

Design of DC Electric Screw Jack Telescopic Push Rod Operated Scissor Lift

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Abstract: The scissor lift is widely used in industries as a lifting system to lift up load vertically. The scissor mechanism or pantograph with linked, folding supports in a criss-cross “X” pattern mostly powered by hydraulic system are used to achieve the upward motion.

The power system employed on the scissor lift usually is a hydraulic system which installed at the lowest set of supports to elongate the crossing pattern and moving the platform on top of the scissor lift vertically. The primary components of the hydraulic system consist of reservoir, filters, pump, control valves, pressure relief valve and hydraulic cylinder. Hydraulic systems are more complex and expensive and subject to leakage.

In this study the solid model and assembly of the part has been developed by the Autodesk Inventor software. The finite element analysis of the system will also be investigated with the same software i.e. stress, deflection, and safety factor values of system elements should be obtained. The formulation of the equation to determine the effective load of scissor lift and general equation of force required to lift up the load versus the angle of inclination of scissor’s link have been derived. A large thrust DC electric screw jack telescopic push rod or electric actuator which is high precision, longer service life, cheaper and easy to be installed will be selected to replace the hydraulic system. As a result of the analyses, a prototype is fabricated with the system designed that should safely be used during loading and unloading operations.

Keywords: Scissor Lifting System, Finite Elements Analysis, Static Analysis, Deformation, Safety Factor.

1. Introduction

Scissor lifts are a type of aerial work platform (AWP) or mobile elevated work platform (MEWP) to lift up load vertically. A scissor mechanism uses linked, folding supports in a criss-cross ‘X’ pattern or pantograph (Kapatel Jainil et al., 2017). The actuator such as hydraulic cylinder is used to provide the necessary expansion and contraction force to elongate and retract the crossing pattern in order to lift up and lower down the platform of the scissor lift. The placement of the actuator is important and the force action on the actuator depends on every new actuator position to move the pantograph.

The aim of this research is derive a generalized actuator force equation which depend of any actuator position when in operation. In 1989 the H.M Spackman, had outlined the deriving a force

equation as a function of the derivative of scissor height with respect to actuator length (Amay Saxena, 2016)

In this paper investigation of actuator force versus angle of lifting, design and analyze using FEA to determine the maximum von misses stress, the maximum displacement and safety factor induced are the primary objectives of this paper (Cengiz Görkem Dengiz et. al, 2016). The final prototype is also fabricated which is able function safely with less components needed and without the problems faced as the current hydraulic system operated scissor lift in the market.

2. The Effective Load L_E of Scissor Lift

A scissor lift with a non-negligible mass with dimensions $x \times y \times h$ as shown in Figure.1 below. A significant amount of work will be required by the actuator in lifting up the mass of the scissor lift itself to a given height h . (Amay Saxena, 2016).

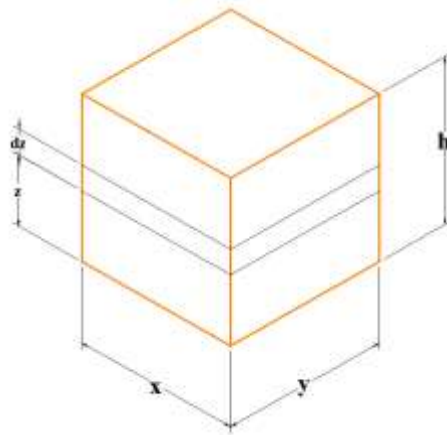


Figure 1. The cuboidal mass of scissor lift

Consider an infinitesimal element of this solid, of thickness dz , at a height z from the base of the solid. The mass of this infinitesimal element is,

$$m = xy(dz)\rho \quad (1)$$

The potential energy of the element at a height z is,

$$dE = \rho xy(dz)zg$$

Thus, the potential energy , E of the entire mass of height h can be approximated by,

