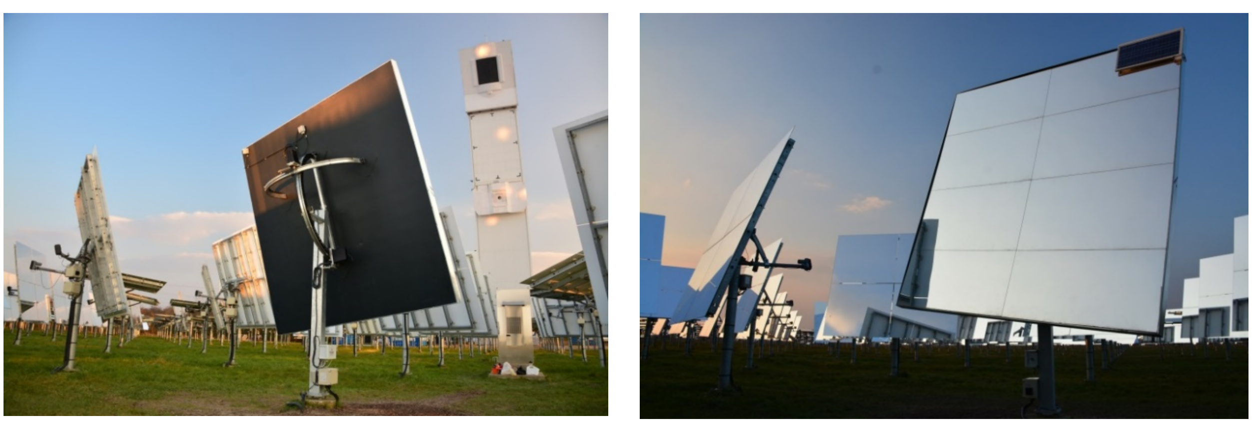

FIGURE 1. 3rd generation Rim drive heliostat at Solar Tower Jülich

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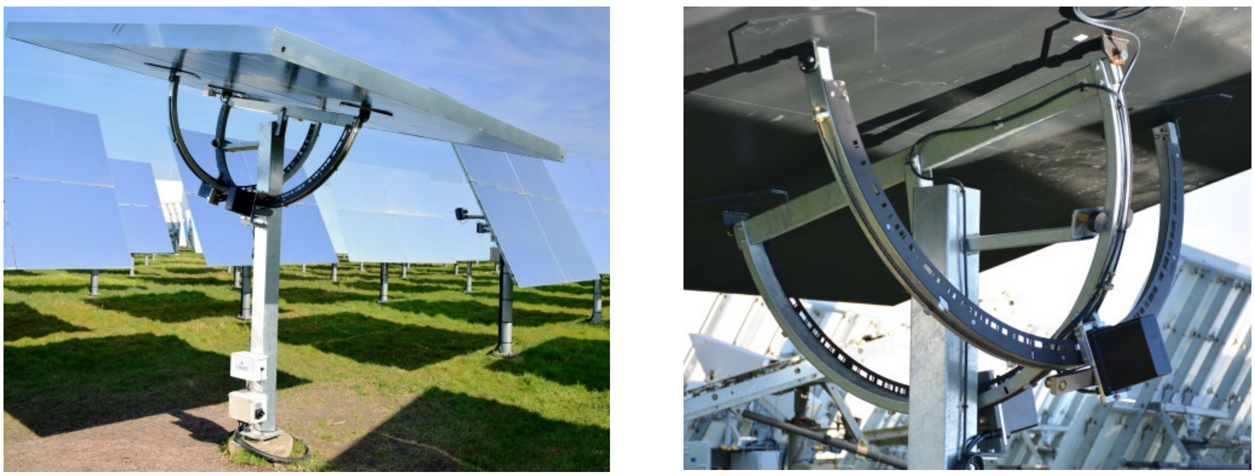
RIM DRIVE SYSTEM

General

The rim drive system consists of two rims with separate drive units (Fig. 2). The rims are mounted at the backside of the concentrator. The first rim is guided by a first pair of rolls mounted directly at the pylon near the drive unit and by a second one mounted at a cantilever arm connected to the top of the pylon. The drive system has been improved by the following points: A chain sprocket arrangement was developed which avoids fluctuating tension in the chain caused by the polygon effect [3] and with bigger chains for reduced elasticity. The first rim is guided at the side of the pylon to avoid an opening in the pylon for higher stiffness. Both rims are designed with the same diameter to reduce variety of components and to increase the lever arm for the second axis. The upper guidance of the first rim is simplified and its stiffness is increased.



