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Application of the Working Model for Simulating Folding Linkages

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ABSTRACT: This study analysis the using of Working Model software to create detailed models and simulate the operation of a folding linkage developed by Tenfold company. By assign precise the connection and dimensions of component frames, the software enables accurate calculations of movement and reaction on joints, as well as cylinder thrust force. The results from the report indicate that the useful of Working Model software in construct complex model of 2D linkages, not only reduces computation time but also offers comprehensive support throughout the design and manufacturing process.

KEYWORDS: Folding linkages, simulation, Working Model, cylinder, force analysis.

I. INTRODUCTION

Folding mechanisms are mechanical devices that enable the efficient folding or unfolding for a space-saving manner. These mechanisms comprise interconnected components that facilitate controlled motion, making them relevant in a range of fields, including aerospace, architecture, civil engineering and even space exploration. The nature of folding mechanisms offers adaptability, portability, and efficiency in scenarios where mobility, rapid deployment, or the creation of temporary infrastructure is essential [1, 2].

There are several types of folding linkages with different configuration and motion pattern [3, 4]. These linkages utilize hinges, pivots to facilitate smooth and controlled folding motions. Some of common folding mechanisms include parallel linkages, scissor linkages and pantograph linkages, which are particularly used for structures like umbrellas, shelters, bridges, or deployable antennas that can be rapidly assembled and disassembled as needed [5, 6, 7]. The design of such structures necessitates meticulous consideration of factors including structural robustness, stability, functionality, and longevity. Consequently, researchers and engineers persist in exploring novel designs and applications, pushing the boundaries of what can be accomplished with foldable mechanisms.

Tenfold Engineering is a specialized company that provide services in structural engineering and architectural design. They offer expertise across commercial, industrial, and institutional projects. Committed to delivering innovative and efficient solutions, Tenfold Engineering supplies a range of services, including detailed structural analysis, precise design and calculations, thorough feasibility studies, and valuable construction support [8].

This paper analysis a particular expanding structure developed by Tenfold Engineering, which utilizes hydraulic cylinders for its operation. By studying the mechanism's motion, the kinematic characteristics of each link can be determined based on fundamental principles of machine and mechanism theories. The Working Model software is employed to calculate the reactions on revolution joints, aiding in the design process and assisting in the selection of components for manufacturing. The findings of this study indicate the practicality of using these simple linkages in the design and construction of complex systems for various practical applications.

II. STRUCTURAL ANALYSIS

Figure 1 provides a configuration of the system's, which is comprised of nine links. When the cylinder (AP) serves as the driving link, responsible for extending or retracting to modify the overall shape of the mechanism, intermediate links (AD, BC, CF, DE, PC, and DN) and the output link (EF) are connected by revolute joints. It's imperative to emphasize that the dimensions of each pair of interconnected components within the system must adhere to the principle of axial symmetry to ensure the desired movement of the output link EF. This means that AB should equal EF, AD should match DE, BC should correspond to CF, and CM should be equivalent to CN.

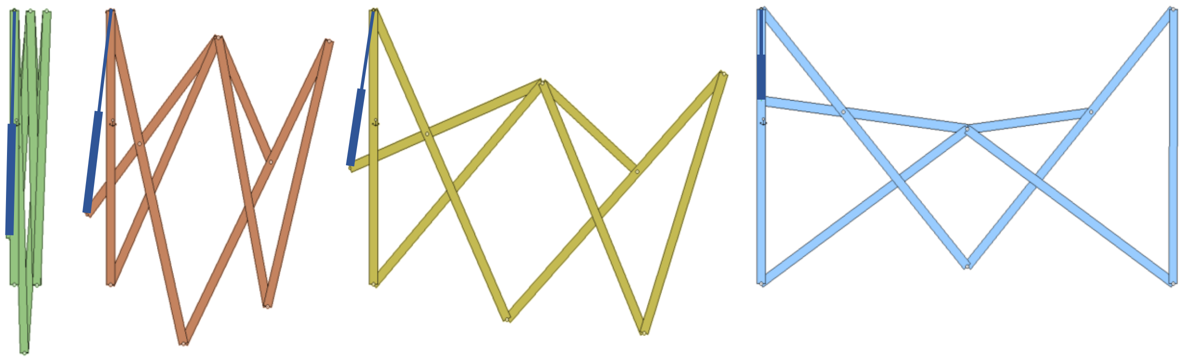

Figure 2. Structure of the proposed device, with displacement positions of the device.

