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Design and Analysis of Hydraulic Scissor Lift Using PTC CREO Simulate

Puneet Channi[1*], Jay Prakash Tripathi[2]
[1,2]*Department of Mechanical Engineering, Thapar University, Patiala, India*

***Abstract*: This paper is mainly focused on calculation of the forces acting on the different joints of the Hydraulic Lift when it is extended and contracted. Generally, a hydraulic scissor lift is used for lifting and holding heavy weights or heavy components. The design is carried out by considering Hydraulic lift as portable, compact and suitable for mild load types. Drafting and drawing of the hydraulic scissor lift is carried out using PTC CREO for modelling of the parts and the final assembly and then model is imported to the inbuilt simulation software of the PTC CREO i.e. CREO Simulate for meshing and static analysis. Von Mises Stress and Maximum Displacement were given the emphasis and all other responsible parameters were analyzed to check the compatibility of the design values.**

***Keywords*: Creo Simulate 6.0, Hydraulic scissor lift, Pantograph, Von Mises Stress.**

1. Introduction

Lifting systems are generally used for purposes of lifting a load or providing at unreachable heights. Nowadays, many lifting systems are designed to be used for various purposes in industry. These systems can be used in multi-purpose applications and a range of services such as cleaning services, maintenance-repair activities, load lifting and lowering activities. Airports and indoor stadium are examples of these.

Scissor lift are generally preferred because of its ease of use, cost effectiveness as compared to the other heavy duty lifts available in the market. It's compactability is also one of the reason why Scissor lifts are preferred over others. The frame is very sturdy & strong enough with increase in structural integrity. A multiple height scissor lift is made up of two or more leg sets. These types of lifts are used to achieve high travel with relatively short platform.

The model to be designed will be Maintenance-Repair work and Construction work. Keeping in mind the usage parameters such as Lifting Height, Load carrying Capacity and the outer dimensions will be finalized and using them further analysis of parts will take place.

A. Types of Lifts

Classification based on the type of energy used

- Hydraulic lifts
- Pneumatic lifts
- Mechanical lifts

Classification based on their usage

- Scissor lifts
- Fork lifts
- Vehicle lifts

2. Mechanism

The basic motion required by a scissor arm is movement in Vertical direction using criss cross X pattern Scissor arm. The upward motion of the machine is achieved by applying the pressure between the different ends of scissor arms by any actuating mechanism which help provide the required vertical displacement.

The basic mechanism used in the Scissor lift is inspired by *Pantograph Mechanism.* A pantograph mechanism is a linkage based on the arrangement in which parallelograms are attached in a way in which one-point trace the path of another point in a scale defined by the length of the sides of the parallelogram. Because of the shape of the original device, a pantograph also refers to a kind of structure that can compress or extend like an accordion, forming a characteristic rhomboidal pattern.

The actuating force for the mechanism will be provided by a Double Acting Hydraulic Cylinder.

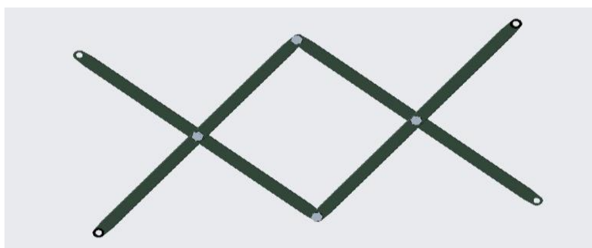

Fig. 1. Pantograph

The reason for selection of the following mechanism are it's ease of designing, any height can be achieved with the help of this mechanism just addition of scissor arm pair is required to change the lifting height.

Selecting pantograph as a basis mechanism dynamics of the system also varies with the position of the hydraulic cylinder. Hydraulic cylinder acts as the actuating force for the model and it's positon will vary all the FBD and also the reaction on the different joints.

*Corresponding author: pchanni_be17@thapar.edu

There can be three different positions of the Hydraulic Cylinder:

- Attached horizontally at the base.
- Attached at an angle with the base
- Attached vertically to the end of scissor arms

Position 1 has few perks like center of mass will shift a little bit downwards as the cylinder will be placed at the base but this type of configuration will be useful and helpful in small scissor lift having single Scissor arm pair on either side, as lifts having more number of scissor arm pairs will need a support also between them.