(a) (b)

FIGURE 2. 3rd generation rim drive heliostat (a), pylon with rim guidance (b)

Evolution of Chain Gear

During the previous generations the drive system has evolved from a cable drive unit with winch wheel [1] to a chain wheel drive [3]. As the winch wheel was considered to be relatively complex in mounting and not suitable for upscaling, chains and other gear options have been investigated [4]. Chain gears have the following advantages: low back lash (if pretensioned), potentially low cost (mass products), and capability to withstand high forces over a well-known lifetime (for example in combustion engines). Nevertheless, chain drives have disadvantages, such as: induced stresses and velocity variations due to the polygon effect [3], potentially complex requirements for weather protection system or maintenance, and lengthening due to elasticity and wear.

To reduce the impact caused by the polygon effect, different sprocket arrangements have been developed (Fig. 3). The 1st generation had a compact “Z”-arrangement (Fig 3, a), but the relatively short distance between the two sprockets led to high tension caused by lengthening of the chain due to the polygon effect which would result in increased wear.

The tensioning of the chain can be avoided by two sprockets with same direction of rotation and same angular alignment. This was realized at the 2nd generation by choosing a distance between the sprockets equal to an integral multiple of the chain pitch (Fig. 3, b). Thus, the chain enters and exits the teeth flanges on both sprockets simultaneously which avoids velocity differences and the resulting fluctuating tensioning of the chain. The two sprockets are tilted to each other to avoid collision of the chain. The distance of the sprockets must be long enough that the flexibility of the chain can compensate the tilt.

To reduce the elasticity of the chain drive system, a stronger chain with larger pitch has been chosen for the 3rd generation. The required distance between the two sprockets for the new chain was too long to be integrated into the existing design. Therefore, a return pulley was added at the bottom of a double-sided sprocket (Fig 3, c). The return pulley can be easily fixed for adjustment of the correct distance to the sprockets. It secures the chain from sliding off the sprockets and guides the non-tensioned part of the chain to make an offset turn.

(a) (b) (c)

FIGURE 3. 1st generation chain gear "Z"-arrangment (a), 2nd generation with tilted sprockets (b), and 3rd generation with stronger chain (c)

Evolution of Mechanical Structure

(a) (b)

FIGURE 4. 1st generation rim arrangement (a), 2nd and 3rd generation rim arrangement (b)

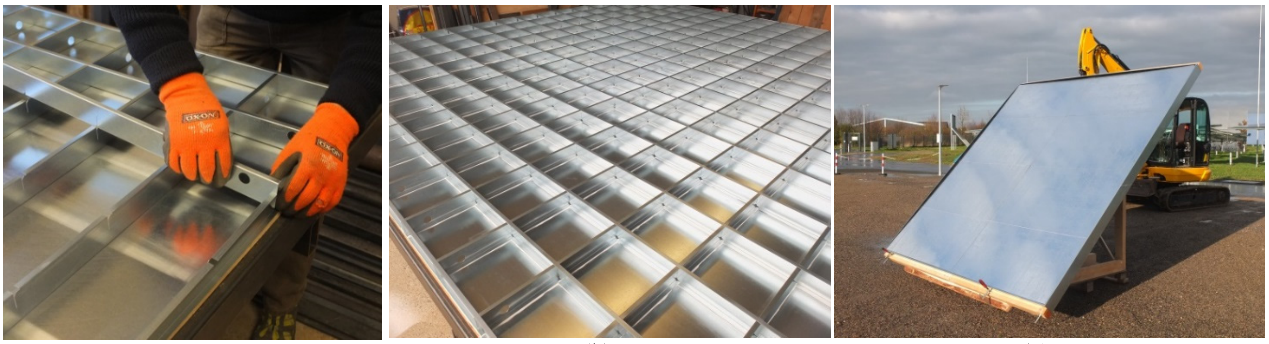
The mechanical structure of the rim drive heliostat has been improved for increased torsional stiffness, reduced manufacturing effort, and better access to the drives. This has been realized by several steps:

- By a slight inclination of the 1st rim it passes at the side of the pylon (Fig. 4, b). By this, the pylon remains a closed structure without the previous opening in the middle which simplifies the manufacturing of the pylon significantly and increases its stiffness (Fig. 4, a).
- Both rims are of same diameter (Fig. 2, b), which reduces manufacturing efforts and increases the gear ratio of the 2nd axis.
- The second rim is now outside of the first one. By this, a simplified horizontal side-arm supporting and guiding of the 1st rim is possible (Fig. 2, b).

- Maintenance-friendly access to external drives and shaft-hub connection for reduced back lash was foreseen.

MONOLITHIC SANDWICH PANEL

For the 3rd generation rim drive heliostat a monolithic sandwich panel with 9 m² reflecting area and focal length of 30 m has been developed. The sandwich structure consists of galvanized 0.5 mm metal sheets. The sandwich front and back layer are adhered to a core mesh, consisting of folded and laser cut metal sheets stuck together (Fig. 5). The sufficiently high stiffness was approved by finite element simulations and mechanical test [5]. In general, 5% higher optical efficiency is achieved by sandwich panels [6].



(a) (b) (c)

FIGURE 5. Assembling of the sandwich core with metal sheets (a), sandwich core mesh (b), sandwich panel with mirror facets, ready for mounting on the tracker (c)

Foam plates of extruded polystyrene were glued on the front layer of the metal sandwich. The plates are formed to provide the required curvature for the eight 1 mm mirror facets which are glued on them (Fig. 6). The foam plates increase the hail resistance of the panel. Gravity and wind loads are resisted by the metal sandwich structure only. Thus, the risk of creeping of the rigid foam plates is avoided.

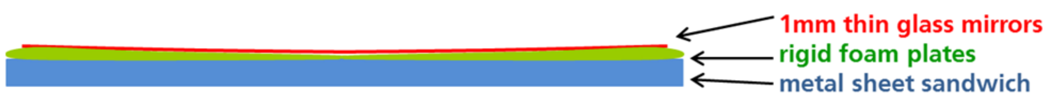


FIGURE 6. Main layers of 9m² mirror sandwich panel

CALCULATION OF DYNAMIC WIND LOADS

A dynamic finite element model (FEM) of the 1st generation rim arrangement was generated for the horizontal stow position for which the highest loads occur because of the high storm wind speeds which overcompensate the lower wind load coefficients of the stow position compared to vertical mirror panel [7] [8]. The dynamic behavior of the structure was determined by a modal analysis. Compared to conventional heliostats, the first two dominant modes of 4.7 Hz and 4.9 Hz are high because of the high stiffness of the structure due to the rims. The first two modes describe the oscillation of the panel about its symmetry axes (Fig. 7). For the 3rd generation rim arrangement with closed pylon even somewhat better results can be expected.