To analysis the operational of the system, a specific set of dimensions, as illustrated in Figure 3, is proposed for the kinematic evaluation.

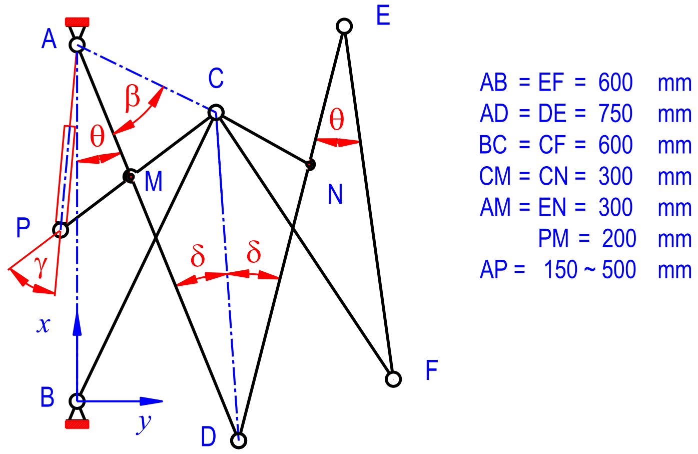

Figure 3. Kinematic diagram of the structure

Based on the system's working characteristics, the process of determining the kinematic positions of the components in the mechanism can be outlined as follows:

- from triangular AMP:

$$\gamma = \arccos\left(\frac{\mathrm{AM}^2 + \mathrm{MP}^2 - \mathrm{AP}^2}{2 \cdot \mathrm{AM} \cdot \mathrm{MP}}\right) \quad (1)$$

Then

$$\mathrm{AC} = \sqrt{\mathrm{AP}^2 + \mathrm{CP}^2 - 2 \cdot \mathrm{AP} \cdot \mathrm{CP} \cdot \cos\gamma} \quad (2)$$

And

$$\beta = \arccos\left(\frac{\mathrm{AM}^2 + \mathrm{AC}^2 - \mathrm{MC}^2}{2.\mathrm{AC}.\mathrm{AM}}\right) \quad (3)$$

Then

$$CD = \sqrt{\mathrm{AC}^2 + \mathrm{AD}^2 - 2\,\mathrm{AC}.\mathrm{AD}.\cos\beta_2} \quad (4)$$

We can draw angle between frames:

$$\theta = \arccos\left(\frac{\mathrm{AB}^2 + \mathrm{AC}^2 - \mathrm{BC}^2}{2.\mathrm{AB}.\mathrm{AC}}\right) - \beta \quad (5)$$

And

$$\delta = \arcsin\left(\frac{\mathrm{AC}.\sin\beta}{\mathrm{CD}}\right) \quad (6)$$

Due to the axial symmetry of the structure, the positions of F can be determined using equations:

$$\overrightarrow{\mathrm{BE}} = \overrightarrow{\mathrm{BA}} + \overrightarrow{\mathrm{AD}} + \overrightarrow{\mathrm{DE}} + \overrightarrow{\mathrm{EF}} = \mathrm{BA}.e^{j\frac{\pi}{2}} + \mathrm{AD}.e^{j\left(\theta - \frac{\pi}{2}\right)} + \mathrm{DE}.e^{j\left(\frac{\pi}{2} + \theta - 2\delta\right)} + \mathrm{EF}.e^{-j\left(\frac{\pi}{2} + 2\delta - 2\theta\right)} \quad (6)$$

