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A method to Improve the Stability of Scissor Lifting Platform by using Finite Element Analysis

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ABSTRACT

Scissor lifting mechanism is widely used in various industries due to its excellent features such as simple structure and easy manufacturing. Through many observations and studies, it is found that half of the worktable (the top plate) is normally not supported and cannot withstand heavy loads when the scissor lifting mechanism is in the highest position. It is raised as an important problem in other facilities using this machine. Therefore, in this paper, one method was proposed to improve the stability of the scissor lifting mechanism. First, by analyzing the position at which the deformation is maximized, a hydraulic cylinder was mounted there to increase the stability of the scissor lift. A hydraulic cylinder was designed based on these physical quantities, the analysis of the position and stress. Next, to analyze the effect of the hydraulic cylinder support on the worktable deformation, ABAQUS program was used to analyze and compare the deformation between the worktable with and without cylinder. As the result of the analysis, after mounting the hydraulic cylinder, the deformation of the worktable decreased by 94.4% and the stability of the scissor lifting mechanism was further improved.

Keywords : ABAQUS, hydraulic cylinder

I. INTRODUCTION

Lifting work platforms are mechanical devices used for height vertical transport, also known as aerial work platforms (AWP). These platforms consist of a metal base and a metal platform, with which different loads can be lifted, controlling the platform ascent and descent [1]. Lifting platforms are used in many areas, for vertical lifting, for example outside buildings at various heights, warehouses, firefighters and emergency services, etc. because they are much more flexible than conventional lifts and elevators [2]. Cornel Ciupan designed the scissor lifting mechanism, put forward the optimization of hydraulic lift algorithm, the algorithm to determine the number of scissors and the algorithm to determine the forces [3]. LIUJunyi analyzed the characteristics of the forces of the scissor lift mechanism with three levels[4]. Georgy and Olenin created a design of the hydraulic scissors lifting platform by selecting the type of platform, the

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design of the structure and the material, calculating the loads and stresses, end creating the 3D model of the lift using SOLDIWORKS program[5].

Doli Rani made the complete study of components (hydraulic cylinder, scissor arms, spacing shaft and platform), selection of matesrials and analyzes the dimensions of components along with their sketches with the help of design software CATIA V5 followed by stress analysis on COMSOL, and further carried out fabrication of all the parts and assembly [6]. Zhongfu Bao reduced the energy consumption of the hydraulic system used in a scissor lift by exchanging the quantitative pump with load-sensitive pump and analyzed the application of load sensing technology to scissor lift [7]. ZHAGN Wei used a characteristic triangle method on input vectors of scissor lift mechanism and applied the method in modeling and analyzing of the scissor lift [8]. Christopher S. Pan developed a multibody dynamic model of the scissor lift and a human lift operator model using ADAMS™ and LifeMOD™ and then evaluated lift stability for four fall-arrest system products and quantified biomechanical impacts on operators during drop/fall arrest, using manikin drop tests [9]. Jared J. Hartsell created the dynamic model of a typical scissor lift using ADAMS and carried out the stability simulation experiment and presented a method to improve the stability based on the experiment result [10]. Tian Hongyu created the 3D simulation model using Pro/E and checked the interference between the components [11]. Ren G. Dong found out the main factors influencing scissor lift stability such as scissor structure flexibility, ground slope and tilt speed of the lift, and then offered some suggestions to prevent the tip-over of scissor lifts [12]. Cheng Yin proposed multibody dynamics model of the scissor lift mechanism which can offer flexibility for modeling of closed loop kinematic systems [13]. Ze Cui used the scissor lift in the design of a novel AGV with automatic pick-and-place system [14].

During making a new robot named "Tree trunk root radar detection robot", the deformation problem of the platform (the half of the worktable with no support) was noticed. In this study, one method was proposed to improve the stability of the scissor lifting mechanism. First, by analyzing the position at which the deformation is maximized, a hydraulic cylinder was installed there to increase the stability of the worktable. A hydraulic cylinder was designed based on these physical quantities, the analysis of the position and stress. Next, to analyze the effect of the hydraulic cylinder support on the worktable deformation, ABAQUS program was used to analyze and compare the deformation between the worktable with cylinder and the worktable without cylinder.