$$E = \int_0^h \rho xyzg dz \quad (2)$$

Let the density, ρ of the scissor lift remains constant as well. The total weight can be written as,

$$W = xyh\rho g$$

$$\frac{W}{h} = xy\rho g \quad (3)$$

From (2) & (3),

$$E = \int_0^h \frac{W}{h} z dz$$

$$E = \frac{Wh}{2} \quad (4)$$

The weight of the block which represent the scissor lift remains the same even the height of the block changes. The work done in changing height is the same as change of potential energy which is,

$$\Delta E = \frac{W}{2} (h_2 - h_1) \quad (5)$$

From the above equation, the work done in keeping the weight of this arbitrary mass at height h_2 , is the work done in bringing half of its weight to height h_2 . Thus, the scissor lift weight can be modelled by placing half its weight acting at the top plate.

The effective load L_E to lift a particular load L is,

$$L_E = L + \frac{W}{2} \quad (6)$$

3. General Equation for Force Required

The actuator force output, F is required to lift the scissor lift to height, h and the length of actuator is s . Applying conservation of energy,

Work done by actuator=Work done to take lift to height h

$$\int_{s_1}^{s_2} F ds = \int_{h_1}^{h_2} L_E dh$$

$$\int_{s_1}^{s_2} F ds = \int_{h_1}^{h_2} \left(L + \frac{W}{2} \right) dh$$

Differentiating both sides gives the required force equation.

$$F = \left(L + \frac{W}{2} \right) \frac{dh}{ds} \quad (7)$$

4. General Equation to Lift Up the Load

Consider the link of scissor lift to be presented as a line in the xy plane as shown in Figure. 2 below.

k is the length of the scissor link.

s is the length of the actuator, for simplicity it has be represented by the green line. θ is the angle between the link and x-axis.

a is the fraction of the full length of the scissor link.

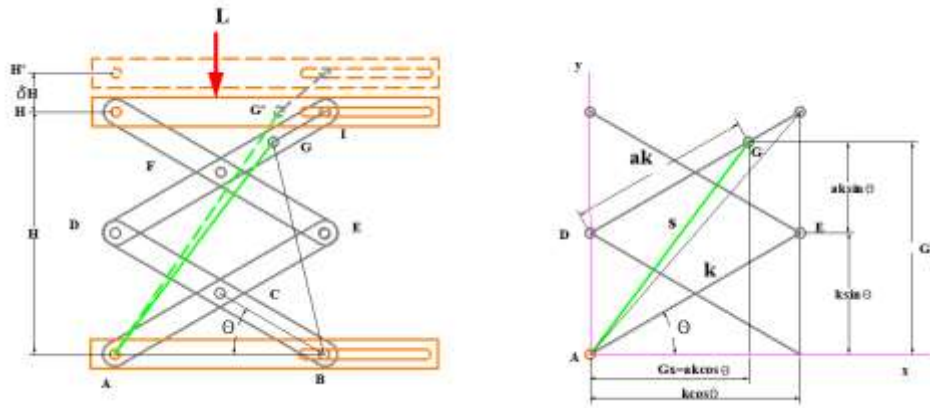


Figure 2. The schematic diagram of scissor lift

Based on the geometry, the relationship between the scissor's lift height and actuator extension can be obtained.

$$\frac{dh}{ds} = n \frac{\sqrt{(a)^2 \cos^2 \theta + (a+1)^2 \sin^2 \theta}}{(2a+1) \sin \theta} \quad (8)$$

From the force equation (7),

$$F = \left(L + \frac{W}{2} \right) \frac{dh}{ds}$$

$$F = n \left(L + \frac{W}{2} \right) \frac{\sqrt{(a)^2 \cos^2 \theta + (a+1)^2 \sin^2 \theta}}{(2a+1) \sin \theta} \quad (9)$$