$$\begin{cases} x_F = \mathrm{BA}.\cos\frac{\pi}{2} + \mathrm{AD}.\cos\left(\theta - \frac{\pi}{2}\right) + \mathrm{DE}.\cos\left(\frac{\pi}{2} + \theta - 2\delta\right) + \mathrm{EF}.\cos\left(2\theta - 2\delta - \frac{\pi}{2}\right) \\ y_F = \mathrm{BA}.\sin\frac{\pi}{2} + \mathrm{AD}.\sin\left(\theta - \frac{\pi}{2}\right) + \mathrm{DE}.\sin\left(\frac{\pi}{2} + \theta - 2\delta\right) + \mathrm{EF}.\sin\left(2\theta - 2\delta - \frac{\pi}{2}\right) \end{cases} \quad (6)$$

The result of this calculation returns the movement of point F and the angular position of the pole EF, as present in Figure 4.

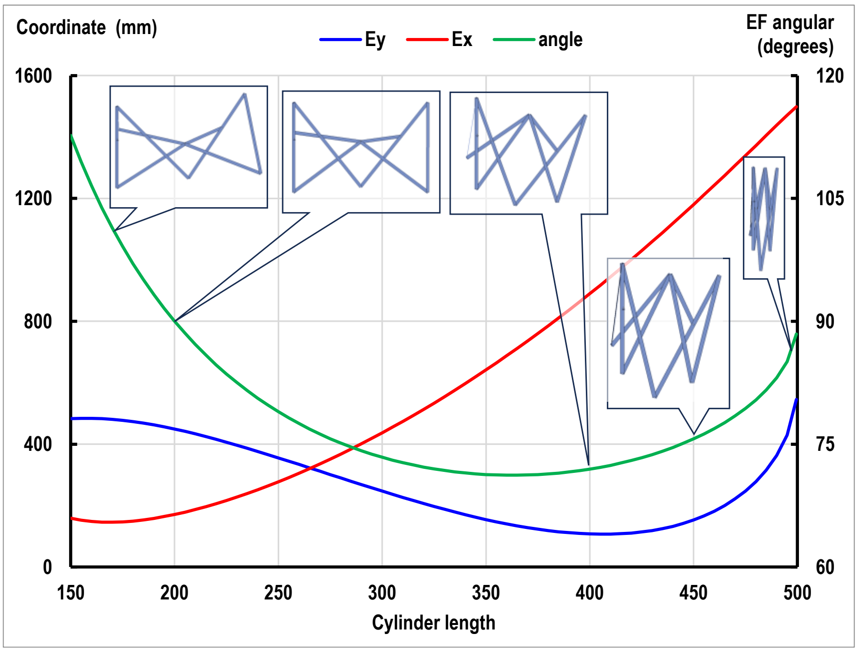

Figure 4. Position of the structure corresponding to the displacement of the cylinder.

III. CONSTRUCT THE MODEL IN WORKING MODEL & DETERMINE THE FORCE AT THE JOINTS

3.1 Construct model in Working Model

The utilization of Working Model software has significantly improved the analysis and simulation of mechanical systems, revolutionizing the practices of engineers and designers. By precisely constructing 2D models of mechanical systems and simulating their operations, this software offers an extensive array of capabilities. These include motion analysis, force and torque calculations, stress analysis, and collision detection. The software also provides advanced features for visualizing and analyzing simulation data, such as graphs, charts, and value measurements. This empowers engineers to thoroughly test and optimize their designs, identify potential issues, and make well-informed decisions prior to the physical manufacturing stage. The integration of Working Model software into the design process enhances efficiency and accuracy, ultimately resulting in improved outcomes and reduced costs.

The procedure to construct a specific model of Folding linkages can be described as follows:

Step 1: Use the Rectangle button to create the frames and base for the structure. The Rectangle is specifically designed for constructing objects with rectangular shapes. During this step, designers have the ability to define the parameters of the arms, including dimensions, weight, and mechanical coefficients, by adjusting the Properties window. To prevent any displacement of the links throughout the simulation, the Anchor option is assigned to the base link. This designation is represented by a black anchor symbol, as illustrated in Figure 1.