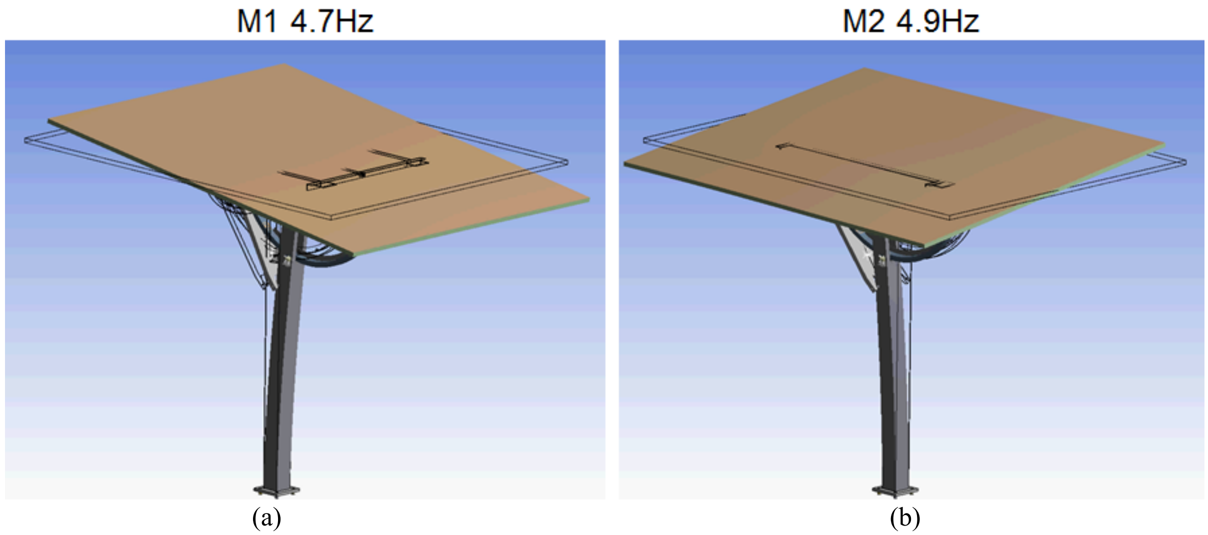


FIGURE 7. First (a) and second (b) dominant mode, numerically determined

The FEM model was loaded by pressure distribution time series gained by wind tunnel tests according to the method described by [9]. The performed wind tunnel tests were similar to the wind tunnel tests described in [10]. Figure 8 shows the oscillation of the heliostat (mainly about the elevation axis according to the first mode) due to fluctuating wind loads.

