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Heliostat Tailored to Brazil

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Abstract

For Brazil, it is important to realize a high national production share because of high import fees and to obtain cost reduction related to implementation of the CSP technology. The rim drive concept offers an alternative for expensive heliostat drive solutions with slew and linear drives from abroad. Sandwich facets (which are usually foreseen for rim drive heliostats) are not available from Brazilian manufacturers and are replaced by a steel frame work structure with mounted 4 mm glass mirrors. The mirrors were bent along one axis. A two-axis curvature, while being optically more precise, would result in excessive stress of the mirrors when short focal lengths (present case: 30 m) have to be attained. For an 8 m² heliostat, the mirror panel was divided into six stripes. The stripes have to be canted to reach a sufficiently small focal spot. A prototype heliostat was designed and built. High stiffness and sufficient durability of the mirror facets against wind loads was reached. For the considered heliostat area of 8 m², the proposed framework design could be further simplified, but for 16m² heliostats (or bigger) it seems to be adequate. A heliostat with high local production share can be accomplished using the rim drive concept. High stiffness can be reached also without sandwich facet mirrors by using a framework mirror support structure with one rim as part of it. Short focal lengths can be achieved by dividing the mirror into several stripes bent in one single axis. The components described increases the feasibility of be manufactured in Brazil and makes possible to avoid increments in CSP plant costs related to import fees.

Keywords: S*olar tower plant; heliostat; mirror facet; local content; FEM; wind loads*

1. Introduction

Due to the great demand for renewable energy sources for electricity and heat generation, different technologies have been made available with increasingly affordable and competitive market costs. Concentrated Solar Power (CSP) technology uses direct solar radiation concentrated to generate heat onto a small area for producing electricity. The main concentrator types of CSP plants are the cylindrical-parabolic troughs concentrators, linear Fresnel concentrators, parabolic dish concentrators (also known as dish/engine systems) and heliostat fields, redirecting sunlight to a stationary receiver (power tower). The first type uses mirrors in the form of parabolic troughs. The absorber positioned at the focal line of the collector is usually a metal tube coated with a layer of selective paint and encased by a second glass tube which should be evacuated to avoid losses by convection. The second type, based on Fresnel technology, uses rotatable linear reflectors to concentrate the radiation on a fixed linear tube absorber. The third type consists of parabolic dishes which are reflectors of paraboloid shape usually with a Stirling engine and a generator located at each focal point. Finally, in the fourth type of technology, up to thousands of mirrors are used to concentrate sunlight on a fixed central receiver (Corgozinho et al., 2014). CSP technologies represent a good alternative to conventional sources for heat and electricity production in Brazil (EPE, 2012). Brazil is a country with high solar resource in significant areas of

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the country. On the other hand, with the presence of a strong industrial and agro-industrial sector entails a high demand of electricity, which is predominantly generated by hydroelectric plants. Increasingly often, due to lack of water, these plants cannot cover the demand during the dry season. The overall goal of the CEISA (Heliothermic Energy Studies (CSP): Educational Consortium for the Integration and Sustainability in the Agro-industry) project was to foster the international cooperation in the area of CSP generation. The project serves as a foundation for the research in the field of sustainable energy generation using the CSP technology and its applications within the agricultural sector in Brazil, where a process heat with a temperature of over 300 °C is needed. Within this project, a heliostat for Brazilian applications was developed with specifications according to the SMILE (Solar-hybrid Microturbine Systems for Cogeneration in Agroindustrial Electricity and Heat Production) project. SMILE is a national R&D project that aim to build two 100 kWel solar/biofuel hybrid thermal power tower plants in Brazil for generate electricity and co-generation of heat by integration with two agro-industrial applications (a dairy factory and a slaughterhouse in Caiçara do Rio do Vento, RN, and in Pirassununga, SP, respectively). The project is being financed by BNDES and industrial partners, coordinated by GREEN/USP (Research Group on Recycling, Energy Efficiency and Numerical Simulation/University of São Paulo), and implemented in partnership with DLR (German Aerospace Center) and Solar Institute Jülich – FH Aachen University of Applied Sciences. Due to the astigmatism effect and the relatively small power range smaller heliostats are expected to result in a better overall efficiency of the system. A small panel size of 8 m² (3.21 m x 2.5 m) was determined as optimal size, from both technical and transportation point of view. The HFLCAL software was used to determine the optimum number and positioning of the heliostats for the two plants. Based on these results, an optimum focal length of 30 m was calculated. Because of very high import tax rates, the use of domestic components and materials presents significant economic advantages. An already existing Brazilian heliostat design (Fig. 1) was considered too expensive, due to its reliance on imported drives, as well as the insufficient stiffness of its mechanical components. The aim of the present work is to find a design which allows for a high local production content and which has a sufficiently rigid structure.