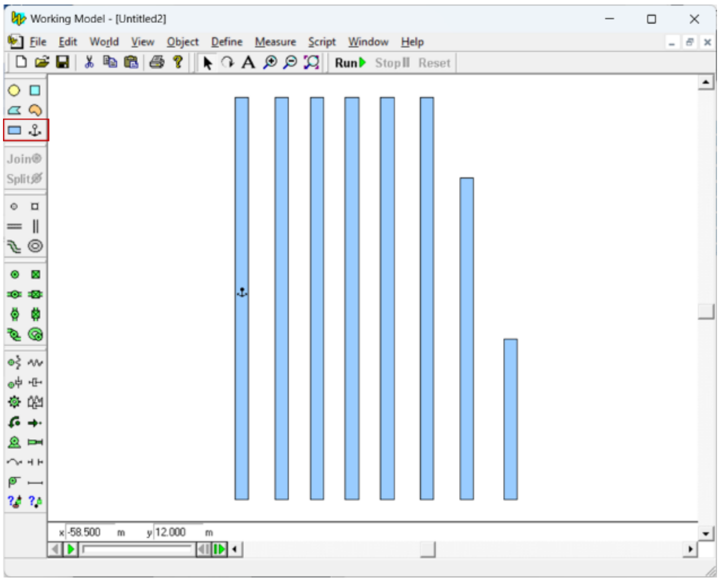

Figure 2. Create rigid links for the system

Step 2: Assigning joints to the rigid bars within the system. Joints are established by incorporating "joints" elements using the Join command. It is important to note that the base is fixed and each platform possess two to three pin joints and.

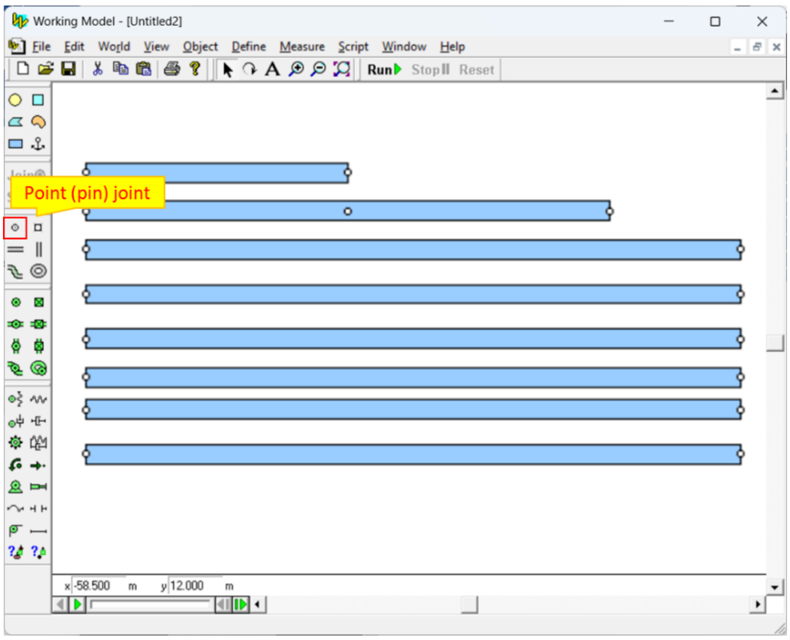

Figure 2. Addingjoints for the rigid links

Step 3: Joining the links (select two different joints from the links and click the Join button). The outcome of this operation is the formation of the complete shape of the structure (excluding the cylinder), as illustrated in Figure 3.