1. Scissor lift mounted on the "Tree trunk root radar detection robot" ~Structure of the "Tree trunk root radar detection robot"

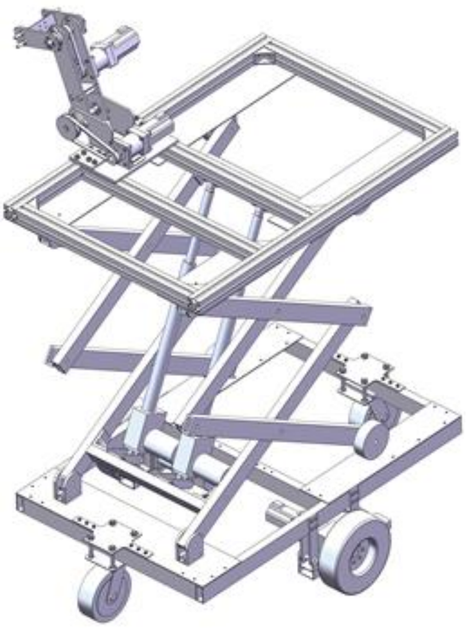

Figure 1. Tree trunk root radar detection robot

"Tree trunk root radar detection robot" is composed of scissor lifting mechanism, mobile chassis and mechanical arm.

˜Structure and parameters of the scissor lift mounted on the robot

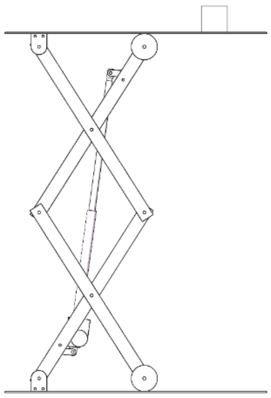

Figure 2. Scissor lift

The scissor lifting mechanism is generally composed of three parts. Bottom plate, lifting mechanism and worktable. As the executive department of the whole organization, the worktable plays a vital role. The object gravity is 1000N, the worktable is a cube of 600*1000*10mm and made of carbon steel. And the fixed hinge seat and wheel contact can be regarded as a constraint state. The specific load position is as follows.

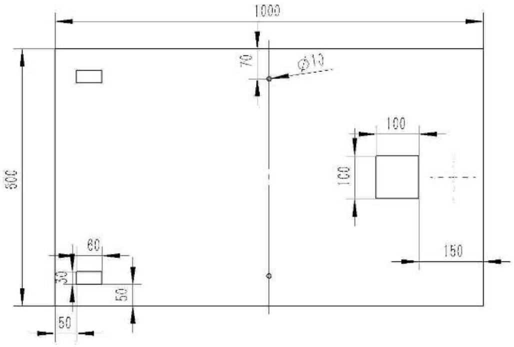

Figure 3. Specific force position without hydraulic cylinder

˜The stress and deformation of the scissor lift

The scissor lift mounted on the robot made the maximum stress of $307.3Mpa$ and the maximum deformation of $3.6mm$. The maximum stress of $307.3Mpa$ has already exceeded the permissible stress of carbon steel (which is $220Mpa$), so it can't satisfy the strength condition and the real deformation of the worktable maybe bigger than $3.6mm$ because the worktable is not in the elastic range anymore. So, it's important to reduce the stress and deformation of the worktable.

2. A new method to improve the strength and rigidity of the scissor lift worktable

The main reason why the worktable which is made of carbon steel can't meet the strength condition is that the object produces great torque and deformation in a section without any support. If a hydraulic cylinder is used to support the unsupported section, not only the maximum stress value can be reduced, but also the deformation can be reduced. According to the above mechanical model, design the hydraulic cylinder in line with the project.

˜Calculation of the piston rod thrust

The load diagram of the table is as follows.

