

Research Article

# Design Automation of a Two Scissors Lift

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## Abstract

*In this study, the design of a two scissors greenhouse lift trolley is considered. The maximum height of the platform from the ground is 3500 mm. A program developed in Visual BASIC to automate the design is introduced. The lift is modeled in SolidWorks (SW) and the finite element (FE) modal and static analyses are performed as an initial design first by using graphical user interface (GUI). The lift contains revolute joints and slider joints. A simply supported beam which has two revolute joints and a slider joint is studied to verify how to model the joints. Pim connectors are defined for revolute joints in SW-FE analysis. Spring connectors with very large values are defined between sliding faces in the normal direction for translational joints. The results obtained with solid finite elements in SW are compared with analytical results for the natural frequency and static analyses and it was observed that the results are in good agreement for the simply supported beam.*

*An Excel file where a main sheet contains the list of the bodies and all the geometric values is created after the initial design. The Excel file also contains sheets for each body. Body sheets have all the dimensions in the sketches and features. The dimension values in the cells of the body sheets are defined by formulas related to the geometric values given in the main sheet. Kinematic, kinetic, and revision of the SW model are performed by the design automation program. The FE analyses are done by GUI and the results are evaluated. If the results are not satisfactory, the geometric values are changed in Excel file and the analyses are repeated. The final design is obtained by the iteration easily. The automation program and the procedure developed in this work can be extended other scissors lifts.*

**Keywords:** Scissors lift, design automation, finite element analysis

## 1. Introduction

Scissor lifts are widely used to raise and lower goods or persons in many areas of industry. There are lifts with different technical specifications with lifting weight, height, and platform sizes. They are used in greenhouses as lift trolleys for cultivation processes. Dengiz et al. [1] designed a two scissors lift with a carrying capacity of 500 kg and lifting height of 2000 mm. They used SolidWorks program and made static analysis. Dang et al. [2] studied a one scissor lift and performed kinematic and kinetic analyses and used a numerical method to determine optimal dimensions. They compared their results with the results obtained by Working Model simulation. Islam et al. [3] used bond graph modeling for the dynamic analysis using the software 20-sim. Hongyu and Ziyi [4] use Pro/E software to design and simulate a three scissors lift having a 500 kg load capacity and lifting height of 8 m. Ciupan et al. [5] developed a program in Mathcad to design and optimize scissor lifts. The program calculates the number of scissors and joint forces depending on the size of the platform and the maximum lifting height. Ismael et al. [6] gave a procedure to design a scissor lift actuated by motor via a ball-screw for a required maximum height. Manoharrao and Jamgekar [7] analyzed a one scissor lift making static, fatigue and modal analysis in ANSYS software. Rashid et al. [8] designed a one scissor lift for commercial aircraft ground support using SolidWorks software and checked safety requirement standards. Cui et al. [9] proposed an Automatic Guided Vehicle with scissor lifting mechanism for medicine storage rooms. They tested their design goals by producing a prototype and compared expected and experimental data. Momin et al. [10] used ANSYS to make static analysis for the design of a two scissors lift. Arunkumar et al. [11] investigated a water driven scissor lift using Autodesk Fusion 360°. Shi et al. [12] used static analysis data obtained in ANSYS Workbench software to evaluate the reliability of scissor lifting structures with different design criteria by using BP neural network. Rani et al. [13] designed and produced a two scissors lift with lifting height of 1.5 m and load of 1.5 tons using CATIA V5 design software and COMSOL finite element analysis software. Dong et al. [14] investigate the dynamic stability of scissor lifts by simulation and experiment. They observed that the fundamental natural frequencies are in the range of 0.30-2.08 Hz in general.

In this work, a two scissors lift is considered which can be used in greenhouse lift trolleys. The maximum height of the lift including the trolley height is 3500 mm and the load capacity is 250 kg. A procedure to automate the design of two scissors lifts is used. The procedure was successfully used to design scrap metal balers [15] in a previous study. The study was improved and extended by including kinematic and kinetic analyses for the lift. A program was developed in Visual BASIC environment by using Excel and SolidWorks interfacing.

## 2. Materials and Methods

Scissors lifts contain revolute and slider joints. A simply supported beam which has analytical solutions is considered to verify defining joints in SolidWorks-Simulation.

### 2.1. Modal and static analysis of a simply supported beam

The SolidWorks (SW) model of the simply supported beam studied is shown in Fig.1.