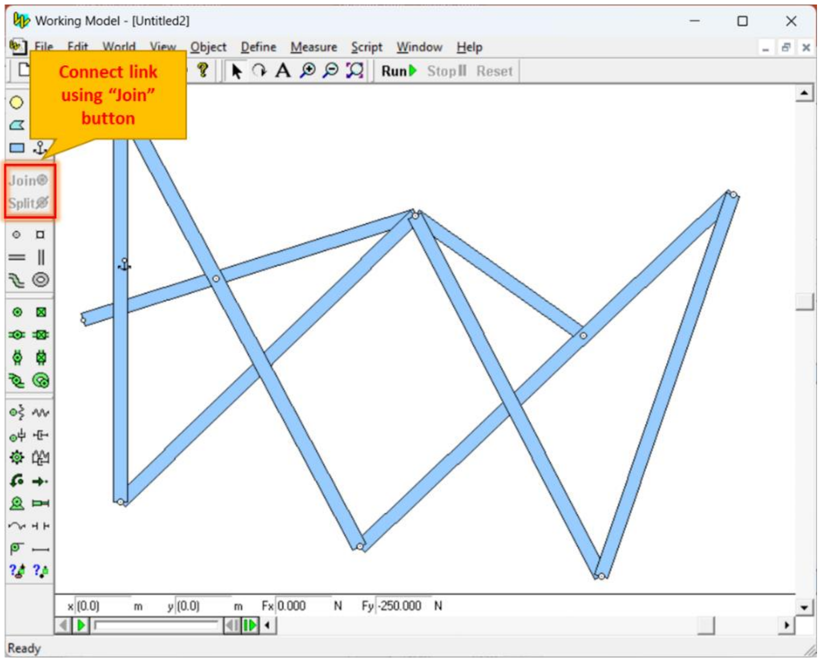

Figure 3. Configuration of the lift

Step 4: Adding cylinder. To incorporate the cylinder, which functions as a rigid bar with a adjustable length, designers can select the "rope," "rod," or "separator" elements from the software. These elements represent the cylinder's characteristics without contributing to the weight of the system. Pin joints are created on each arm before connecting to the "cylinder". This can be achieved by using the "Join" button, as depicted in Figure 4.

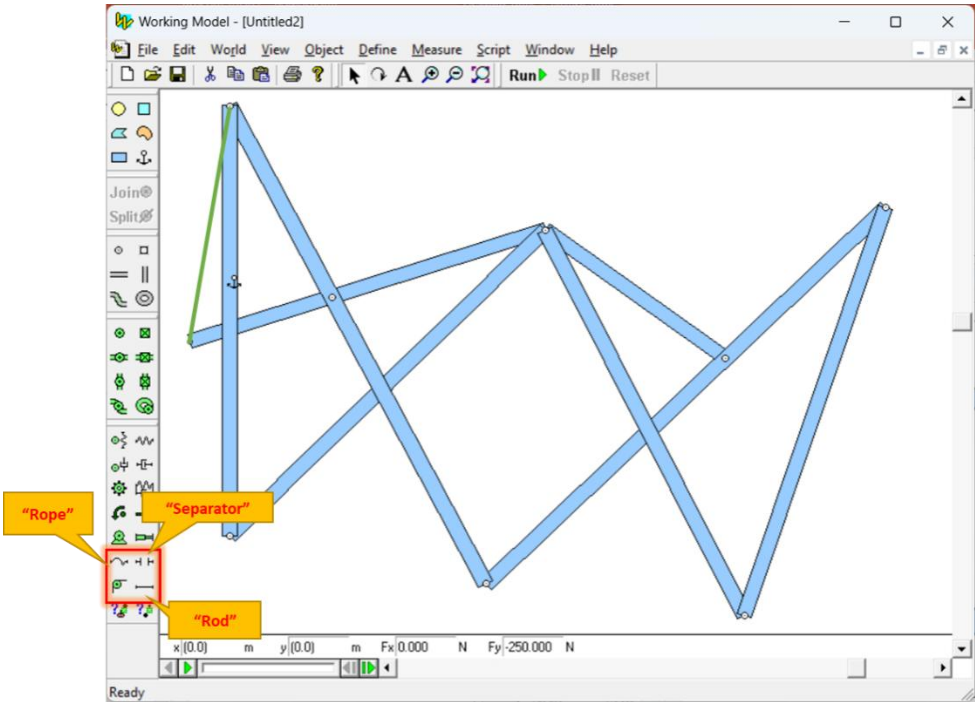

Figure 4. Using rod button to create cylinder

The placement of pin joints plays a crucial role in determining the geometry and orientation of the cylinder in scissor lifts. Engineers and designers have the flexibility to experiment with different configurations based on specific requirements and desired functionality. This allows for customization and optimization of the scissor lift design to meet application needs such as lifting height, stability, and load capacity.

