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MOVABLE STRUCTURE FOR A TWO-AXES SOLAR TRACKER TRACKING A SUSTAINABLE FUTURE

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ABSTRACT

The population growth and development in underdeveloped countries has led to a rise in the demand for energy and the fact that conventional energy sources cause damage to the environment means that the sustainable future must be based on alternative energy sources. This paper describes an application of movable structures for alternative energy sources. We present the design of a movable structure-mechanism for an innovative two-axes solar tracker with ratios of generated energy per consumed energy, and generating surface per occupied surface are higher than double the usual ones for two-axes trackers (minimum consumption of energy and occupation of surface). The device has minimum height (minimum environmental impact, easy assembly) and is strong and reliable.

Keywords: *Solar energy, movable structure, two-axes, tracker, prototype*

1. INTRODUCTION

1.1. Context

The sourcing, transport and consumption of conventional energy sources have an impact on the environment. It has been demonstrated that this is the cause of the most serious environmental problems on the planet, like the climate change and acid rain. The demand of energy is to increase as a consequence of population growth and the development in underdeveloped countries.

These environmental problems, the predictable increase in demands for energy and the fact that conventional energy sources are limited means that conventional energy sources are unsustainable and must be replaced by alternative ones. Observing nature, we can see that the sun is the engine of the planet, allowing the photosynthesis of plants, affecting the water cycle, generating pressure differences that create wind. This is why most renewable energy sources, directly or indirectly, are based on the Sun.

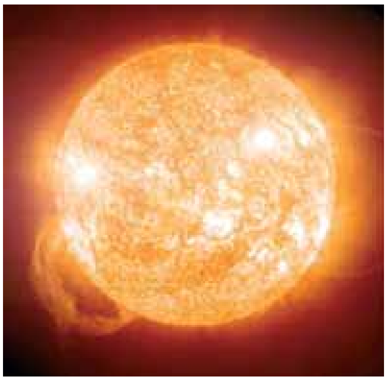


Figure 1. Image of the sun

1.2. Natural solar tracking

Looking at the vegetable world, we can see that a lot of sources of energy are based on the sun. Generally, plants have tracking systems to increase the amount of solar energy they capture. Sunflowers are an obvious example of this.

Figure 2. Sunflowers

1.3. Solar trackers

A solar tracker is a device for orienting a solar energy receptor (photovoltaic panel or concentrator) or reflector, towards the sun. The sun's position in the sky varies according to the season (elevation) and the time of day as the sun moves across the sky (azimuthal). As the tracker follows the sun, the effectiveness of the energy system increases.

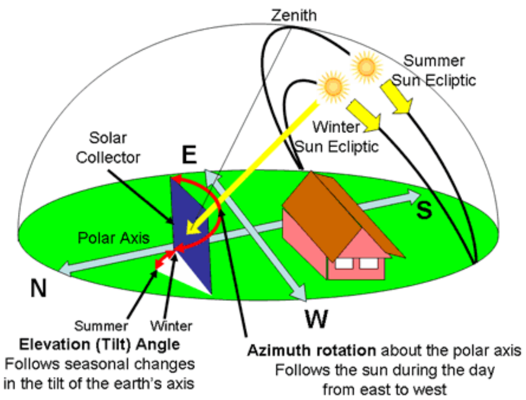


Figure 3. Solar tracking [3]

There are several kinds of trackers: one-axis (horizontal axis or polar axis) and two-axes. Two-axes trackers can obtain the best energetic efficiency.

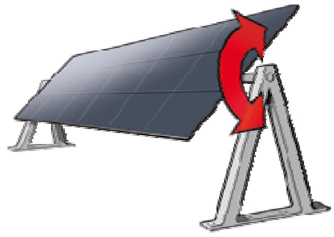


Figure 4. One axis tracker (horizontal) [4]

Figure 5. One axis polar tracker (inclined) [4]

Figure 6. Two axis tracker (elevation / azimuthal) [4]

Generally, two-axes trackers are designed as monopost units. Two-axes trackers are formed by a monopost structure with a big number of panels. This means that the height of the unit causes a greater environmental impact because of the huge size of the free surface facing the wind. This type of tracker has some disadvantages: the structure must be strong, it needs protecting systems against the wind (flag position), powerful motor devices and the assembling process is difficult. Most of these problems can be solved with a tracker that moves small units of panels, but for reasons of cost, maintenance, electronics and reliability, it is necessary that several small units of panels be moved with the minimal number of actuators.