Position 2 is the most commonly used position in medium scale scissor lifts as it will distribute the force of the hydraulic cylinder on different scissor arm not on a single arm. Moreover, it is attached between different scissor arm pairs using a support arm which will also provide support to scissor arm pairs.

Position 3 is in which hydraulic cylinder are attached to the ends of the scissor arms and in vertical position. Main disadvantage of this configuration is that we need to use hydraulic cylinder in pairs as to balance the bending moment acting due to the cylinders to avoid the toppling of the system.

So Position i.e., Hydraulic cylinder attached to the horizontal with an angle is selected for the benefits among the all.

3. Specifications

The Specifications selected for the Model are:

1. Maximum Lifting height = 2000 mm.
2. Maximum Loading capacity = 500 kg.
3. Maximum Scissor Arm angle with Horizontal = 45 degree
4. Minimum Scissor Arm angle with Horizontal = 5 degree

4. Major Components

The major components are listed below and all the components are modelled using PTC CREO 5.0.

1) *Scissor Arms:* In Hydraulic Scissor Lift, scissor arms plays the most important role as it helps achieve the variable height requirement, This is the only part which moves up and down on requirement and bears the load on the Top Platform of the Lift.

Fig. 2. Scissor arm

2) *Top Platform:* The top platform in the scissor lift gives the frame and the surface to accommodate the load. It is required to design a platform which can serve under high loads.
3) *Double Acting Hydraulic Cylinder:* It provides the required force to lift the Scissor lift. The selection of the hydraulic cylinder is based upon the required working pressure and the maximum force to lift.

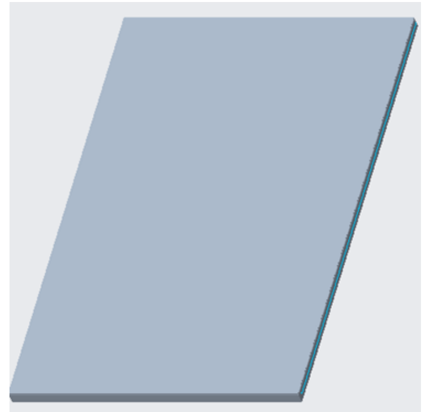

Fig. 3. Top platform

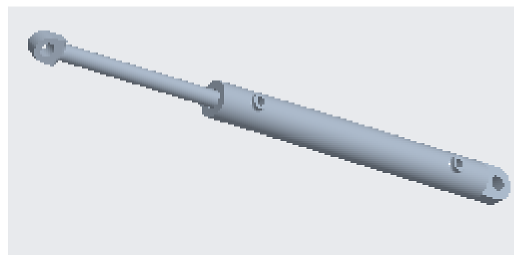

Fig. 4. Double acting hydraulic cylinder

All the above major components with some other minor components are assembled in the PTC CREO 5.0 using the mechanical constraints available.

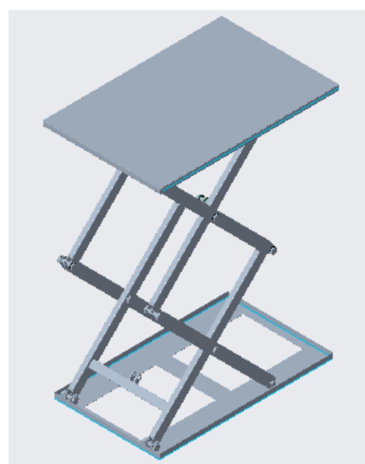

Fig. 5. Assembled model

5. Analytical Analysis

In this section we will concentrate on the calculation on forces acting on different parts of the scissor lift and further calculation of the stresses is done using simulation software.

1) *Top Platform:* For the calculation purpose total weight on the Top platform is divided into 2 parts, for each side of Scissor arm. Also the weight is considered to be a UDL load acting on the platform.