3.2 Determine the Force at the Joints

Force is a fundamental concept used to simulate and analyze mechanical devices, specified by its magnitude, direction, and application point. By applying forces to various components, users can observe how the system responds and analyze its resulting motion, stress, and other mechanical behaviors. Working Model offers the capability to calculate and display the forces acting on different parts of the model during simulation. These forces can be visualized using vectors, diagrams, or numerical values, allowing users to understand the distribution and magnitude of forces within the mechanism. In the case of, the main forces include the load, scissor arms, and the weight of the platform. These forces can be assigned by adding mass to the links or using the Force button to input the forces, as demonstrated in Figure 5.

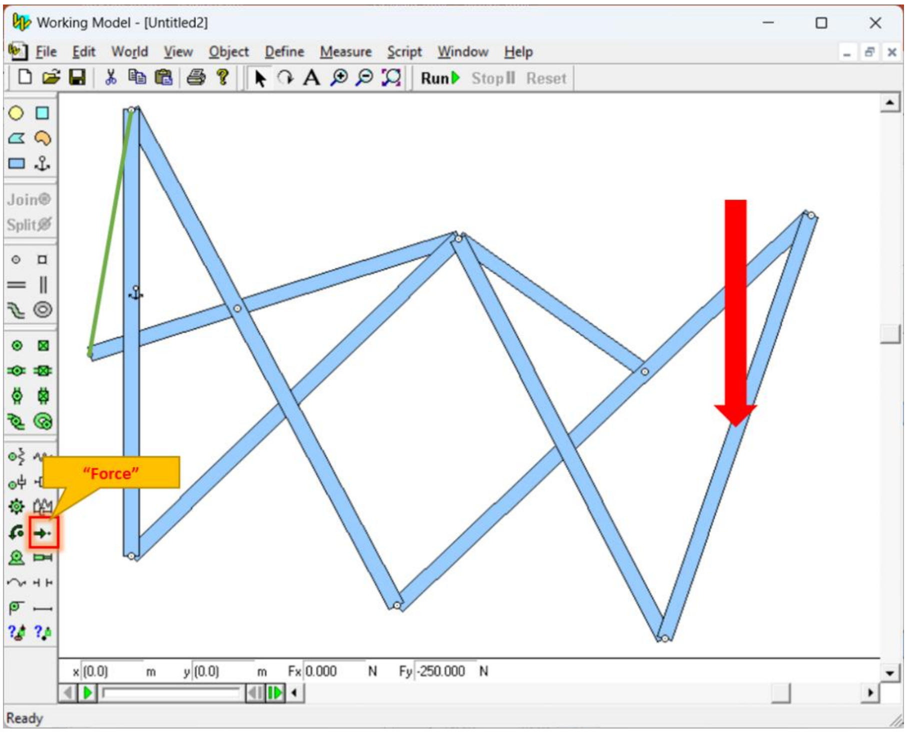

Figure 5. Using Force/Moment button to add external force to the system

After checking the linkage to ensure every input information, designer Run the simulation to check the force in cylinder (tension of rope/rod element) and reactions at joints (see Figure 6).