Figure 7. ADES™ two axis monopost tracker (Photovoltaic)

Figure 8. SBP™ two axis tracker (Concentrator)

The solar Tracker described below is the synergic response to this and is highly innovative in today two-axes solar trackers market. The tracker moves a matrix of 7x9 pairs of panels (parallel movement, non-solid rigid movement) with only two actuators. Therefore, the ratios of generated energy per consumed energy, and generating surface per occupied surface are higher than double the usual ones for two-axes trackers (minimum consumption of energy and occupation of surface), the wind effect is minimized, environmental impact is reduced and the assembling process is made easier.

Figure 9. Image of designed two axis tracker

2. CONDITIONING FACTORS FOR DESIGN

The conditioning factors for the Tracker design are:

- Two-axes tracker (elevation and azimuthal) for photovoltaic panels (possible applications for other kinds of energy).
- Tracker height limited to 1.85m in assembly position and 3m in tracking mode.
- Two-axes rotation angles:
- Azimuthal: -45 º to 45º. Total angle: 90º.
- Elevation: -15º (North orientation) to 55º (South orientation). Total angle: 70º asymmetric.
- Movement generation using two linear actuators (one for each axis) for the movement of 126 280W photovoltaic panels. 35 kW total power for a tracker unit. The actuator power must be minimal and they must be situated in the same position in a tracker unit.
- Uncoupled transmission system. Each axis transmission system must be mechanically uncoupled.
- Simple joints and bearings.
- Able to withstand maximum wind speed of 140km/h. Unlimited reduction speed during tracking.
- 25 years lifespan for structure with minimum maintenance.
- Rectangular layout. Non linear tracker.
- Minimum consumption of steel.
- Maximum prefabrication in workshop and minimum work in-situ. Small-sized pieces for transportation and assembly in-situ. Non-crane assembly.
- If possible, surface foundations.

3. CONCEPT

Nowadays, there are a lot of one-axis, polar and two-axes trackers. All of them are based on the same principles and use hollow-section steel structures. The tracking system shown in this text follows the same principles (hollow section steel structure), but adds an innovative transmission system that allows for the uncoupled movement of a panels matrix (parallel movement of 7x9x2 panels, non solid-rigid movement) using two small actuators (one for each axis or DOF)

The transmission system minimizes the movement of the center of gravity of the panels and the free surface against the wind. This implies a reduction in the necessary energy for orientating the panels, structure member forces, actuators size and power. The ratio between generated energy and consumed energy for tracking is higher than double the usual one for two-axes trackers, resulting in maximum efficiency.