Based on the design, $n = 2$ levels and $a = \frac{3}{4}$

$$F = 2 \left(L + \frac{W}{2} \right) \frac{\sqrt{0.5625 \cos^2 \theta + 3.0625 \sin^2 \theta}}{1.25 \sin \theta} \quad (10)$$

Different value of actuator force F can be obtained at various angle of θ of inclination of scissor's link with respect to horizontal x-axis, a graph of electric actuator force F versus angle θ can be plotted based on the above equation. If the load to be lifted $L=200$ N, and the weight of the scissor lift links obtained from the properties provided by the Autodesk Inventor software is $W=180$ N. The actuator force versus angle θ of scissor link with respect to x-axis is plotted in graph 1. below and the graph is best fit with the power curve from trend line option of Microsoft excel.

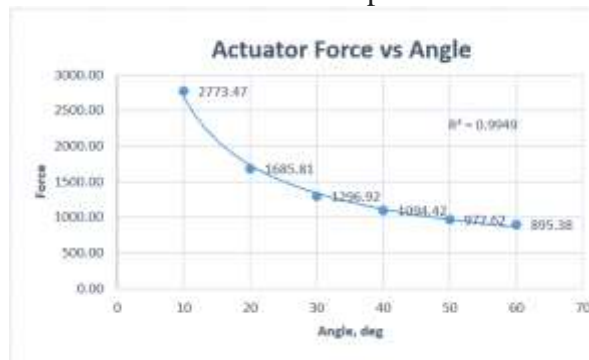


Figure 3. Graph of Actuator Force vs. Angle

According to graph 1 view of electric lifting force, when the lifting rods are relatively horizontal, the actuator force needed is at maximum value to push the scissor link. This force needed is gradually reduced and reaches 895.38 N with maximum angle of 60°.

5. FEA Analysis with Autodesk Inventor

The design was analyzed with stress analysis feature or FEA Analysis of Autodesk Inventor. For clarity the platform had been suppressed from analysis (P S K Narasimsha et. al, 2014) The maximum allowable load applied to be lifted is 200 N and the load is carried evenly at the 4 joint, the 50 N loads are applied at the 4 joints. The von Mises Stress analysis are usually applied on ductile material such as steels, aluminum, copper, magnesium, alloys etc. In the Autodesk Inventor software, the results are showed in a colored contour as shown in Figure 3 below and the maximum Von Misses Stress is 2.217 MPa.

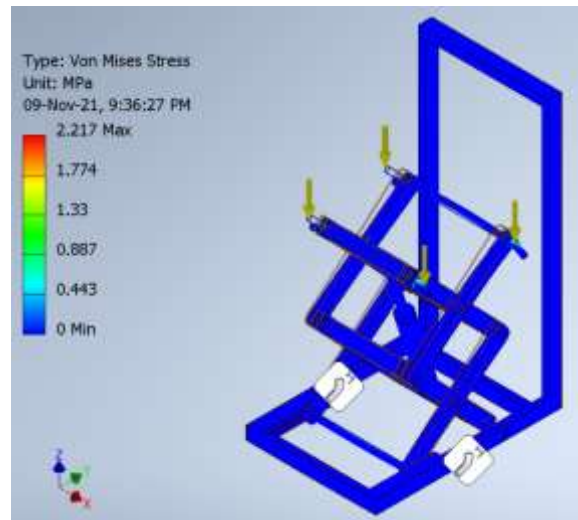


Figure 4. The maximum Von Misses Stress obtained with full extension of scissor lift

The yield strength is an important material property which is corresponding to the yield point at which the material starts to plastic deformation. It is often used to determine the maximum allowable load that can be withstand by a mechanical component or the upper limit to forces that can be applied without producing permanent deformation. The selection of the mild steel with yield strength approximately 317 MPa is more than enough to support stress induced due to the load to be lifted.

6. The wiring diagram for Electrical Lead Screw Actuator model 3500 N

The electrical wiring diagram based on items purchase is shown in Figure 4. The Circuit diagram for Electrical Lead Screw Actuator model 3500 N below. The battery is rechargeable and an emergency button is installed as a safety device. (Liew Han Wei, 2020).