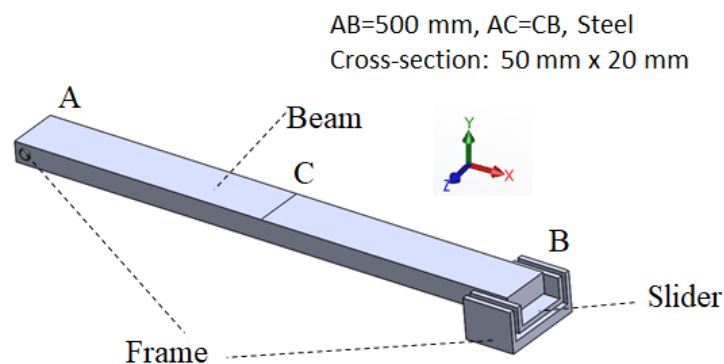


Fig. 1 SW model of simply supported beam

The bodies of the system are the frame, the beam and the slider. There are no contacts between the bodies. The frame is fixed. There are revolute joints between the frame and the beam at A, and between the beam and the slider at B. There is a slider joint between the slider and the frame at B. Pim connectors are defined between the bodies for the revolute joints and spring connectors are defined between the sliding faces of bodies normal to the faces. A large value of normal stiffness as  $10^{20}$  (N/m)/m<sup>2</sup> is assigned. The SW simulation is run for frequency and static analysis. A force with a value of 1000 N in the -y direction is applied on the line at C in the static analysis. The analytical results obtained by the Bernoulli-Euler beam theory and the SW simulation results obtained using solid finite elements are shown in Table 1.  $f_1$  is the first natural frequency,  $S_x$  is the normal stress, and  $u_y$  is the displacement in the -y direction. The formulation for the analytical results are well known and can be found in the literature [15, 16].

*Table 1 Analytical and SW simulation results*

|                            | Analytical | SW Simulation |
|----------------------------|------------|---------------|
| $f_i$ (Hz)                 | 182.52     | 182.05        |
| $S_x$ at bottom at C (MPa) | 187.5      | 185.3         |
| $u_y$ at bottom at C (mm)  | 1.95       | 1.96          |

It is observed that the analytical and SW simulation results are in good agreement.

## 2.2 Flow chart of design automation process

The flow chart of the design automation process is shown in Fig. 2. An initial model of the system is created in SW by graphical user interface (GUI). The model is shown in Fig. 3. The bodies of the system are bottom chassis, inner and outer scissors, cylinder frame, piston rod, platform with load. The names of the SW files are given in the parentheses. There are revolute joints and slider joints between bodies. The joints are modeled as described in Section 2.1 in SW Simulation. Then, an Excel file is created where the list of the bodies and all the geometrical values in the system is defined in a main sheet. The main sheet is given in Table 2.

*Table 2 Main-Excel sheet*

| A        | B                                                   | C       |
|----------|-----------------------------------------------------|---------|
| frame    | $n_{sc}$ : Number of scissors                       | 2.00    |
| lifti    | $h_{pmax}$ : Maximum height of platform (mm)        | 3500.00 |
| lifto    | $h_{veh}$ : Height of trolley (mm)                  | 286.10  |
| wheels   | $\theta_{max}$ : Maximum scissor angle (deg)        | 57.50   |
| frame_up | $m$ : Mass of load (kg)                             | 250.00  |
| plateso  | $w_{pl}$ : Width of platform (mm)                   | 420.00  |
| platesi  | $b_{prf}$ : Width of profile (mm)                   | 30.00   |
| cyl_frm  | $h_{prf}$ : Height of profile (mm)                  | 60.00   |
| cyl_rod  | $t_{prf}$ : Thickness of profile (mm)               | 3.80    |
| load     | $h_{frm}$ : Height of chassis (mm)                  | 320.95  |
|          | $t_{plate}$ : Thickness of plate (mm)               | 10.00   |
|          | $D_{out}$ : Outer diameter of cylinder (mm)         | 60.00   |
|          | $D_{in}$ : Inner diameter of cylinder (mm)          | 50.00   |
|          | $D_{prod}$ : Diameter of piston rod (mm)            | 25.00   |
|          | $x_L$ : Load location (mm)                          | 1000.00 |
|          | $L_{AQ}$ : Location of joint of cylinder frame (mm) | 1040.00 |
|          | $L_{CP}$ : Location of joint of piston rod (mm)     | 96.00   |