Fig. 1: Drives of a first heliostat design with comparably expensive drives from abroad and too flexible mirror support structure (mirror not complete).

2. Approaches for high local content

2.1 Rim drives

From a broad variety of heliostat concepts (Coventry and Pye, 2014) (Pfahl, 2014) the rim drive concept (Pfahl et al., 2013) was individuated because of its avoidance of excessively expensive high precision drives, which would require to be imported. An illustration of a heliostat with horizontal primary axis and rim drives is given by Fig. 2. The 1st (red) rim can be supported by a guidance bar with rolls to increase stiffness. The 2nd rim (blue) is fixed to the mirror panel. The drive for the primary axis is mounted at the pylon, the drive for the secondary axis on the first rim. The gears may be realized by chains with bevel wheels (which have low backlash when pre-tensioned) or by winch wheels (which eliminate backlash). Both rims are locked during stow to relieve the drives and cables or chains under storm conditions.

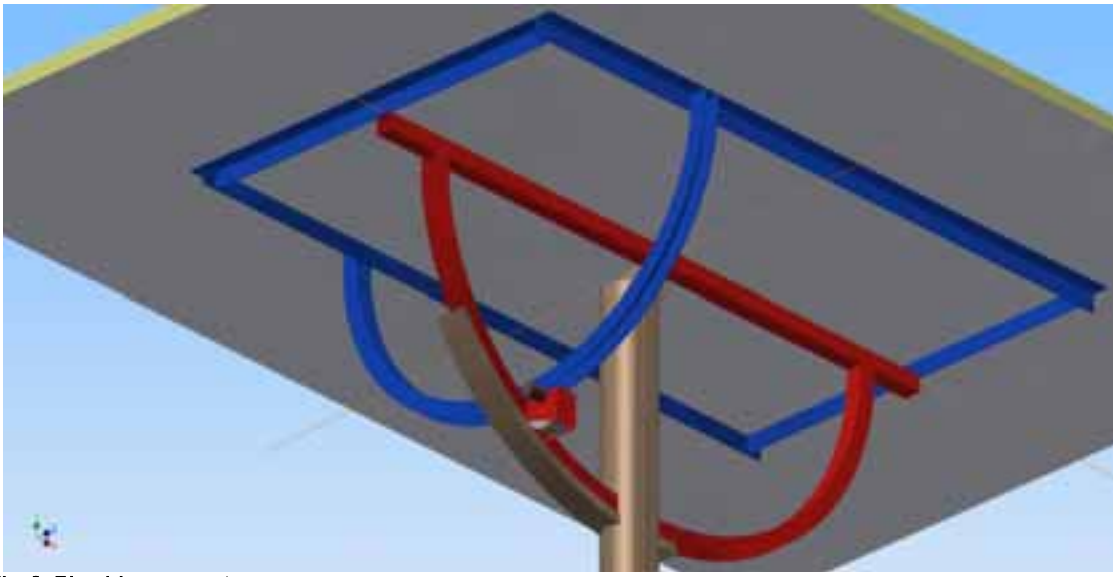

Fig. 2: Rim drive concept

The main advantages of the rim drive concept are: 1) small loads on the drives, 2) the backlash of the drives can be relatively high because of the long lever arm (distance between drives and centre of rotation) realized by the rims, which enables the usage of low cost drives (Fig. 3), 3) reduced loads on bearings, mirror panel, upper part of pylon and stow-position-locking devices during stow. On the other hand additional parts (rims, guidance bar for first rim, and stow-position-locking devices) are required. However, local manufacture of those is possible.

