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A MECHANISM DESIGN AUTOMATIC FOR A HOSPITAL MOBILE UNIT DEPLOYMENT

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Abstract: A principal challenge in big disasters is the well-timed attention and the help to the victims. Some countries have developed help plans for the civilian population, such as the Plan DN-III-E implemented by the Mexican Secretariat of National Defense. There are different engineering systems designed to carry out help in the place of the disaster. An example is a movable unit that is transported to the place of the disaster to transform it into a small fixed unit to offer first aid. The paper presents an evaluation of the original mobile unit and shows a new proposal of mechanisms that allow the actions necessary to automatic its deployment. The new proposal was developed using dimensional synthesis methods with restricted optimization techniques, obtaining a design that allows reducing the operation time considerably compared to the original design.
Keywords: Mechanical design, Mechanisms, Plan DN-III-E, Dimensional synthesis.

INTRODUCTION

On our planet, there are natural phenomena such as Geological (volcanoes, earthquakes), Hydrometeorological (winter systems, tropical systems), Chemical-Technological phenomena (fires) (Secretaría de la Defensa Nacional, 2019), and man-made disasters, that we still do not have the capacity or knowledge to control them. These disasters are usually accompanied by human losses. Given this situation, the different countries have prevention plans which must be supported or carried out by trained staff. Currently, the Mexican government has a plan to help the civilian population called Plan DN-III-E (Secretaría de la Defensa Nacional, 2019), which is carried out by the Mexican army and air force. The actions performed during this plan are to safeguard the integrity of the people affected directly or indirectly during the incident; as well as prevention and recovery. The response capacity that can be given during a disaster depends, among other things, on the appropriate technological tools that are available. For this reason, several engineering designs have been developed that aim to support these initiatives at key moments.

Among these designs, those that bring to the disaster site what is needed in addition to food, trained personnel, clothing, and other necessities stand out.

Such is the case of the removable bridge, which can be assembled manually in estimated times of 48 to 72 hours at the scene of the sinister. Another example is that of a container that inside and outside carries what is necessary to form a mobile hospital where there is the opportunity to immediately attend to the harmed ones, providing them with at least first aid. These mechanical designs are important; since on many occasions, the hospitals are far from the accident zones or, it is impossible to transport them conventionally. The speed of installation of these systems is of vital importance without losing aspects such as stability, and mechanical resistance.

This article shows the evaluation carried out on the mobile unit previously developed by a company. In addition, it presents a development of a new proposal for the design of the mechanisms that carry out the deployment of the mobile hospital at the scene of the accident. The design, generally, was changed from a hydraulic system to a mechanical system, which allowed to considerably reduce the deployment time of the unit.

ORIGINAL DESIGN: EVALUATION AND ANALYSIS

The procedure to install the mobile unit at the scene of the accident consists of the following steps:

- Transfer: The mobile unit is taken to

the scene of the accident by land.

- Download: The mobile unit is dismounted from the mechanical transportation system and placed in the appropriate place.
- Deployment: The mobile unit is deployed on ceilings and walls to form a hospital-like structure.
- Assembly: The assembly of the entire mobile hospital is carried out to make it usable.

The design evaluation focused mainly on the download and deployment stages, which are described in the following sections.

DOWNLOAD STAGE

Once the place where the mobile unit will be installed is chosen, it is raised using 4 hydraulic pistons, which allows the mechanical transportation system to be removed, each one of the pistons of this system is called a stabilizer. These pistons must be capable of carrying the full weight of the unit for a considerable time until it is stabilized in place. The above is not recommended; since as is known, the pistons are not designed to maintain weights for long periods since their main use is for actuation, in addition, they work with hydraulic hoses that can burst during use.

DEPLOYMENT STAGE

When the mobile unit is in the correct position and location, the wall and floor system are activated. First, the side that needs to be opened (right or left) is chosen, then the ceiling is displayed, followed by the floor, and finally the wall. These same steps are performed for the other side, still folded. Like the stabilizers, the use of roofs and walls is conducted by hydraulic pistons. Fig. 1. shows the sequence of use of one of the sides of the mobile unit.