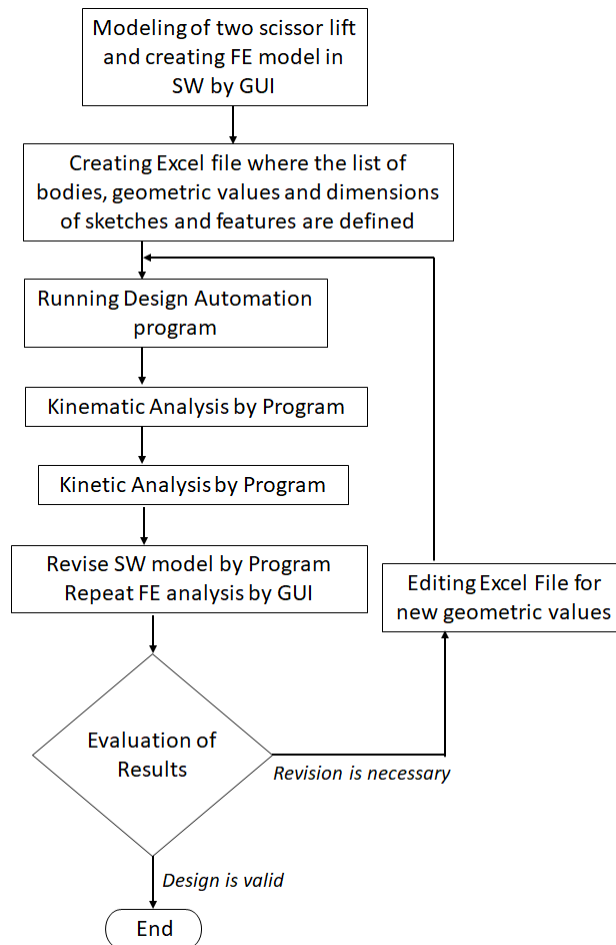


Fig. 2 Flow chart of design automation process

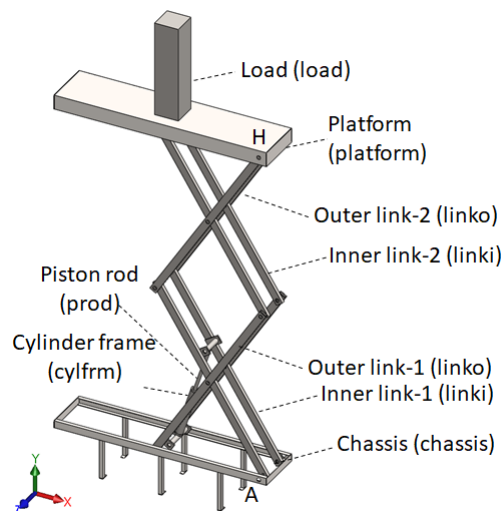


Fig.3 SW model of system

Excel file also contains sheets for each body. The dimensions of sketches and features are given in the body sheets. The SW model of the platform and its history tree are shown in Fig.4.

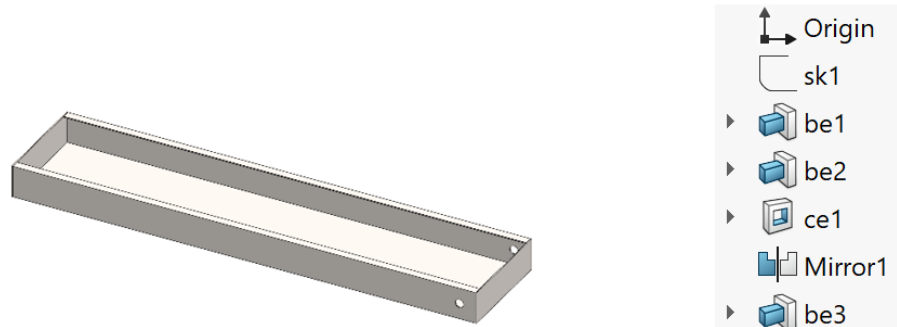


Fig. 4 SW model of platform (platform.SLDPRT) and its history tree

Excel sheet for the platform is given in Table 3.