Max Loading Capacity = 500 kg
Max Weight on either side = 250 kg

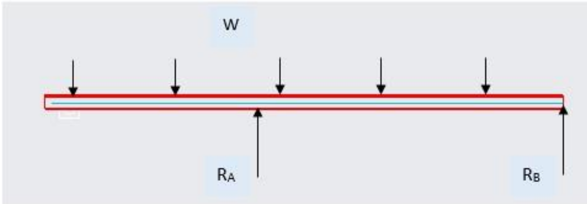

Fig. 6. FBD of top platform

$W = (250*9.81)/1400$
$W = 1.75$ N/mm
$\sum F_y = 0$
$R_A + R_B = 2500$ N
$\sum M_B = 0$
$R_A (990) = 1.75*(1400/2)^2$
$R_A = 1732.32$ N
$R_B = 767.68$ N

2) *Scissor Arms:* There are total of 2 pairs of scissor arms used in the model for the required height i.e. there are total of 4 scissor arms used, so every link will have different forces acting on every link.

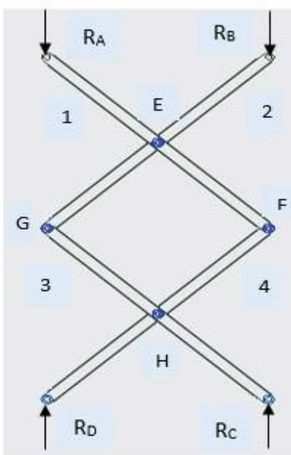

Fig. 7. FBD of scissor arm assembly

From the symmetry of the FBD it is clearly visible that
$R_A = R_D$
$R_B = R_C$

FBD of Link 1:

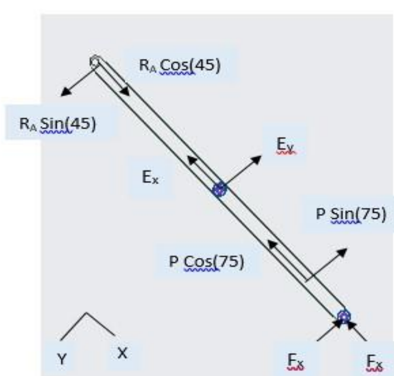

Fig. 8. FBD of Link 1

Force analysis of the Scissor Arm is done at the highest position of the Platform (α = 45 deg) Here,

Hydraulic Piston Force = P = 5250 N (at α = 45 deg)
Reaction Force at joint E = E
Reaction Force at joint F = F
$\sum F_y = 0$

$F_y + E_y + PSin(75) = R_A Sin(45)$
$F_y + E_y + 5071 = 1224$
$F_y + E_y = -3847$ N (1)

$\sum F_x = 0$

$F_x + E_x + Pcos(75) = R_A cos(45)$
$F_y + E_y + 1358 = 1224$
$F_y + E_y = -134.1$ N (2)

$\sum M_F = 0$
$E_y *(0.7) + P sin(75)*(0.16) = R_A cos(45)*(1.4)$ (3)

Using the Equation 1, 2, 3 and the relation $E_y = E_x = E/1.414$

$E_y = E_x = 1225$ N
$F_x = -1257$ N
$F_y = -5070$ N

Resultant $F = (F_x^2 + F_y^2)^{1/2} = 5249$ N (Magnitude)

FBD of Link 2

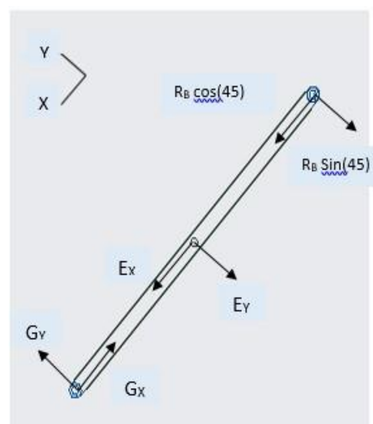

Fig. 9. FBD of Link 2

$\sum F_y = 0$
$G_Y = E_y + R_B cos(45)$
$G_Y = E_y + 544.5$ $(R_B = 770$ N)
$G_Y = 1767.9$ N $(E_y = 1223.47$ N)
$\sum F_x = 0$
$G_X = E_x + R_B sin(45)$
$G_X = E_x + 544.5$
$G_X = 1767.9$ N $(E_y = 1224.47$ N)
Resultant $G = (G_x^2 + G_y^2)^{1/2} = 2500$ N (Magnitude)

Similarly the FBD's of all the remaining 2 links are made and the forces are calculated using the equilibrium of forces.