It was crucial to carry out a kinematic analysis for verifying the mobility (Suh, C. H., & Radcliffe, C. W.,1987) of the system, to determine the velocities and accelerations of the links, which directly influence the dynamic forces (Norton, R. L., 2020) (Given the magnitudes of the masses to be displaced by the mechanism used). A dynamic analysis was accomplished to identify the hydraulic force that must be applied by the actuator to carry out the movements in a given time.

The kinematic and the dynamic analysis were solved in the Wolfram Mathematica Software.

The ceiling and floor panels are heavy components, with a mass of approximately 1000 Kg each, these being the links with the greatest mass in the mechanisms. The opening time of each panel used for the kinematics and dynamics calculations was 60 seconds. The kinematic equations were formulated using matrix methods, particularly rotation matrices, whose advantages for programming are shown in the works of authors such as Suh (Suh, C. H., & Radcliffe, C. W.,1987), McCarthy (McCarthy, J. M., & Soh, G. S., 2011) and Chiang (Chiang, C. H., 2000; Chiang, C. H., 2000). Fig. 2. shows the ceiling and floor mechanisms with their respective links. Meanwhile, in Figs. 3(a)-(b). plots of piston stroke versus roof and floor angle are shown. A maximum displacement of 307 mm is reached, the minimum stroke that the piston must have to rotate the roof panel 90 degrees, Fig. 3(a). Likewise, there is a displacement of 1407 mm of minimum required stroke that the piston must have to rotate the floor panel 90 degrees.

With the position obtained, the velocity and angular acceleration of the floor and ceiling were calculated, which were used to calculate the effect of the inertial forces on the mechanism in question. The analysis of the reactive forces and moments for a static and a dynamic case was carried out by specifying a deployment time of 60 seconds for the roof.

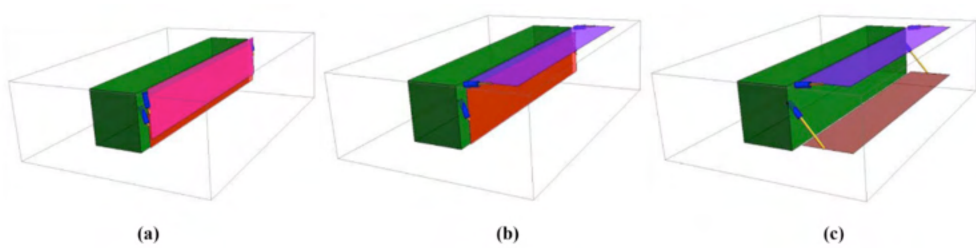

Figure 1. Mobile Unit Deployment Sequence. (a) Closed unit; (b) Unfolded roof; (c) unfolded floor.

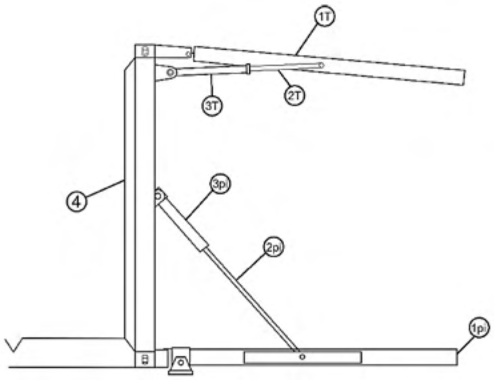

Figure 2. Roof and floor mechanisms for unit mobile.