Table 3 Platform-Excel sheet

| A  | B      | C       |
|----|--------|---------|
| D2 | sk1    | 1650.60 |
| D3 | sk1    | 62.00   |
| D1 | sk1    | 210.00  |
| D2 | sk-be1 | 30.00   |
| D1 | sk-be1 | 120.00  |
| D3 | sk-be1 | 3.80    |
| D1 | sk-ce1 | 32.00   |

For example, the data “D1, sk1,210” stands for the dimension named as D1 in the sketch named as “sk1” given the value of 210.00 mm. The value is determined by the formula “=!mainC6”. The value of “!mainC6” is 420 in Excel sheet-main in Table 2. The data “D3, sk-be1,3.80” stands for the dimension named as D3 in the sketch of named as “sk-be1” of the feature Boss-Extrude named as “be1 given the value of 3.80 mm. The value is determined by the formula “=!mainC9”. The value of “!mainC9” is 3.80 in Main-Excel sheet in Table 2.

### 2.3 Design automation program (DAP)

The design automation program (DAP) is run after developing the initial design and obtaining the initial simulation results in SW by GUI; and creating the Excel file. The main window of DAP is shown in Fig. 5. The program has been developed in Visual BASIC which uses “Application Programming Interface” (API) commands of SW and Excel.

## BLM- TWO SCISSORS LIFT DESIGN AUTOMATION

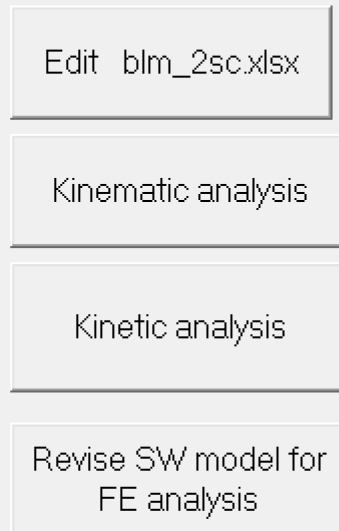


Fig.5 Main window of Design Automation Program

### 2.3.1 Kinematic Analysis

The vector loop for the kinematic analysis is given in Fig. 6. The values found by the kinematic analysis given below are for the initial design values in Table 2. They change as the design values change.

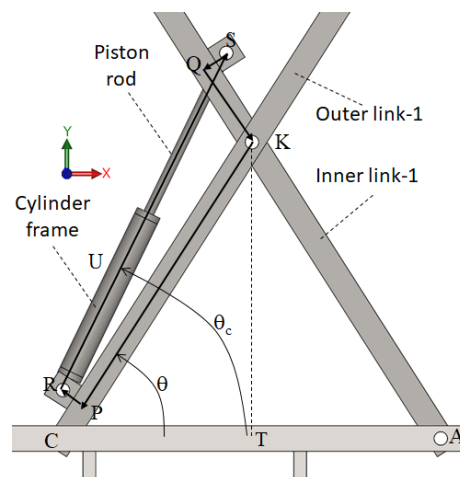


Fig. 6 Vector loop for kinematic analysis

$\sin(\theta) = (h_{AH}/n_{sc}/2)/L_{AK}$ , where  $L_{AK}$  is the distance between the points A and K.  $h_{AH}$  is the distance between the points A and H, where H is the point at the revolute joint in the platform.  $h_{AH}$  depends on the height of the platform.  $\theta$  is the scissor angle, which has a maximum value of 57.5 deg.  $h_{AH}$  can be calculated for  $\theta = \theta_{max}$ , and it is found as 2799.15 mm for the initial design values given in Table 2. The minimum value of  $h_{AH}$  is found as 274.15 mm. The initial design values for  $L_{CP}$  and  $L_{AQ}$  are 96 mm and 1040 mm, respectively. The vector loop equation can be written by complex numbers as

$$-L_{KP}e^{i\theta} + L_{PR}e^{i(\theta+\pi/2)} + r_{RS}e^{i\theta_c} + L_{SQ}e^{i(-\theta-\pi/2)} - L_{QK}e^{-i\theta} = 0 \quad (1)$$

Here,  $L_{KP} = (1659.50/2 - 96)$  mm,  $L_{PR} = L_{SQ} = 62$  mm,  $L_{QK} = (1040 - 1659.50/2)$  mm are constant values for the initial design. For a given value of  $\theta$ ,  $r_{RS}$  and  $\theta_c$  are found from Eq.1.  $r_{RS}$  is  $h_{AH}$  dependent distance between the points R and S. The real and imaginary parts of Eq.1 gives 2 equations, which are a non-linear set of algebraic equation. They can be solved by Newton-Raphson iteration [17]. The error equations for the Newton-Raphson iteration are given below.