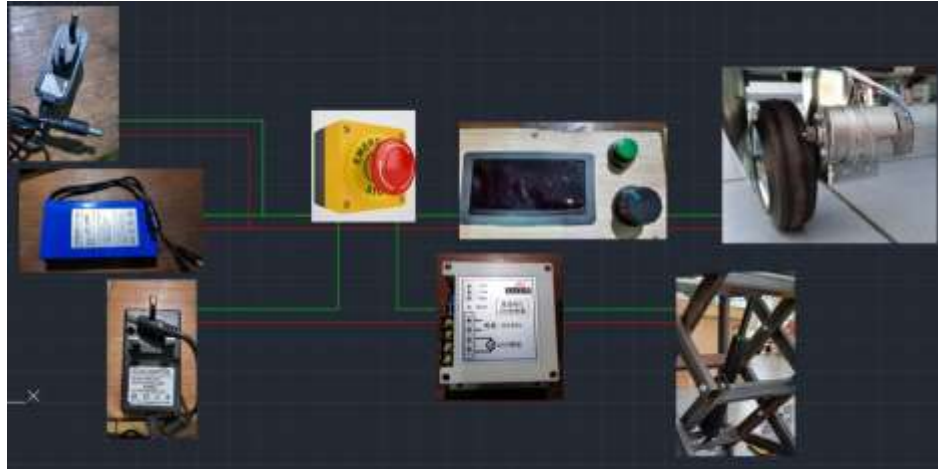


Figure 5. The Circuit diagram for Electrical Lead Screw Actuator model 3500 N

7. The Prototype DC Electric Screw Jack Telescopic Push Rod Operated Scissor Lift

The completed prototype in fully extension is shown in Figure 5 below. In the demonstration a remote controlled is used to control the extension of Electrical Lead Screw Actuator model 3500 N.



Figure 6. The Lifting of Cooking Gas Cylinder

A home cooking gas cylinder tank (17.5kg) was lifted successfully during the presentation. The prototype is simpler with less components needed as in the current hydraulic system scissor lift.

8. Result and Discussion

The variation of piston force F versus angle θ of scissor link of graph 1 shows that for a maximum angle of 60° a 895.38 N force is needed to lift up a load with weight 200 N. An Electrical Lead Screw Actuator model with 3500 N push force is powerful enough to provide a push force needed to lift up the load. The maximum stress is 2.217 MPa at the upper four points of the scissor lift based on the Von Misses Stress hypothesis. The maximum Displacement with full extension of scissor lift obtained is 0.009169 mm. The safety factor analysis provides rating for the safety level of

the prototype designed. The range of rating for prototype is between 15 to 0, where 15 represents the safest rating whereas 0 means that the prototype is unsafe to be used and needs immediate study and modification. In this case, the rating granted by the software of the scissor lift has a maximum and minimum value of 15 Thus, this means that the prototype is safe to be used.

9. Conclusion

In this study, the design and analysis of the scissor lifting system the static analysis was used to formulate the equation of actuator force F at various angle of θ of inclination of scissor's link with respect to horizontal x-axis. A push force of 895.35 N is required at the maximum angle of 60° . The stress analysis of Autodesk Inventor has provided a great tool to solve complex engineering problem to determine the maximum Von Misses Stress, the maximum displacement with full extension of scissor lift.

Based on the research carried out, the design and calculation process, the selection of materials, the fabrication and testing on the prototype, the project was completed successfully. The outcomes meet the objective of the study and the scissor lift is able to lift up the load as predicted. The prototype fabricated is able to function safely with less components needed and without the problems faced as the current product in the market. This will reduce the price of the product, the down time of production and the cost of maintenance. Also, by finding out other important parameters related to scissor lift, further modification can be carried out for optimizing the design for future improvement.

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