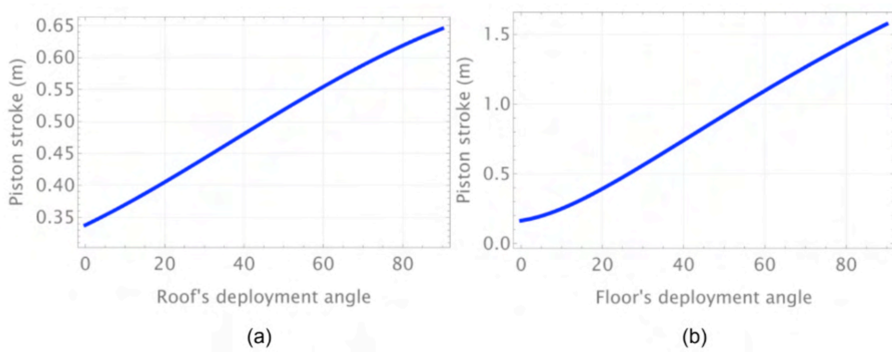

Figure 3. Piston stroke vs Deployment angle. (a) Roof's piston stroke vs roof's deployment angle; (b) Floor's piston stroke vs Floor's deployment angle.

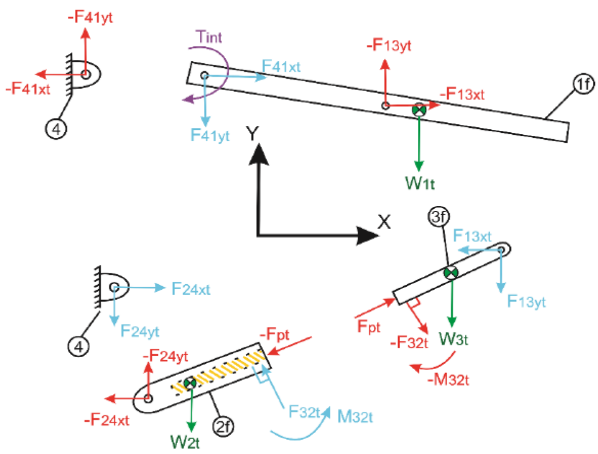

Figure 4. Active and reactive forces on the roof.

In Fig. 4. the active and reactive forces present in the roof mechanism are shown. Fig. 5. presents the force required in the roof piston to maintain static the mechanism and for the dynamic case in which the deployment time is done in 60 seconds.

The calculation report indicated that the maximum action force on the piston for static and dynamic conditions is 2210.18 Kg and 2210.78 Kg, respectively. This result shows that under these opening conditions, the inertial forces do not increase significantly. The magnitude of the reactions for the static and dynamic case is maintained without great separation in the values up to a deployment time of approximately 20 seconds. This is because, with these opening times, very small angular velocities and accelerations are generated in the links of the mechanism, which generates very small inertial forces.

Based on the above, it stands out that the magnitude of the force in each piston is about 2.2 tons, that is, approximately 4.4 tons of force, to lift a 1-ton panel. This force relationship is because the roof rotates due to the perpendicular force component of the piston to the panel. This component, being almost collinear, have a very inefficient force transmission angle which must remain as close as possible to 90 degrees to be optimal (Paul, B., 1979). For this reason, it is necessary for the force on the piston to increase drastically until its component perpendicular to the ceiling is large enough to make it rotate. The aforementioned force is within the capacities of the pistons; however, it produces considerable reaction forces that could damage elements that have not been designed to support said loads or even the structure of the mobile unit.

MECHANISM DESIGN

MECHANISMS

For the new deployment mechanisms, it was proposed to use a 4-bar kinematic chain (rod-crank-rocker). Which changed the principle of operation of the mechanism that previously worked through a linear actuator to a rotary motor that rotates the crank of the 4-bar mechanism.

The main problem was to determine the length of these 4 bars, in such a way that they could carry out the deployment of the mechanism. In addition, it should be inside a reduced space, invading as little as possible the architectural space inside the mobile unit. Matrix methods based on displacement matrices (Suh C.H., & Radcliffe C. W., 1967) were used to define the design equations of the problem, known as a function generator. An objective function was formulated according to the need to optimize the space that the mechanism would occupy, (Suh, C. H., & Radcliffe, C. W., 1987). It allows restricting the ranges of the variables of the coordinates of the nodes of the crank of the mechanism, which was solved by optimization methods with the Wolfram Mathematica FindMinimum (Wagon S., 2010) command. The function generation synthesis (Erdman, A. G., Sandor, G. N., & Kota, S., 2001) allows the creation of a mechanism that satisfies a desired input-output relationship, which is recommended since the crank turn required to completely open the floor and ceiling panel can be specified. The definition of the pivots of the ceiling mechanism is shown below:

$$\boldsymbol{a_0} = (a_{0x}, a_{0y}, 1) \quad (1)$$

$$\boldsymbol{b}_0 = (0,0,1) \quad (2)$$

Followed by the floating nodes in their initial precision positions:

$$\boldsymbol{a}_{1,1} = (a_{1x}, a_{1y}, 1) \quad (3)$$

$$\boldsymbol{b}_{1,1} = \begin{bmatrix} Cos10° & -Sen10° & 0 \\ Sen10° & Cos10° & 0 \\ 0 & 0 & 1 \end{bmatrix} \cdot (1.2,0,1)^T \quad (4)$$

The relative displacement matrices from position 1 to the i-th precision position are

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defined as follows:

$$[\boldsymbol{DR}1i] = [\boldsymbol{D}\phi 1i] \cdot [\boldsymbol{D}\theta 1i] \text{ (5)}$$

Where $[\boldsymbol{D}\phi 1i]$ and $[\boldsymbol{D}\theta 1i]$ are the displacement matrices:

$$[\boldsymbol{D}\phi 1i] = \begin{bmatrix} [\boldsymbol{R}_{-\phi 1i}] & (\boldsymbol{b}_0 - [\boldsymbol{R}_{-\phi 1j}]\boldsymbol{b}_0) \\ 0\ 0 & 1 \end{bmatrix} \text{ (6)}$$

$$[\boldsymbol{D}\theta 1i] = \begin{bmatrix} [\boldsymbol{R}_{\theta 1i}] & (\boldsymbol{a}_0 - [\boldsymbol{R}_{\theta 1j}]\boldsymbol{a}_0) \\ 0\ 0 & 1 \end{bmatrix} \quad \text{(7)}$$

With $[\boldsymbol{R}_{\theta 1i}]$ and $[\boldsymbol{R}_{-\phi 1i}]$ as rotation matrices where, the angles θ_{1i} and ϕ_{1i} are the angles of the i-th position relative to the first precision position:

$$[\boldsymbol{R}_{\theta 1i}] = \begin{bmatrix} Cos\theta_{1i} & -Sen\theta_{1i} & 0 \\ Sen\theta_{1i} & Cos\theta_{1i} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{(8)}$$

$$[\boldsymbol{R}_{\phi 1i}] = \begin{bmatrix} Cos\phi_{1i} & -Sen\phi_{1i} & 0 \\ Sen\phi_{1i} & Cos\phi_{1i} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \text{(9)}$$

Then those of constant length can be considered as follows, for i=2,3:

$$ec_1 = (\boldsymbol{a}_2 - \boldsymbol{b}_1)^T(\boldsymbol{a}_2 - \boldsymbol{b}_1) - (\boldsymbol{a}_1 - \boldsymbol{b}_1)^T(\boldsymbol{a}_1 - \boldsymbol{b}_1) \text{ (10)}$$

$$ec_2 = (\boldsymbol{a}_3 - \boldsymbol{b}_1)^T(\boldsymbol{a}_3 - \boldsymbol{b}_1) - (\boldsymbol{a}_1 - \boldsymbol{b}_1)^T(\boldsymbol{a}_1 - \boldsymbol{b}_1) \text{ (11)}$$