The table comprising of all the reaction forces is listed below:

Table 1
Magnitude of the reaction forces

Pin Joint	Magnitude (N)
R_A	1733
R_B	767
R_C	767
R_D	1733
E	1729
F	5250
G	2500
H	1730

3) *Selection of Hydraulic Cylinder:* The double acting hydraulic cylinder will provide the required force for lifting the platform.

As hydraulic cylinder will be inclined to the horizontal and the angle varies with the increase in Platform height. The system was designed so that the scissors were positioned at an angle of 5° in a fully closed position. Also, the scissors were positioned at an angle of 45° at a fully open position. Hydraulic cylinder in the system was located at a different angle comparing with the scissors. When the starting angle was small such as the angle of β, the horizontal component of piston force was increased and the vertical component of piston force was decreased. This variation caused the increase of resultant force in order to obtain the required horizontal force for lifting the platform. So the vertical component of the Hydraulic cylinder will be responsible for balancing of the Total weight on the lift i.e. initial position of the cylinder will be a crucial parameter in selection of the Hydraulic Cylinder.

Piston Force:

Max Loading capacity of the Lift = 500 kg f.o.s for the mass on the pallet = 1.6

Total Mass on the pallet = 800 kg

Taking Mass of the Lift = 100 kg (Approx.)

Total Mass = 100 + 800= 900 kg

Total load which hydraulic cylinder will accommodate = 9000 N

This Load will be balanced by the Vertical Component of the Piston Force

$$9000 = P*\sin(\beta)$$

Where:

Angle of the hydraulic Cylinder with horizontal = β

Piston Force = P

$$P = 9000/\sin(\beta)$$

$$\text{Pressure} = \frac{Force}{AREA}$$

For d=63 mm:

Pressure = $34500/(3.14* 63^2 *0.25)$

Pressure = 110 MPa

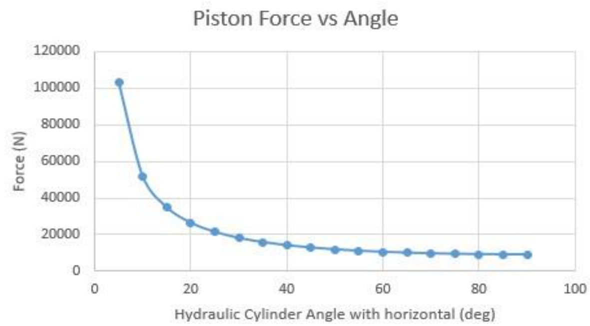

Fig. 10. Piston Force vs. Horizontal Angle

4) *Design of Scissor Arm:* For the design of the Link it is being considered that the load is acting on the half of the link length. The load pattern is considered to be UDL, So the load pattern on the half length of the link will be an Uniform Varying Load (U.V.L) due to it's inclination with the horizontal. The calculation is done for the link in shut height position, i.e. when the angle made by the links with horizontal is 5 deg.

Total Length of Link = 4.6 feet (or) 1400 mm.

Length of the link considered to be a beam for the calculation purpose = 700 mm.

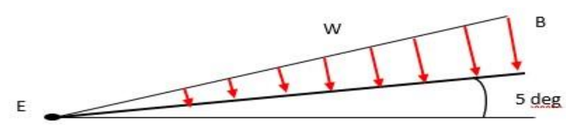

Fig. 11. UVL on Link

W = force per unit length of the beam

= Total Perpendicular force acting on the link

= 9000*cos (5) = 8950 N

As the UVL is a triangle,

H = (base * W)/2

8950 = (700*W)/2

W = 25.57 N/mm

Now for triangular UVL,

(M) Max Bending Moment = $(WL^2)/9*1.732$

M = 803754.96 Nmm

Using the Bending Equation:

$$\frac{M}{I} = \frac{\sigma}{y}$$

Where,

M = Max Bending Moment

I = Moment of Inertia

Y = Max distance from axis

σ = Bending Stress

Here we will be preferring a Hollow rectangular tube of Standard dimensions keeping in mind the ease of manufacturability. 60*40*2.6, 60*40*5, 80*40*2.6 these 3 were initially selected for the calculations.

Calculations for all the 3 selected tubes were performed.

For 60*40*5 tube profile:

I = 407500 mm4
M = 803754.96 Nmm
Y = 30 mm
σ =101.5 Mpa

6. Finite Element Analysis

FEA analysis of the CAD models was carried using CREO SIMULATE 6.0. Then from the data obtained fos was calculated using different Theories of Failures finalized based upon the materials finalized and the type of loading.