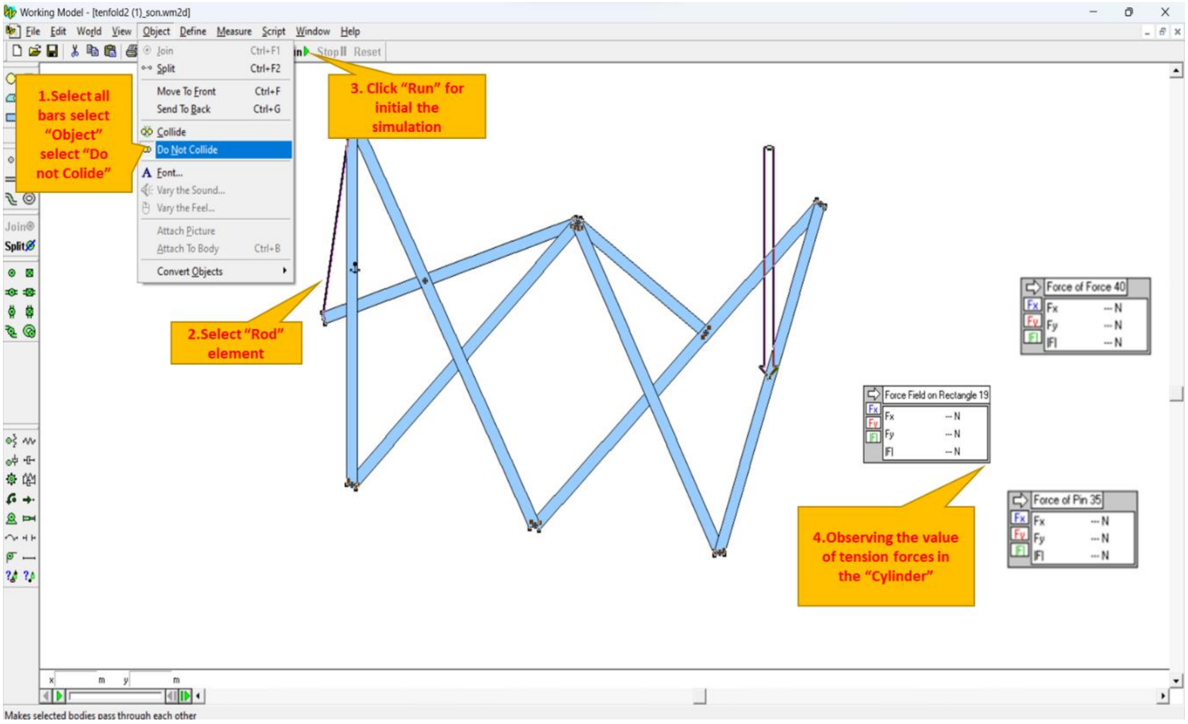

Figure 6. Extract thrush force in the cylinder

The resultant forces in the whole system can be visualized by enabling display options within the software, as illustrated in Figure 7. Depending on the weight of the bar, the larger the angle of the force vector and the rod