$$\begin{bmatrix} \frac{\partial f_1}{\partial r_{RS}} & \frac{\partial f_1}{\partial \theta_c} \\ \frac{\partial f_2}{\partial r_{RS}} & \frac{\partial f_2}{\partial \theta_c} \end{bmatrix} \begin{Bmatrix} \epsilon_1 \\ \epsilon_2 \end{Bmatrix} = \begin{Bmatrix} -f_1 \\ -f_2 \end{Bmatrix} \quad \begin{aligned} A_{11} &= \frac{\partial f_1}{\partial r_{RS}} = \cos(\theta_c) & A_{12} &= \frac{\partial f_1}{\partial \theta_c} = -r_{RS} \sin(\theta_c) \\ A_{21} &= \frac{\partial f_2}{\partial r_{RS}} = \sin(\theta_c) & A_{22} &= \frac{\partial f_2}{\partial \theta_c} = r_{RS} \cos(\theta_c) \end{aligned} \quad (2)$$

Here  $f_1$ , and  $f_2$  are the real and imaginary parts of Eq.1, respectively. The difference between the maximum and minimum values of  $r_{RS}$  give the stroke of the cylinder, S. The stroke is found as 356.03 mm for the initial design. The flow rate, Q, of the hydraulic system is calculated by  $Q = (\pi R_i^2 S / t_L)$  where  $t_L$  is the lifting time from the minimum height to the maximum height of the platform,  $R_i = D_{in}/2$ . The lifting time can be determined considering 0.15 m/s lifting velocity. The kinematic analyses are performed by DAP and the results are saved to a text file.

### 2.3.2 Kinetic Analysis

The free body diagrams of the bodies are shown in Fig. 7. The action-reaction law of mechanics [16] is applied for the joint forces. The application of the equilibrium equations gives 14 equations for 14 unknowns.

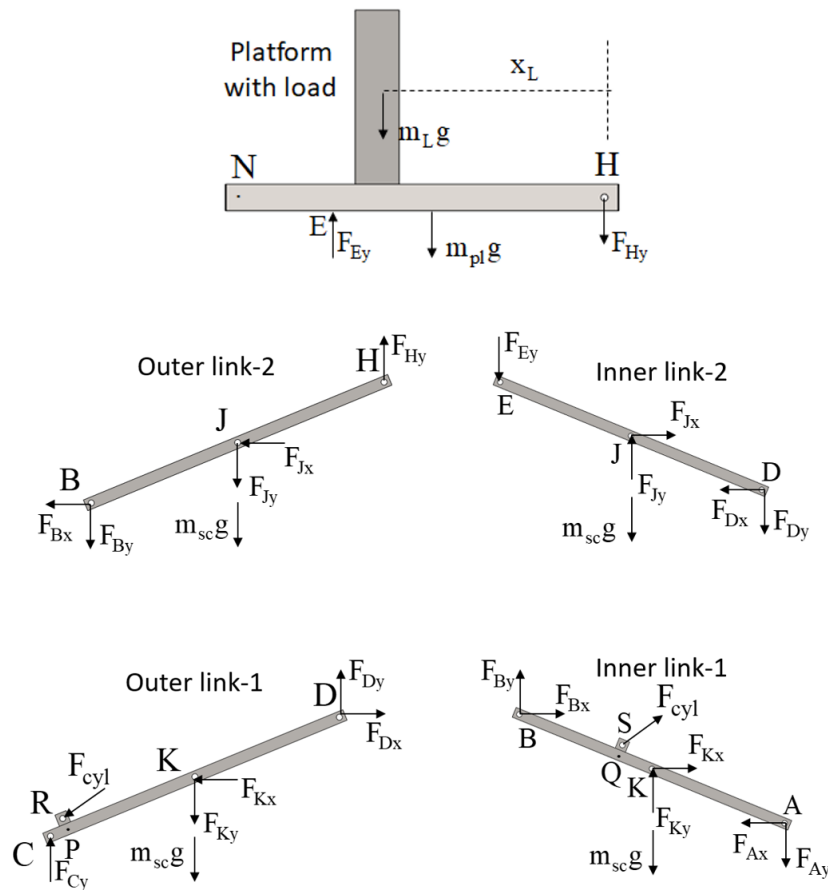


Fig.7 Free body diagrams of bodies

The equilibrium equations are a set of linear algebraic equations which can be written as  $[A]\{F\}=\{B\}$ . Here  $[A]$  is a  $14 \times 14$  square matrix,  $\{F\}$  is a  $14 \times 1$  column matrix of unknown forces,  $\{B\}$  is a  $14 \times 1$  column matrix. Here,

$$\{F\}=[F_{cyl}, F_{Ax}, F_{Ay}, F_{Bx}, F_{By}, F_{Kx}, F_{Ky}, F_{Cy}, F_{Dx}, F_{Dy}, F_{Ey}, F_{Jx}, F_{Jy}, F_{Hy}]^T$$