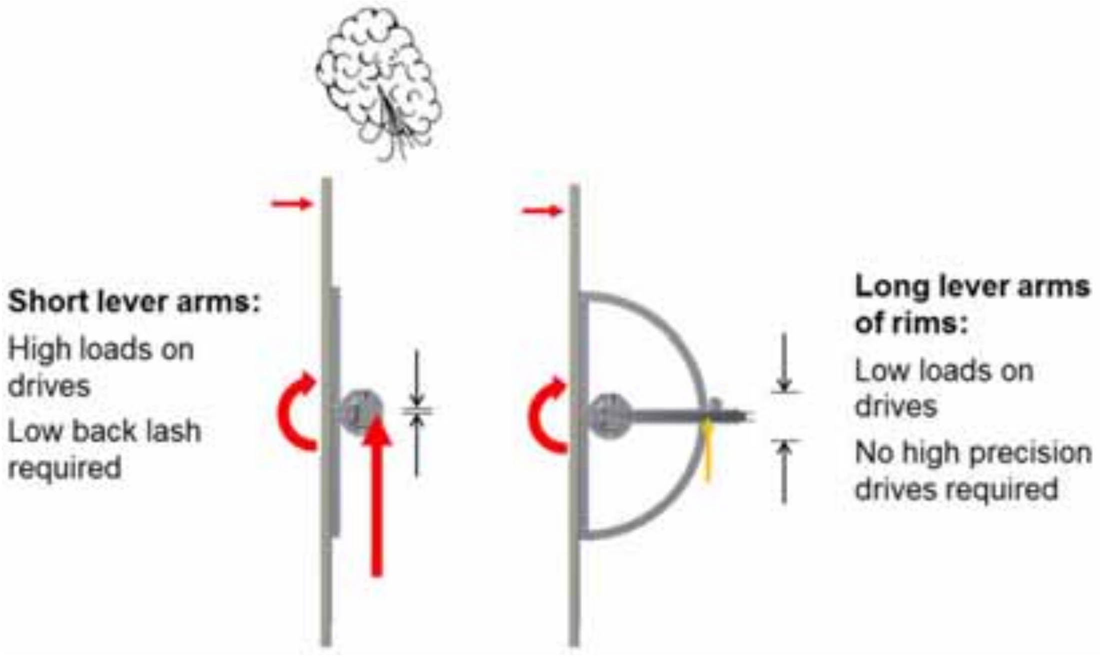

Fig. 3: Reduced requirements on drives due to longer lever arms realized by rims.

2.2 Framework mirror support structure

The first rim drive heliostat was built with sandwich panel (Fig. 4) (Pfahl et al., 2015). However, sandwich panels are not available in Brazil yet and thus their use would result in high transport cost and import taxes.

Fig. 4: First rim drive heliostat with sandwich mirror panel

Therefore, a framework mirror-support-structure with 4mm mirrors was chosen as an alternative for the sandwich facets. At this design the 2nd rim is integrated in the frame work (Fig. 5).