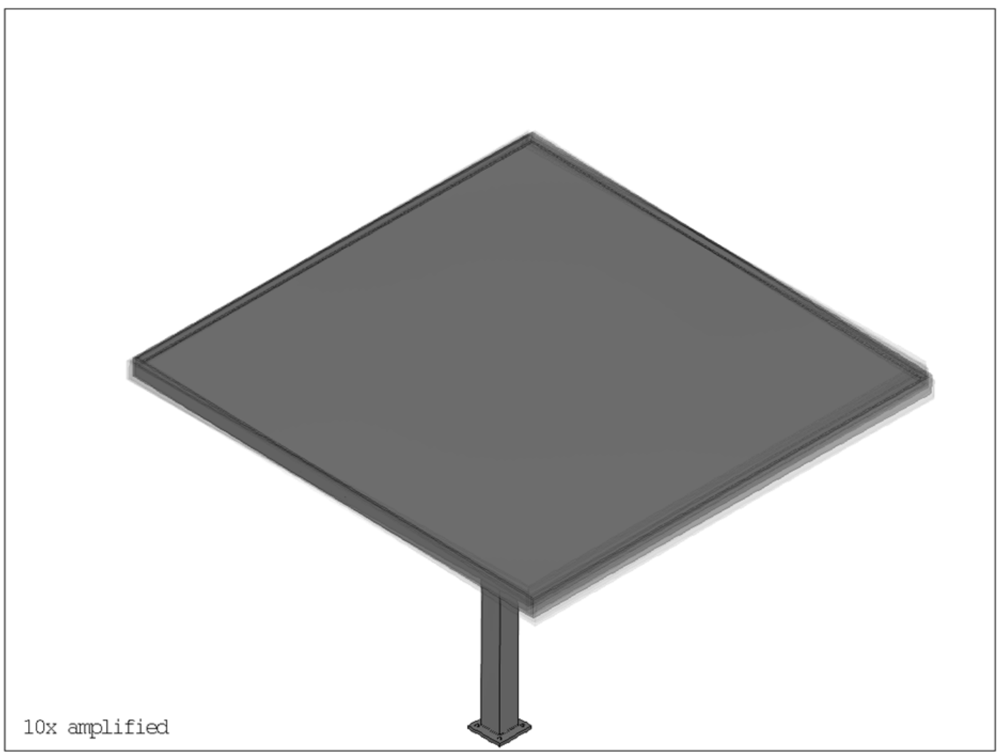
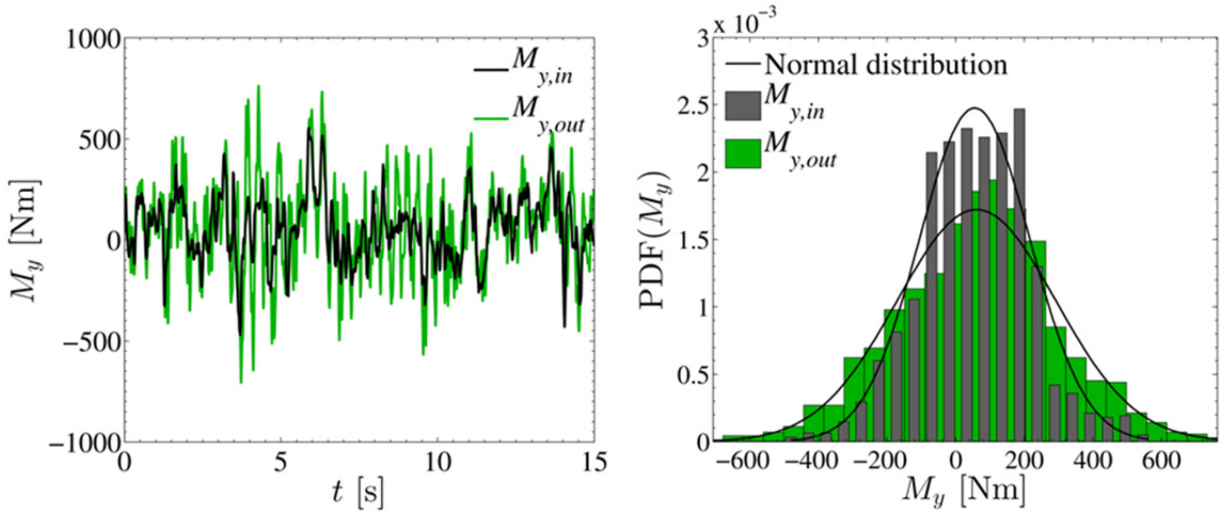


FIGURE 8. Simulation of the heliostat oscillation due to fluctuating wind loads

Figure 9 (a) shows the time signal of the input hinge moment resulting from the integrated pressure distribution on the panel compared to the output hinge moment resulting from the calculated dynamic reaction force at the drive multiplied by the lever arm of the rim. Obviously, the output moment peaks are more pronounced. The probability density function is close to a Gaussian distribution (Fig. 9, b). The ratio of the standard deviation of the input hinge moment and the output hinge moment is 1.4. For conventional heliostats this ratio is near to 2.0 [8]. The lower value results from the higher stiffness of the structure due to the rims which also lead to the comparably high dominant modes. The resulting lower dynamical wind loads reduce the requirements on the mechanical structure and therefore its cost.



(a) (b)

FIGURE 9. Time signal (a) and probability density function (b) of the hinge moment

SUMMARY AND CONCLUSIONS

For the 3rd generation rim drive heliostat a new chain drive system was found which avoids the negative effects of the polygon on the lifetime of the chains. As concentrator, a monolithic sandwich panel with 9 m² reflecting area and a focal length of 30 m has been developed with expected 5% increased optical efficiency compared to standard panels. The rigid foam plates are formed to the required curvature and increase the hail resistance, but are not loaded by wind and gravity which eliminates the risk of creeping. Due to the rims, high stiffness of the structure is achieved which leads to high dominant modes and low dynamic wind loads compared to conventional T-type heliostats. All these improvements and findings and some further simplifications reduce the cost significantly. Further cost reduction can be achieved by increasing the mirror surface and should be followed up at the next rim drive heliostat generation.

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