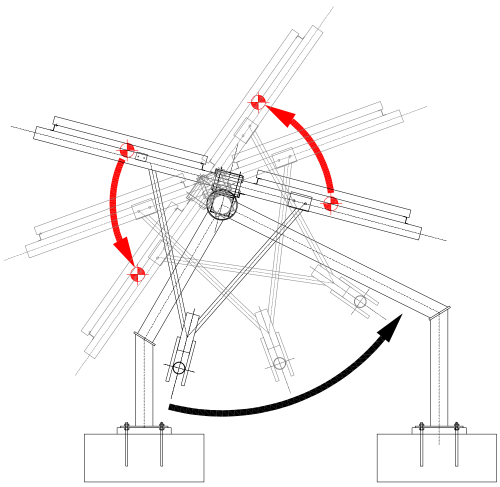
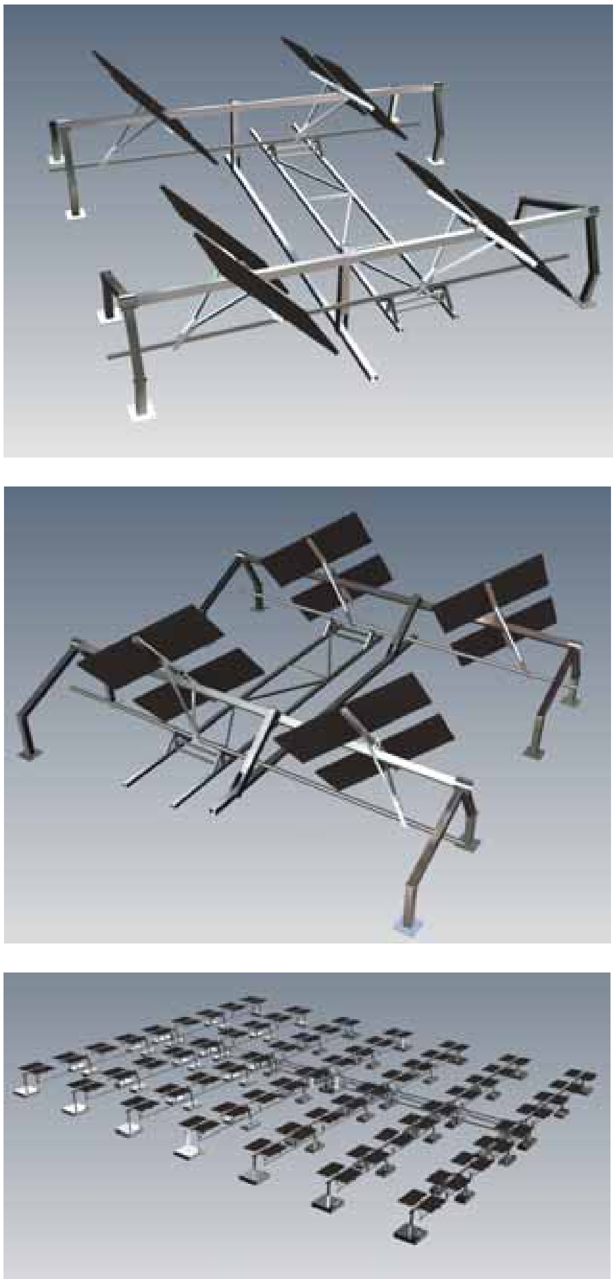


Figure 10. Center of gravity movement

Furthermore, the designed trackers have the following advantages: minimum height, minimum environmental impacts, they are reliable and easy to assemble. The two actuators and tracking electronics are concentrated on a central position of the layout, which saves space out of the layout. Having two actuators simplifies the electronics, saves wiring and maintenance, balances the forces in the structure.



Figures 11, 12 & 13. Conceptual design

4. TRACKER DESCRIPTION

4.1. Nomenclature

In order from the panels to the actuators, the tracker is composed of: panels, rotation axis, transmission system, actuators and electronics.