Where:

$$\boldsymbol{a}_2 = [\boldsymbol{DR}12] \cdot \boldsymbol{a}_1 \text{ (12)}$$

$$\boldsymbol{a}_3 = [\boldsymbol{DR}13] \cdot \boldsymbol{a}_1 \text{ (13)}$$

Finally, from Eqs. (10)-(11) the following objective function is formulated with the unknowns a_{0x}, a_{0y}, a_{1x}, a_{1y}, under the restrictions a_{0y}<-0.5, a_{1y}<-0.5, $||\boldsymbol{b}_1-\boldsymbol{a}_1||<1$, this to delimit the space of search for uniquely viable solutions to the available (geometric) space:

$$f = ec_1{}^2 + ec_2{}^2 \text{ (14)}$$

A diagram used for the function generation synthesis of the floor mechanism is shown in Fig. 6. For the ceiling mechanism, the diagram has the same variables. One of the most important considerations was the fact of keeping the roof bracket or pivot in its original position. This is of the utmost importance to guarantee that the dimensions of the container do not exceed those required for its transportation on highways. The mechanism for the floor is identical in terms of dimensions to the mechanism for the ceiling, only changing the way it is assembled concerning the pivot of the floor panel.

Taking into account the observations obtained in the dynamic analysis of the original proposal, carrying out the deployment in a time between 20 and 60 seconds will not generate speeds and accelerations that make the inertial forces significant and increase the reactions. Therefore, only position and static analysis were performed for the synthesized mechanism.

The crack torque required to move the system is of the main importance since it allows the proper selection of a motor that provides the power to perform the task. The torque graph is shown in Fig. 7. To perform the deployment in a time of 60 seconds, the crank must rotate at an average speed of 0.347 rpm. Finally, in Fig. 8. the final dimensions of the synthesized mechanism are shown.

MECHANICAL TRANSMISSION SYSTEM DESIGN

The principal characteristics of the new design are mainly divided into two parts:

1. Stabilization system.

Since the mobile unit must be transported to different locations, it is required a device that can load and unload the unit without the help of external machines, so it was decided to use the same original principle of "stabilizers". For the design of these elements, it was considered that they are outdoor conditions, the weight of the mobile unit and that the transport will be on a low bed type platform. The stabilizers are composed of a power screw that is driven by an AC motor, its nut is fixed to a static part of the stabilizer body. Tubes and seals were used

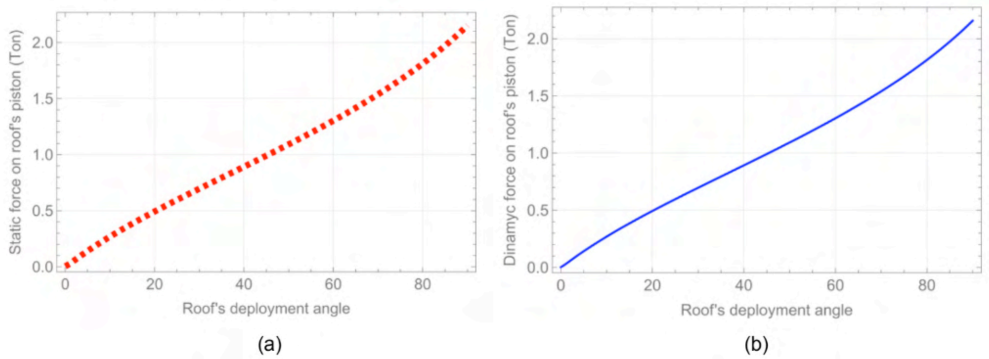


Figure 5. Roof piston forces for deployment in 60 seconds (a) Static force; (b) Dynamic force.

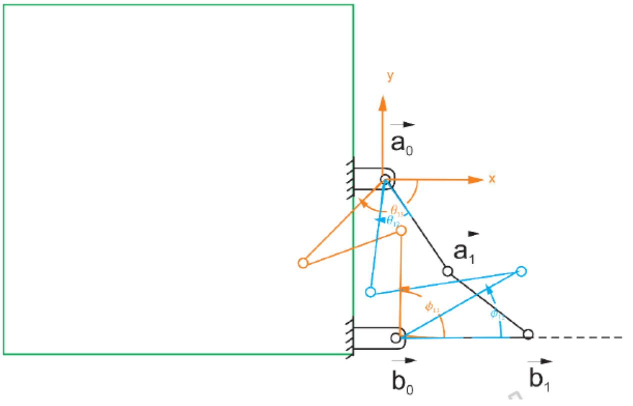


Figure 6. Diagram for floor function generation synthesis.