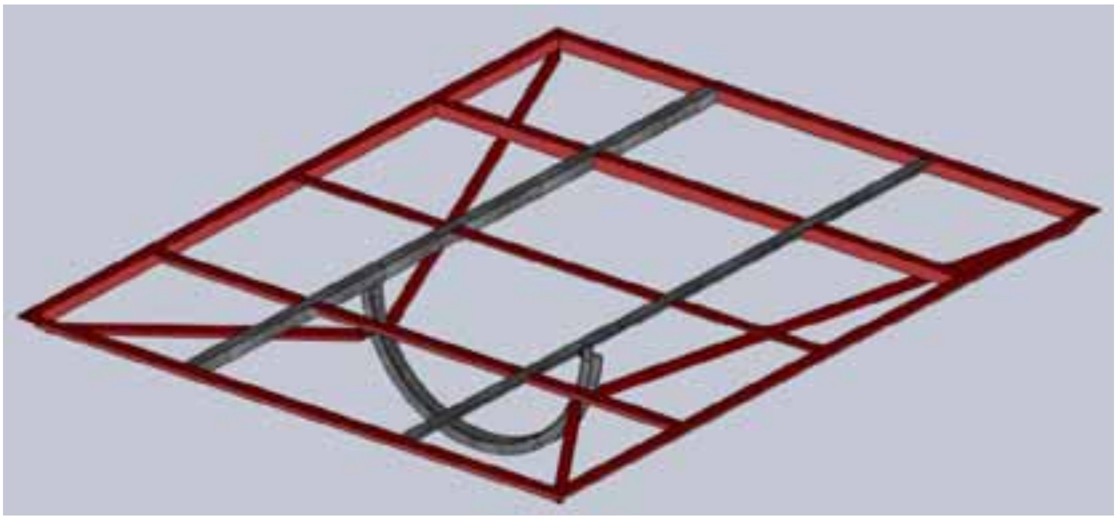

Fig. 5: Framework design of mirror support structure

2.3 One-dimensionally bent mirror stripes

For the solar power plants of the SMILE project, a relatively short focal length of only 30 m is required, resulting in a comparably small curvature radius of 60 m for the mirrors. To avoid excessive mechanical stress, the mirrors are bent only in one dimension. To achieve the required small focal spot of the reflected rays on the receiver the mirror is divided into six stripes of 2.5 m x 0.54 m x 4 mm. These mirror facets are canted to each other to achieve a step-wise approximation of a parabolic shape.

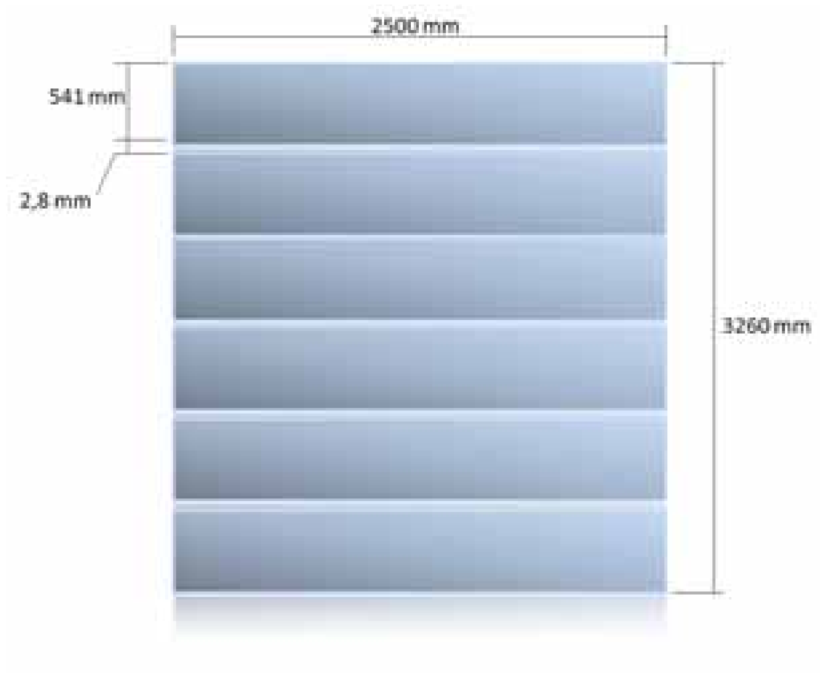

Fig. 6: Dividing of mirror surface into six stripes of only one dimensional bending.