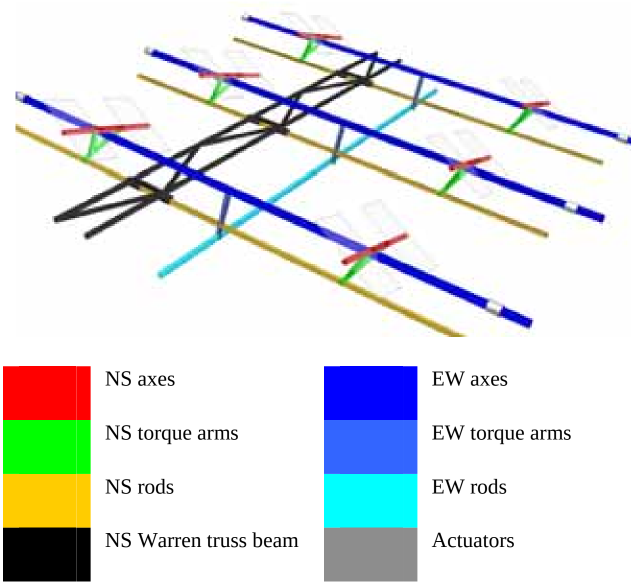


Figure 14. Elements nomenclature

4.2. Tracker layout

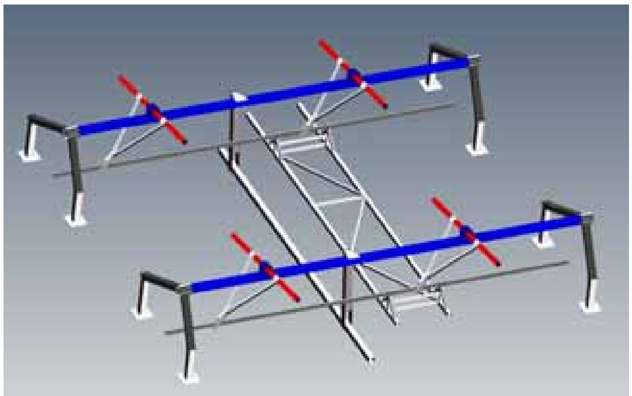
The tracker layout is formed by a matrix of 7 EW axes (positioned from East to West) and 9 NS axes (positioned from North to South) in each EW axis. Each NS axis has 2 photovoltaic panels (unitary module). The photovoltaic panels are 2x1m. All in all, the tracker layout is formed from 7 EW axis x 9 NS axis x 2 panels = 126 photovoltaic panels.

Figure 15. Layout

Figure 16. Unitary module

4.3. Rotation axes

The movement of the two-axes panels is based on a system of two axes (North-South axes and East-West axes, called NS and EW) with uncoupled DOFs (rotation in the direction of the axes). Both axes are serial connected, the torsion movement of EW axes resulting into planar rotation of each NS axis in an orthogonal plane from each EW axis. Between the axis EW and NS there is a hinge to allow the torsional rotation DOF and plane rotation of each NS axis.



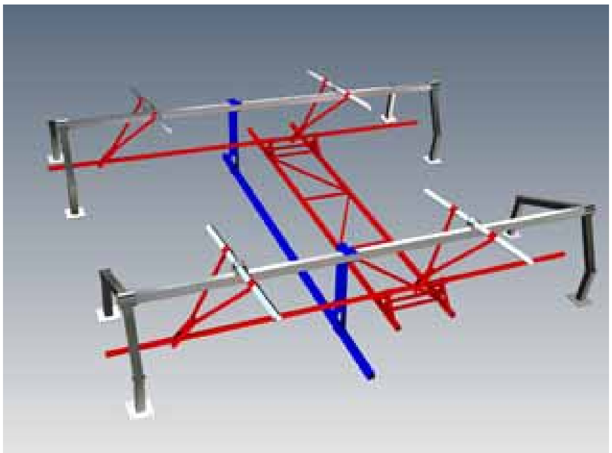
North-South Axes (Azimuthal movement)

East-West Axes (Elevation movement)

Figure 17. Axes system

4.4. Transmission system for acting in the two-axes system

In order to transmit the movement from the actuators to the rotation axes system it is necessary to design a transmission system (two DOF). The designed system is a mechanism based on torque arms in serial connections with rods. In the case of the NS transmission subsystem there is a parallel connection between several rods. The whole system is composed of hollow steel sections connected by rigid joints or hinges (plastic bearings). The innovative system is based on the uncoupled two-DOFs transmission system to transmit the movement to all the panels in a 126 rectangular panel matrix, using only two small actuators situated in a central position of the matrix. The transmission system from the actuators to the axes system can be divided into two transmission subsystems, one for each DOF or axis torsional movement. This is due to the uncoupling between the movement of each DOF or axis movement (it is commented upon in point 4.5).



EW axis transmission subsystem (elevation DOF)

NS axis transmission subsystem (azimuthal DOF)

Figure 18. Transmission system

Next, we will describe the two transmission subsystems:

4.4.1. EW axis transmission subsystem

The first transmission subsystem is the East-West (elevation movement/DOF) hereafter called EW ATS. In order of transmission from the actuator to the axes, the system is composed of a hollow rod, connected to the middle point by the associated linear actuator and linked with hinges to torque rods. Each torque rod is rigidly linked to each EW axis.