The unknown forces can be found by  $\{F\}=[A]^{-1}\{B\}$ . The derivation of the equilibrium equations and the solutions are well known in the literature [17]. The kinetic analyses are performed by DAP and the results are saved to a text file. The oil pressure in the cylinder can be found by  $P=F_{cyl}/(\pi R_i^2)$ . The cylinder pressure was found as 97.5 bar for  $h_{AH}=2799.15$  mm.

### 2.3.2 Modal Analysis by SW-Simulation

The first and second natural frequencies in lifts are in the range of 0.3-2 Hz and they are important to evaluate the rigidity and dynamic stability [14]. There is no need to make any changes in the FE model after defining the revolute and slider joints as described in Section 2.1. The bottom faces of the chassis are fixed in the initial design. The “run” command is given by GUI only, in the iteration process after making changes in the dimension values and read the results. The mode shapes and natural frequencies for the first three modes are given in Fig. 8.

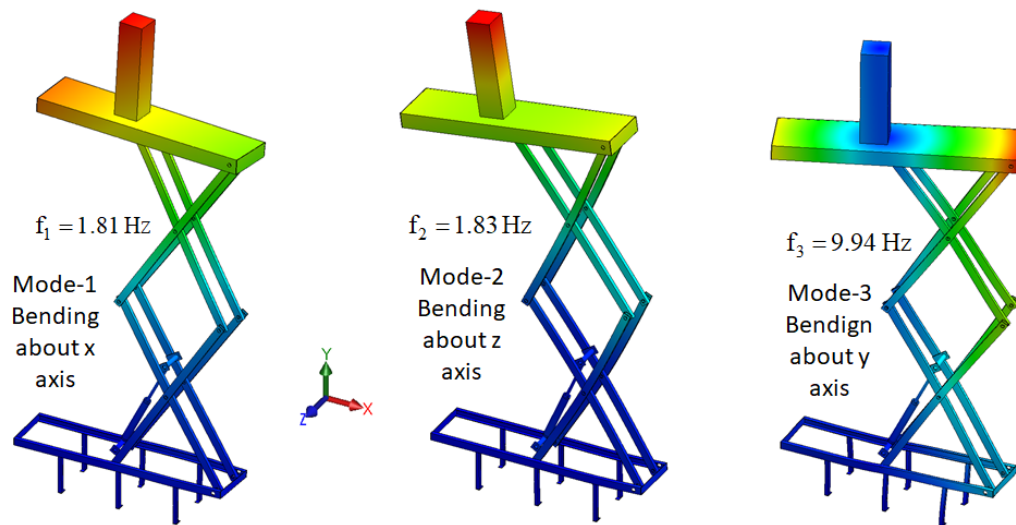
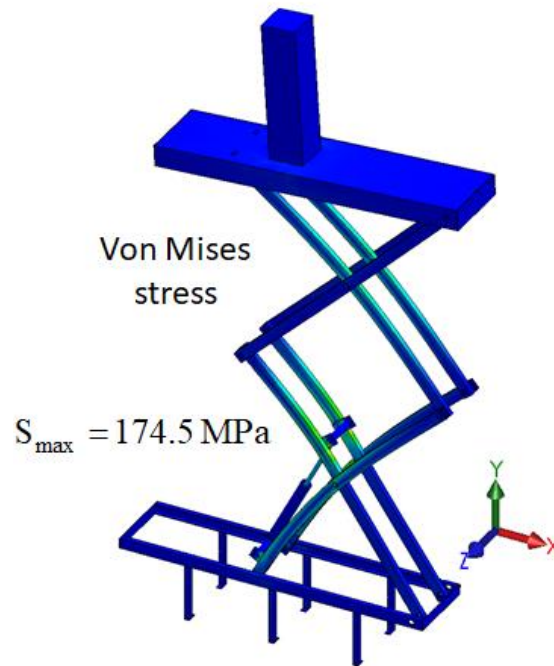


Fig.8 Mode shapes and natural frequencies for the initial design and  $h_{AH}=2799.15$  mm.