Because of the small width of only 0.54 m thermal expansion is not critical in that direction. Hence, thermal expansion has to be accounted for only in the direction of the facet's length. This simplifies the connections of the mirrors with the steel frame which are realized by simple metal sheets bent to form “L” profiles. The metal sheet is flexible and allows for the compensation of thermal expansion differences between the steel frame and the mirror facets (Fig. 7). The “L”-shaped metal sheet can be adapted to the mirror curvature by choosing the angle α and by rotating it around the axis of the upper mounting screw. The defined geometry requires low amount of steel and simple handling during installation and further, it is an alternative with the ability to move even after installed on frame. The mirror stripes were switched on the metal sheet by double-faced scotch tape manufactured by 3M company, resistant to wind force and weather.

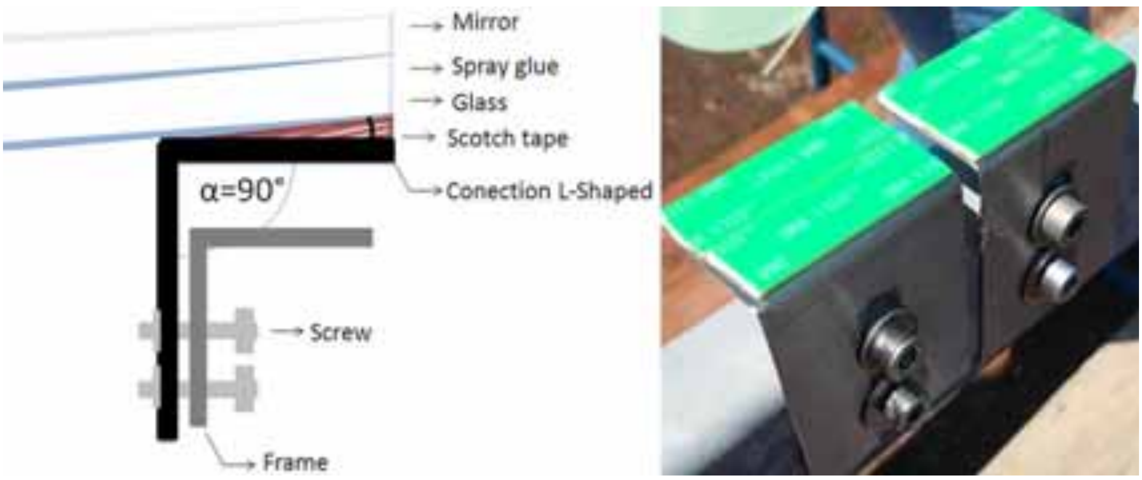

Fig. 7: “L”-shaped metal sheets as flexible connection between steel frame and mirror stripes.

3. Dimensioning

By FEM-analyses (Finite Elements Method), stress and deformation of the metal structure was computed. Maximum wind loads were determined according to (Pfahl et al., 2011b). The shape of the pressure distribution was known from full scale measurements (Pfahl et al., 2014). The maximum stress of 60 MPa is far below the acceptable value of structural steel (Fig. 8).