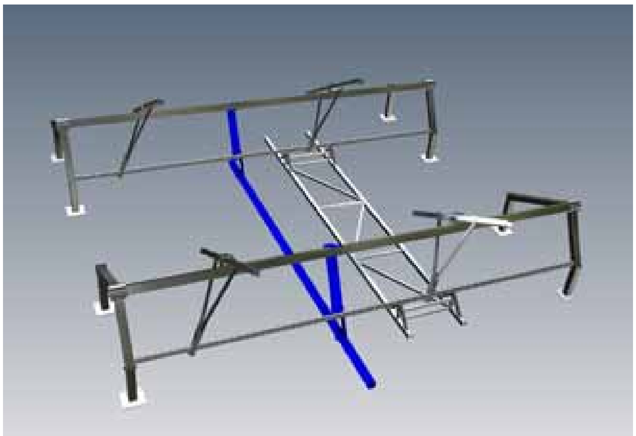


Figure 19. EW transmission subsystem

The kinematic of members in EW ATS for elevation movement is planar: parallel planar rotation of EW torque arms with EW axes as rotation axes, circular translation of EW rod and axial rotation of EW axes.

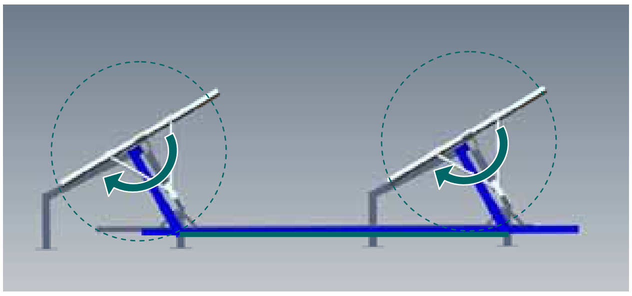


Figure 20. EW ATS kinematics

The flow of forces in EW for elevation movement from the actuator to the EW axes is: actuator impulse the EW rod, the EW rod distributes the force from the actuator in each EW torque arm extreme, theses forces produces a torque moment in every EW axis.

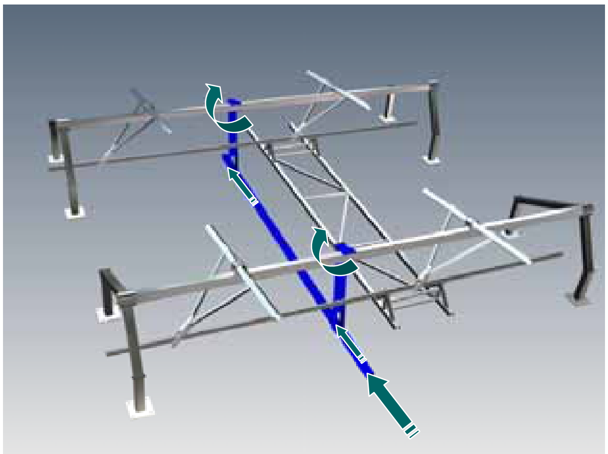


Figure 21. EW ATS flow of forces

4.4.2. NS axis transmission subsystem

The second transmission subsystem is the North-South NS axis transmission subsystem (azimuthal movement/DOF) hereafter called NS ATS. Due to spatial position NS axes depend on EW rotation movement/DOF, the NS ATS depends on EW rotation movement. That implies the NS ATS has two DOF, EW and NS axes movement. In order of transmission from the actuator to the axes, the system is composed of a Warren truss beam linked to all NS rods with hinges. Each EW axis carries a NS rod. Each NS rod is linked to all NS torque arms associated to an EW axis. The NS torque arms are Y-shaped for stabilizing each NS axis and avoiding the interference with the EW axis.