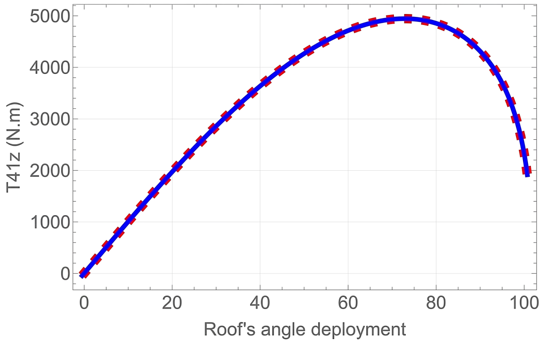


Figure 7. Required torque at the crank to move the system.

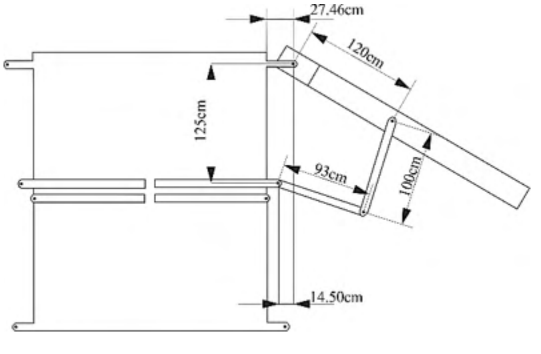


Figure 8. Lengths of synthesized ceiling mechanism.

to cover and protect the power screw due to the conditions in which it will be exposed. In Fig. 9. the stabilizers supporting the container are shown.

2. Mechanical transmission system.

The mechanical transmission system begins with the activation of a single motor located at one end of the mobile unit. The motor has a power of 5 Hp and with it, the unfolding and folding of the panels (Floor and Roof) are carried out. This power element is an AC electric motor since, economically compared to axial piston hydraulic pumps, they are a better option. For the unfolding and folding of the panels, a slow and uniform movement is required, which is why a speed reducer is required.

As mentioned earlier in this design, the floor and ceiling openings are independent. First, both roofs are opened, and then both floors are opened. Because there is only one motor to carry out these actions, a clutch system is necessary. The geared motor has the lowest possible power to optimize energy consumption. Likewise, it is necessary to use shafts and gears for the changes of direction and bearings to hold the shafts. The dimensions of the elements that transmit the power (gears, shafts, pillow block, bearings, shaft keys, etc.), are minimal; as they will be subjected to lower loads. The clutch is activated by an AC motor, in this way the desired panel is selected to transmit the movement by gear trains. In this case, it was decided to use helical gears to easily engage and transmit the movement to the panels, in addition, pillow blocks supporting axial loads were used. In Fig. 10. The proposed clutch system is shown.

In this design, a power transmission system is essential to drive the opening and closing mechanism of the panels. This system must be capable of activating elements at considerable distances, which is achieved by implementing shafts and bevel gears; since changes in the direction of rotation are required. Self-aligning bearings were used to absorb misalignment between the shaft sections throughout the container. For the handling of shafts, the flexion presented by their own weight and the torque to which they are subjected were considered. Therefore, the arrows were sectioned for each of the panels, and hence their operation simultaneously opens both panels, whether they are floors or ceilings.

In Fig. 11., it can be seen how the system is coupled to the mobile unit. Sprockets and chains were used to drive the power transmission system from the clutch system.

The activation of the panel opening and closing mechanisms is through an irreversible worm gear set, which satisfies the need to maintain the panels in a certain position without the help of the geared motor. This device is divided into two parts, one of which is the worm gear that is coupled to the power transmission shaft and the helical gear that is coupled to the panel opening and closing mechanism shown in Fig. 12. Each panel consists of two mechanisms with a worm gear set each; therefore, the loads are distributed, and these elements become slenderer. Considering the above, it can be deduced that when activating the shaft of one of the panels, four worm gear set devices will be activated.