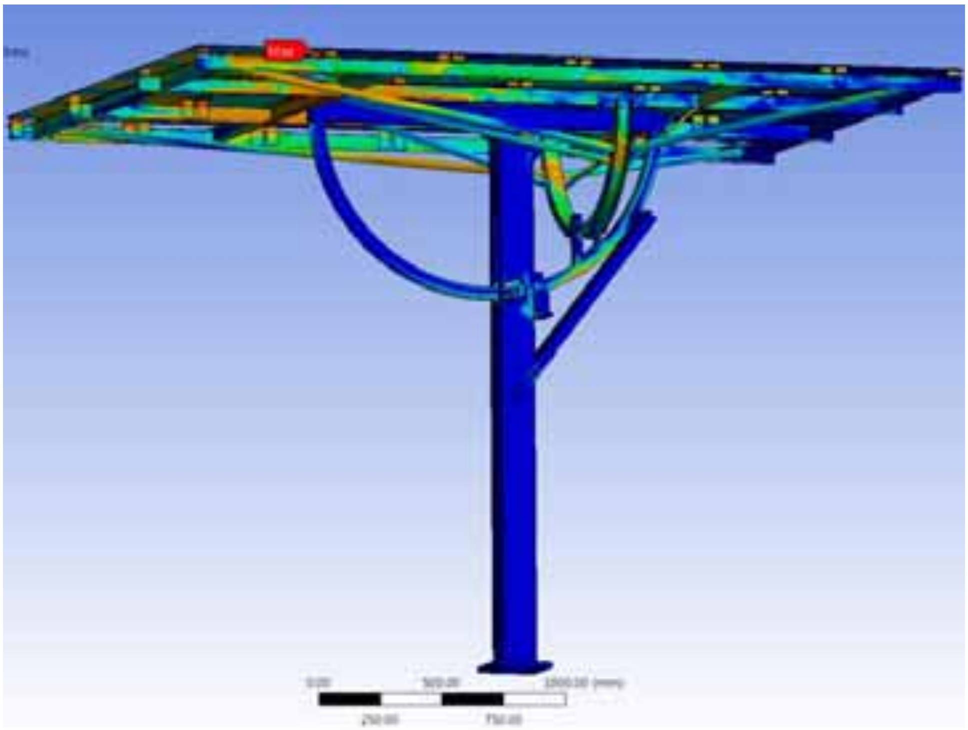

Fig. 8: FEM simulation of stress of the heliostat structure at storm conditions.

The stress of the mirror facets was calculated separately. It was concluded that four connecting points would lead to excessive stress (Fig. 9) (Von Reeken et al., 2011). Therefore, the amount of connecting elements per facet was increased to twelve.

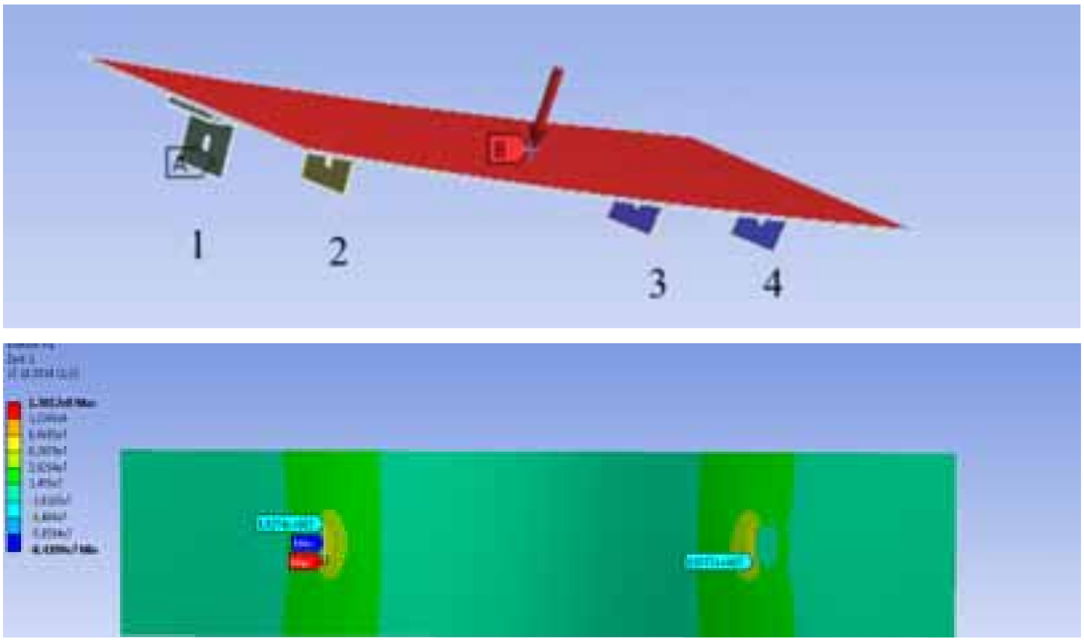

Fig. 9: FEM calculations of stress of mirror panel.