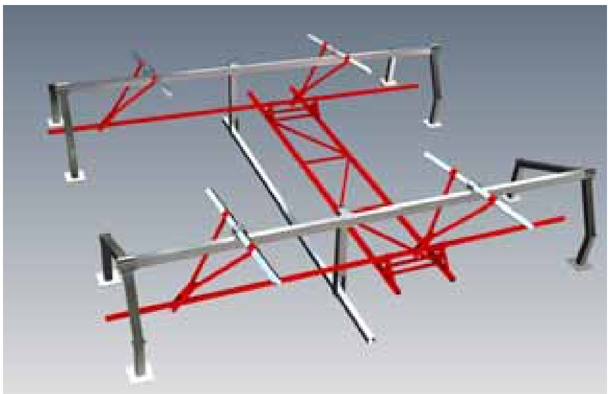


Figure 23. NS transmission subsystem

The kinematic of members in NS ATS for elevation movement is planar: parallel planar rotation of NS torque arms, NS axes and NS rods with EW axes as rotation axes, and circular translation of NS beam.

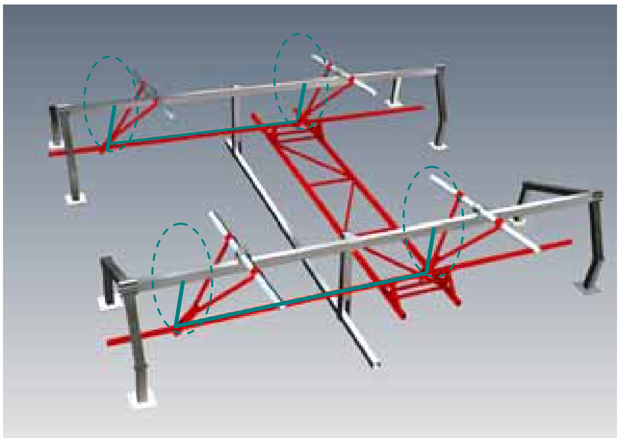


Figure 22. NS ATS kinematics due to EW movement

The kinematic of members in NS ATS for azimuthal movement is planar: circular translation of NS rod and beam, planar rotation of NS torque arms with NS axes as rotation axes and axial rotation of NS axes.

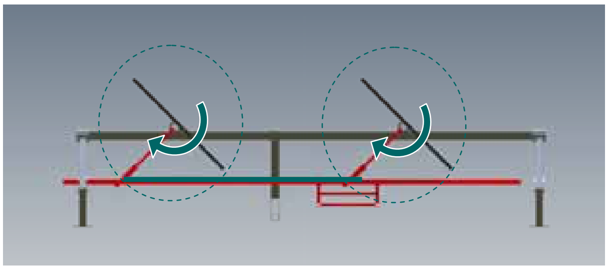


Figure 24. NS ATS kinematics

The flow of forces in NS for azimuthal movement from the actuator to the NS axes is: actuator impulses the NS beam, the NS beam distributes the force from the actuator in each NS rods, the force in each rod is distributed in every NS torque arm, which produces a torque moment in every NS axis.

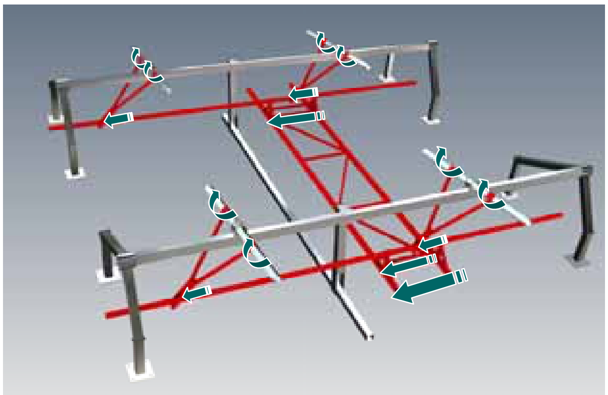


Figure 25. NS ATS flow of forces

4.5. Uncoupled rotation movement/DOFs

The two-axes spatial movement is not independent. However, the DOF are not coupled. As previously mentioned, this uncoupling is a design condition that avoids breakdowns, transmission system overloads or collapses due to non-coordination between actuators, an actuator breakdown or excessive tolerances. That uncoupling also simplifies the electronics (the electronics would coordinate the two actuators for every position).