CONCLUSIONS

An evaluation of the stabilization system and deployment stage of a mobile unit was carried out. The main disadvantages presented in the original design are:

- The original system performs the main actions with pistons, which are not recommended for dynamic loads and have high costs.
- The mechanisms have a poor design, due to their inappropriate distribution, which generates very high reactions in

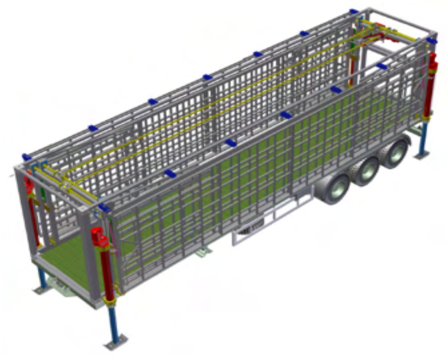


Figure 9. Mobile unit with stabilizers.

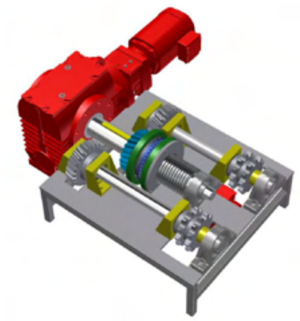
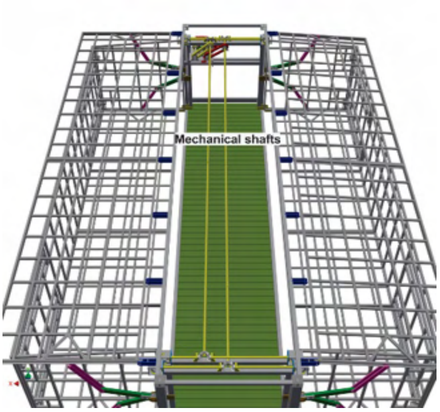


Figure 10. Clutch for roof and floor panels.



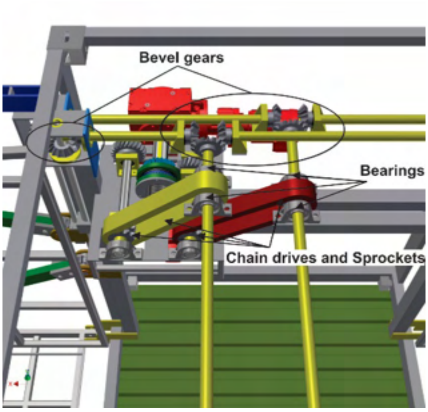


Figure 11. Power transmission system and transmission essentials components.

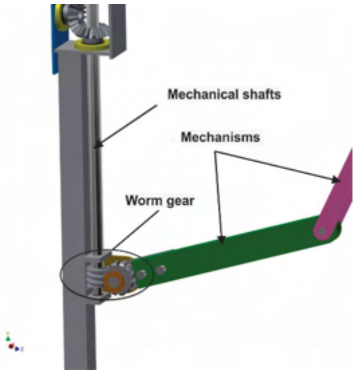


Figure 12. Worm gear set.

the structure.

The piston system was completely changed to mechanical transmission systems. The details of the new design are:

- The movement of the stabilizers will be carried out with a 3 Hp motor in each of them. The movement from top to bottom is through a worm gear set.
- The opening of floors and ceilings will be carried out using a single 5 Hp motor where its movement is transmitted employing mechanical elements such as shafts, gear trains, etc.
- For the opening of floors and ceilings, there is a clutch and disengage system that is activated by a ¼ Hp motor.
- Due to the inefficiency of the original mechanisms, new ones were designed to operate the floors and ceilings. These mechanisms are 4 bar mechanisms that will now be driven by rotary motors, and the 2 ceilings are deployed at the same time as each floor.
- It is estimated that the approximate opening time is between 20 and 60 seconds for both ceilings and both floors.

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