It is observed that the first 2 natural frequencies are important in using the lift. Mainly the second mode is excited when the operator moves in the x direction and when the lift starts or stops. Mainly the first mode is excited when the operator performs cultivation job in the greenhouse in the z direction. The third mode has higher natural frequency and can be not considered.

### 2.3.3 Static Analysis by SW-Simulation

The connectors defined for the frequency analysis can be copied and pasted to the static analysis in the initial design. The bottom faces of the chassis are fixed. The gravity in the -y direction is defined in the static analysis. The “run” command is given by GUI only, in the iteration process after making changes in the dimension values and read the results. The static analysis result is given in Fig.9.  $S_{max}$  is the maximum von Mises stress



*Fig.9 Static analysis result for the initial design and  $h_{AH}=2799.15$  mm.*

### 3. Results and Discussions

The main design criteria of a lift are the extended platform height, lifting time and load. An iterative procedure is given in this study for two scissors lifts. A design automation program (DAP) is introduced. The initial design developed in SolidWorks (SW) and SW-Simulation, and the Excel file can be used to design two scissors lifts with different criteria. The Excel file contains the geometrical values for all the bodies. The lift height and the location of the load changes. DAP calculates the hydraulic oil pressure and joint forces. The first two natural frequencies and maximum von Mises stress are found by using “run” command in SW-simulation only for the frequency and static analyses, respectively. The results are evaluated and the geometrical values in the Excel file are changed only if the outputs are not satisfactory and the iterative design process is continued by using DAP.

The procedure is applied to design a greenhouse lift trolley having the extended platform height as 3500 mm, and lifting velocity 0.15 m/s, and 250 kg of load. The initial design values given in Table 2 are used. The results are given in Table 4.

Table 4 Analysis results for the initial design values in Table 2

|                   | $h_{AH}$ (mm) |        |         |         |         |
|-------------------|---------------|--------|---------|---------|---------|
|                   | 274.15        | 905.40 | 1536.65 | 2167.90 | 2799.15 |
| P (bar)           | 245.4         | 137.8  | 108.1   | 97.4    | 97.5    |
| $F_{cyl}$ (N)     | 48178         | 27054  | 21222   | 19123   | 19147   |
| $F_{rev-max}$ (N) | 16989         | 2951   | 447     | 599     | 1173    |
| $f_1$ (Hz)        | 3.53          | 2.50   | 2.08    | 1.89    | 1.81    |
| $f_2$ (Hz)        | 3.95          | 3.30   | 2.75    | 2.28    | 1.83    |
| $S_{max}$ (MPa)   | 350           | 221    | 207     | 213     | 181     |

It is observed from Table 4 that as the lift elevates oil pressure, joint forces, natural frequencies, and von Mises stresses decrease. Maximum von Mises stress is evaluated for the strength of the lift. The joint forces are evaluated to select bushings.  $S_{max}$  is high (350 MPa) for  $h_{AH}=274.15$  mm. The location of  $S_{max}$  is examined in SW plot and the thickness of the plates ( $t_{plate}$ ) in Excel sheet-main is increased from 10 mm to 20 mm, and the analysis is repeated and  $S_{max}$  is found as 275.8 MPa. P is high (245.4 bar) for  $h_{AH}=274.15$  mm. The outer diameter and inner diameter of the cylinder is increased from 60 mm to 70 mm, and from 50 mm to 60 mm, respectively. P is found as 170.4 bar.

#### 4. Conclusion

In this study, a design automation program (DAP) for two scissors lifts has been developed in Visual BASIC (VB). VB uses the application programming interfacing (API) command of Excel and SolidWorks (SW). An analysis model of a two scissors lift is created in SW and revolute joints are defined by pim connectors and slider joints are defined by spring connectors in SW-Simulation. An Excel file where the dimension values of the bodies are defined. The dimension values are edited in in Excel file and DAP performs kinematic and kinetic analyses and revises the model in SW automatically. The results are evaluated and the dimension values are changed and a satisfactory design is obtained by iteration easily. The procedure has been used to design a two scissors lift trolley which has the extended platform height of 3500 mm.

The SW model and DAP can be used to develop two scissors lifts with different technical specifications. The stud can be extended to lifts with different scissor numbers, and different mechanical systems

#### 5. Acknowledge

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