4.6. Actuators

The movement generators are linear actuators, devices that control the relative position of two points in a line, controlling the length of a piston rod. The actuators have engines with a power of 0.75KW (elevation) and 0.55KW (azimuthal). Therefore, the ratio between generated and consumed energy is higher than double the usual one for two-axes trackers, with benefits in consumption, electronics and maintenance.

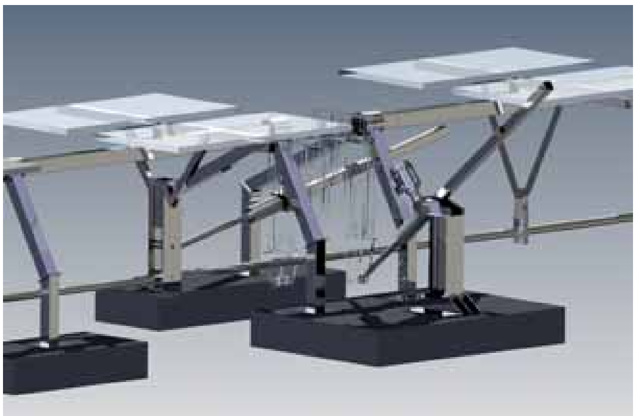


Figure 26. Actuators

5. DIGITAL MODELS

During the engineering detailing phase, we made several numeric and digital models. The numeric models have the objective of checking the structural behavior, mechanical interferences and energy gain (no part of the authors work). We made global and local FEM models as shown below:

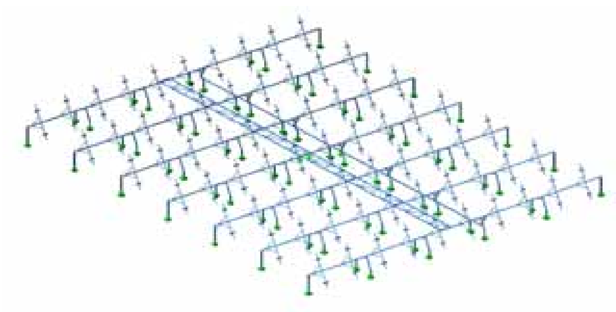


Figure 27. FEM global model

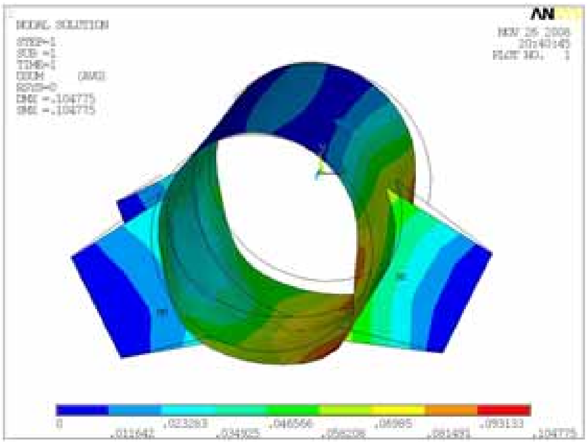


Figure 28. FEM local model

We made digital models of the trackers to check for any mechanical interferences and detailing drawings as shown previously:

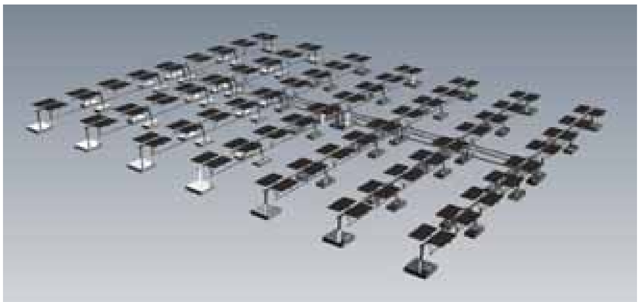


Figure 29. Digital global prototype (Autodesk Inventor™ model)