4. Improvements of prototype

4.1 Stiffness

A rim drive heliostat prototype with frame work mirror support structure of 8 m² was realized (Fig. 10). The mirror support structure was observed to be excessively flexible regarding bending about its diagonals, leading to deformation of the 2nd rim.

Fig. 10: First frame work mirror support structure with too high flexibility regarding bending about its diagonals.

Therefore, additional bars were included to avoid this deformation. Additionally, diagonal bars across the whole panel were added (Fig. 11). By these measures a sufficient stiffness was reached.

Fig. 11: Frame work mirror support structure with diagonal bars across the panel and bars for fixing of the 2nd rim for high stiffness.

Furthermore, for upright panel positioning, excessive flexibility of the vertical axis, entailing deformations of the 1st rim were observed. Therefore, the "U"-profile of the 1st rim was closed (Fig. 12) to mitigate this issue and improving the overall stiffness of the system.

Fig. 12: "U"-profile of 1st rim (left); closed profile of 1st rim (right) for increased stiffness.

4.2 Mirror support

The results of the FEM calculation of the mirror facets were validated by mechanical tests. The mirrors are connected to four bars of the steel frame. It was investigated whether only one connection per bar (and four connections per facet) would lead to excessive stress, as predicted by the FEM computations. For this, a glass stripe of 2.5m x 0.54m x 4mm was connected to the steel frame by twelve "L"-shaped metal sheets. The maximum hinge moment in stow position was determined according to Pfahl et al., (2011a). For the stow position, the peak hinge moment results from instantaneously increased pressure on the wind facing edge of the mirror panel. The pressure increase is caused by eddies hitting the mirror panel at the edge (Pfahl et al., 2011b). This was simulated by loading the glass stripe mounted at the edge of the panel by sand. The weight which would lead to the peak hinge moment was calculated. Indeed, the glass broke before the calculated required maximum weight was reached (Fig. 13). Hence, only four central mirror mounting devices would not be sufficient to withstand the expected storm wind loads.

Fig. 13: Breakage of 4mm glass stripe before reaching of maximum expected load.

In a successive step, the amount of mirror connections was doubled. Each glass stripe was connected to the four bars with two "L"-shaped metal sheets for each bar located at the edges of the glass stripe. With the eight mirror connections the glass stripe could be loaded with the full amount of sand simulating the maximum wind load (Fig. 14).

Fig. 14: Glass stripe of 4mm thickness loaded with sand simulating the maximum expected wind loads.

The established methodology for assembling the mirror facets was the best sequence found from the viewpoint of practicality reduced risk of damage. First, the "L"-shaped metal sheets were positioned coplanar to the metal frame (Fig. 15). The stripe composed by glass and mirrors showed sufficient stiffness to withstand the tension on the external connectors, while being flexible enough to provide the height of curvature.

Fig. 15: Assembling of the stripes using L-shaped metal sheet.

5. Conclusions

A heliostat with high local production share can be accomplished using the rim drive concept. High stiffness can be achieved also without sandwich facet mirrors by using a framework mirror support structure with one rim as part of it. Short focal lengths can be reached by dividing the mirror into several stripes bent in one single axis. For 8 m² heliostats the framework structure appears to be extensive. For bigger heliostats (16m² or 32m²) an accordant framework structure could be used and seems to be adequate. For 8 m² heliostats the framework structure should be simplified by using closed profiles for the basic frame which would allow to reduce the amount of bars of the framework. The components described increases the feasibility of be manufactured in Brazil and makes possible to avoid increments in CSP plant costs related to import fees.

Acknowledgements

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