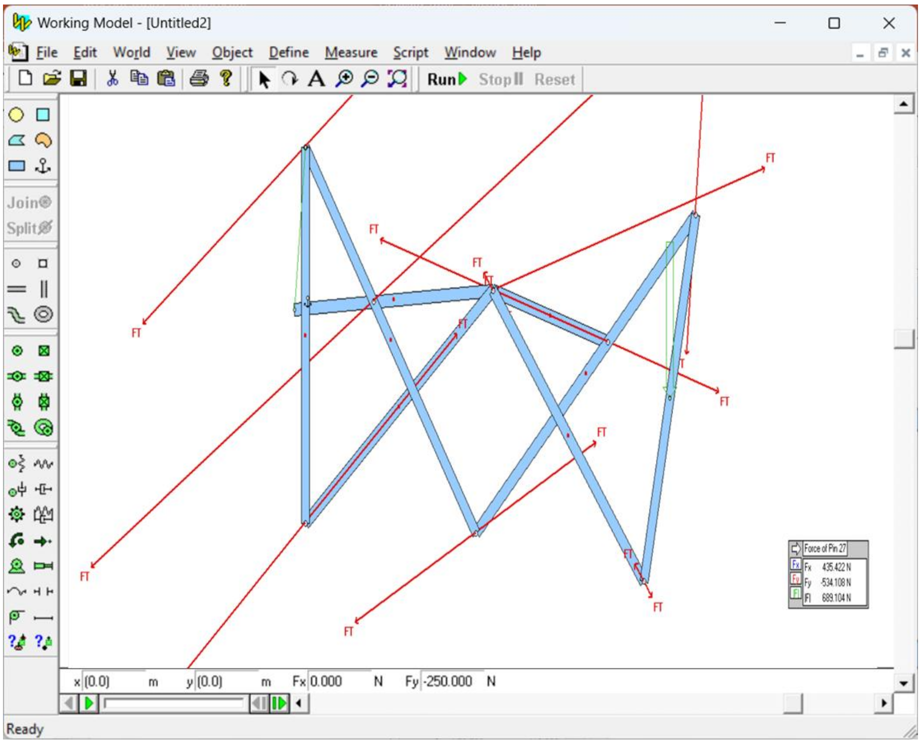

Figure 7a. Display force in the system (insignificant weight).

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In the case of gravity the bars are negligible, the forces acting on the bars are mostly forces in the same direction as the bar as shown in Figure 7a, but when the bars have gravity the forces will create an angle with the bar depending on the bar's gravity. like Figure 7b.

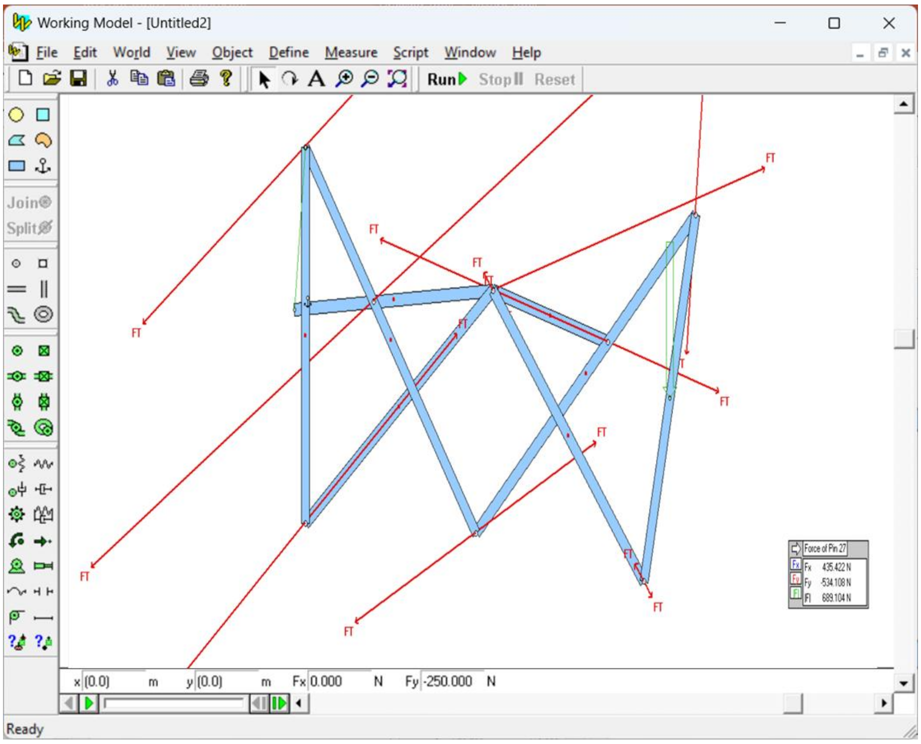

Figure 7b. Display force in the system (has weight).

IV. CONCLUSION

This study introduces a solution for positioning a special folding mechanism used in commercial systems. By solving specific mathematical equations, the position of each component in the mechanism can be accurately determined, supporting the determining of velocity and acceleration of the system. Based on the proposed design, a 2D model was constructed using the Working Model software, allowing for precise determination of the loads at joints and providing the requirements load for the cylinder. It serves as the basis for optimizing the detail dimensions and selecting the equipment for manufacturing the device.

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