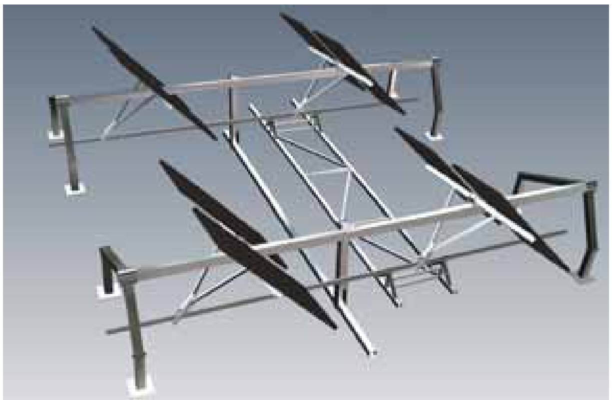
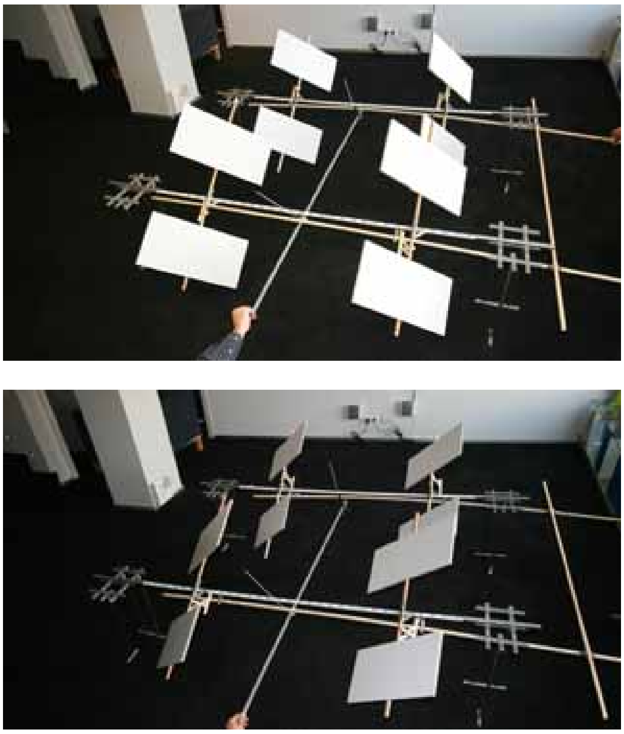


Figure 30. Digital local prototype (Autodesk Inventor™ model)

6. REDUCED MODELS. SCALE MODEL AND PROTOTYPE

In the design process we made a conceptual scale model and a real scale prototype. The conceptual scale model was made in an alternative study and a conceptual design. The scale model was intended for checking the kinematics and main mechanical interferences. The scale model was made to a 1:4 scale and with a 2-EW axis x 2-NS axis x 2 panels. Next, some images of the scale model are shown:



Figures 31 & 32. Scale model.

After the conceptual design, we started the engineering details and component-drawing phase, after that phase the client made a real scale prototype in order to check the real behavior, assembling process, interferences, actuators behavior and electronics. To optimize the actuators the client assembled load cells, anemometer and weather vane. Next, some images of the prototype are shown:

Figures 33 & 34. Prototype

7. CONCLUSIONS

This text briefly presents a clear application of lightweight structures as a small step towards a more sustainable future based on alternative sources of energy. The innovation consists of a two-axes tracker structure formed by a two DOF mechanism that tracks on two-axes a matrix of 7x9x2 photovoltaic panels with only two small linear actuators. The ratios of generated energy per consumed energy and occupied surface per generating surface higher than double the usual ones for two-axes trackers (minimum consumption of energy and occupation of surface) with the same steel consumption. Furthermore, the height of the tracker is similar to that of fixed photovoltaic structures, with obvious benefits such as environmental impact reduction and ease of assembly.

8. ACKNOWLEDGEMENTS

We would like to thank GSF Capital for give as this job, with special thanks to Mr. Francisco Estela. We would like to thank Engineer Mrs. Maria Navarro for his work during the engineering detail phase.

The tracker described in this text is under patent process.

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