1) *Top platform:* Top platform will be subjected to the weight of the workers and it's equipment and at any position it will act as beam with one end overhanging.

Analytical calculations were not carried out and FEA analysis was carried out for top platform. Force applied at the Top = 5000 N

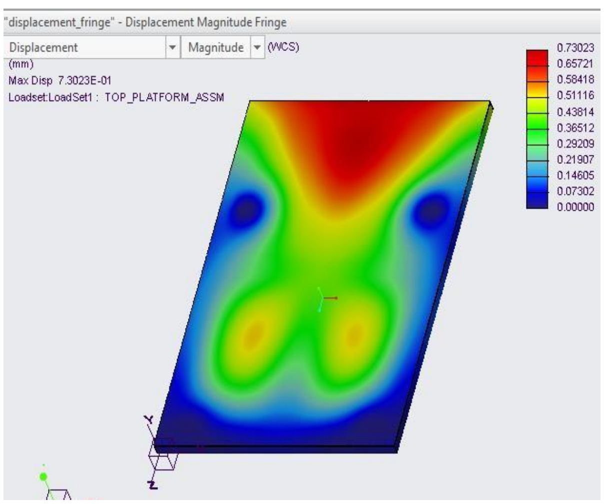

Fig. 11. Displacement magnitude of top platform

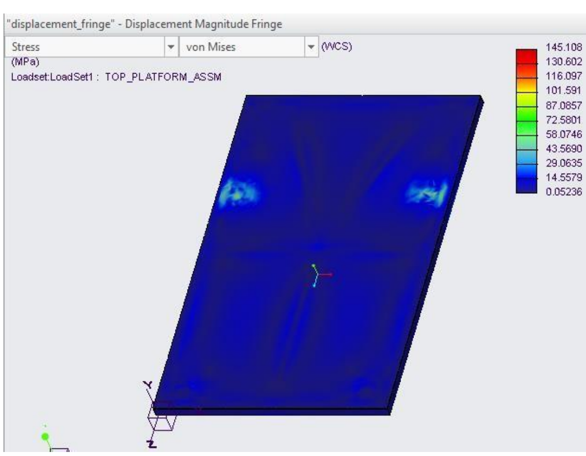

Fig. 12. Von Mises Stress of Top Platform

Table 2
FEA results of top platform

Maximum Von Mises Stress	145 MPa
Maximum Displacement	0.7 mm
FOS(Distortion Theory)	2.55

2) *Scissor Arm Assembly:* A FEA analysis of a scissor arm assembly was carried out to get a real time picture of the behavior of the assembly under loading and failure of different parts can also be predicted from the same analysis.

Force on the Scissor Arm = 1750 N (each)

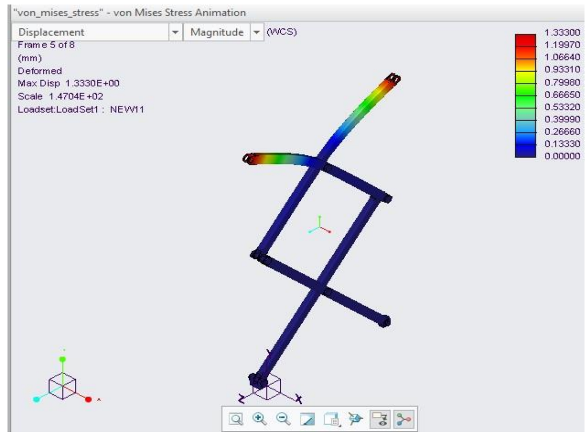

Fig. 13. Displacement magnitude of scissor arm assembly

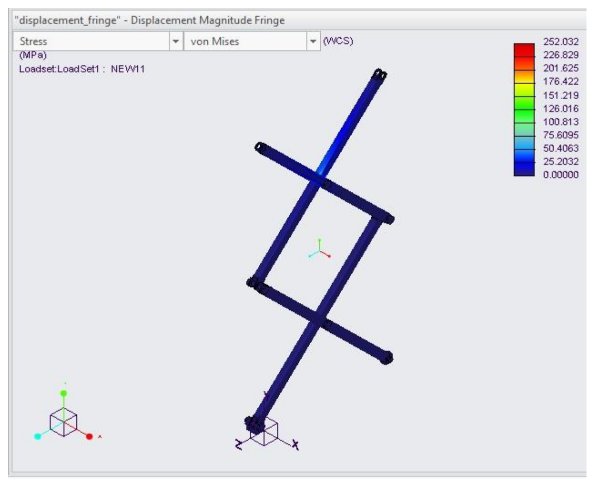

Fig. 14. Von Mises Stress of Scissor Arm Assembly

Table 3
FEA Result of Scissor Arm Assembly

Maximum Von Mises Stress	109 MPas
Maximum Displacement	1.33 mm
FOS(Distortion Theory)	3.6

The maximum stress in the assembly was found to be on the small shaft used to maintain scissor arms at a certain distance.

3) *Support Arm:* It is the part on which the hydraulic cylinder is attached and it transfers the force to the Scissor Arm Assembly.

Force applied at the pin joint = 34500 N (10 deg from vertical)

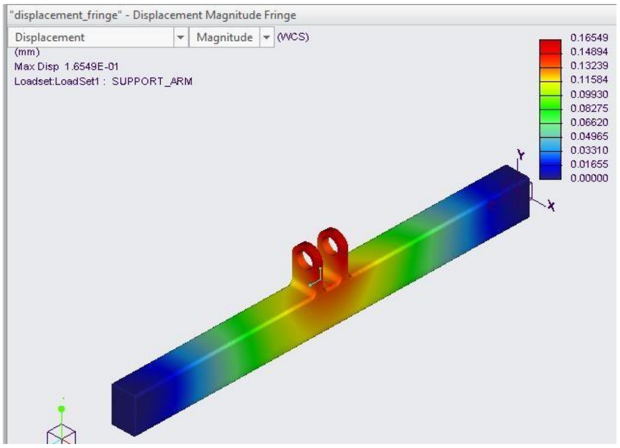

Fig. 15. Displacement magnitude of support arm

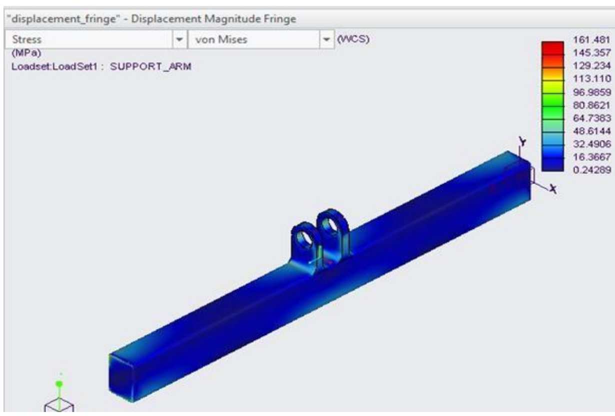

Fig. 16. Von Mises stress of support arm

Table 4
FEA result of the support arm

Maximum Von Mises Stress	161.5 MPa
Maximum Displacement	0.165 mm
FOS (Distortion Theory)	2.3

7. Conclusion

In this study Design and Analysis of a Hydraulic Scissor Lift was performed with Analytical Analysis and FEA using Creo Simulate. The system had a working height of 2m and a load carrying capacity of 500kg. The results obtained from the study performed were summarized as follows:

- In order to carry the load in the system safely, the scissors, top platform and pins were produced from the AISI 1080, Carbon steel and Stainless Steel material. Also, the solid model and simulation of the system were performed in PTC CREO Parametric.
- The maximum deformation occurred at the connection point of the upper shear and this value was determined as 1.3 mm.
- The maximum stress of the system (σ_{eq}=250 MPa) was determined at the connection points of the upper pair of scissors (Small shaft used to maintain distance between scissor arms) according to the von-Mises hypothesis.
- A scissor lifting system has a double acting hydraulic cylinder with 350mm stroke and Ø63 mm cylinder diameter in order to open and close the system safely. Also, the maximum working pressure of the pump was determined as ~110 bar.
- Electric motor was selected for this system according to the calculation of motor power as 1.4 kW.

From the present study, it was predicted that the designed scissor lifting system designed should carry a 500kg load to a height of 2m safely.

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