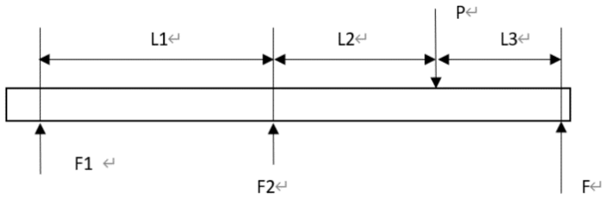

Figure 4. Force diagram of the worktable

Here F_1 and F_2 are the constraint force, F is the thrust of the piston, and P is the weight of the object. $P = 1000N, L_1 = 420mm, L_2 = 300mm, L_3 = 130mm.$

Reducing the maximum stress value is one of the reasons for setting the hydraulic cylinder, so the premise of determining F is to minimize the constraint force. Assume that $F = 0N$.

Write out a mechanical equilibrium equation.

$$\begin{cases} F_2 + F = P \\ F \times (L_2 + L_3) - P \times L_2 = 0 \end{cases}$$

(1)

Finally, $F = 698N, F_2 = 302N$. Round the result and adjust F to $800N$ because F_2 is too large.

Write down the mechanical equilibrium equation again.

$$\begin{cases} F_1 + F_2 + F = P \\ F \times (L_2 + L_3) - P \times L_2 - F_1 \times L_1 = 0 \end{cases} \quad (2)$$

Finally, $F_1 = 104.8N, F_2 = 95.2N$.
These two constraint forces are all small and it has reached a relatively ideal state.

˜Working pressure of hydraulic system

Table 1. Select the working pressure of the hydraulic cylinder according to the load

Load(F/KN)	< 5	5~10	10~20	20~30	30~50	> 50
Pressure(p/MPa)	0.8~1.0	1.5~2.0	2.5~3.0	3.0~4.0	4.0~5.0	> 5.0~7.0

Table 2. Hydraulic cylinder pressure series (Mpa)

0.63	1	1.6	2.5	4	6.3	10	16	25	40

As the load is 800N, it can be seen from Table 1 that $p < 0.8MPa$. The pressure of the hydraulic cylinder is $0.63Mpa$ according to the series specified in Table 2 (GB2346-93).

˜Determination of inner diameter D of hydraulic cylinder

The inner diameter of the hydraulic cylinder can be calculated from the working pressure and load, and the calculation formula is

$$D = \sqrt{\frac{4F}{\pi p}} = 40.2(mm) \quad (3)$$

Table 2. Inner diameter series of hydraulic cylinders (mm)

8	10	12	16	20	25	32	40	50
63	80	（90）	100	（110）	125	（140）	160	（180）
200	220	250	320	400	500	600		

*Considering safety, choose $50mm$ cylinder diameter.

˜Determination of piston rod diameter D

Select according to Table 4 and round according to Table 5.

Table 3. Selection of piston rod diameter (mm)

Stress on the piston rod	Working pressure p/MPa	Piston rod diameter d
Tension	-	$(0.3\sim0.5)D$

Tension and compression	≤ 5	$(0.3\sim0.5)D$
Tension and compression	$(5,7]$	$(0.6\sim0.7)D$
Tension and compression	>7	$0.7D$

Table 4. Piston rod diameter series (mm)

4	5	6	8	10	12	14	16	18
20	22	25	28	32	36	40	45	50
56	63	70	80	90	100	110	125	140
160	180	200	220	250	280	320	360	400

˜Piston rod stroke S

Table 5. Piston stroke (mm)

25	50	80	100	125	160	200	250	320	400	500

As the working height of the worktable is about 1m, so choose $500mm$ stroke.

3. Stress and deformation analysis of the worktable with the hydraulic cylinder using finite element analysis

˜Structure of scissor lifting mechanism

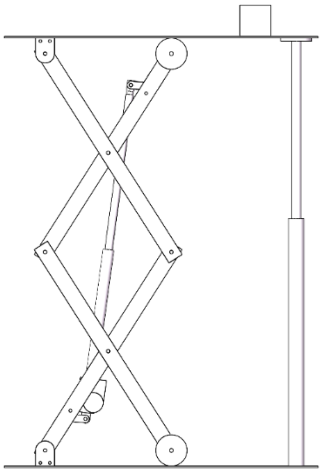

Figure 5. Structure of scissor lift

The specific position of the hydraulic cylinder and each support is shown below.

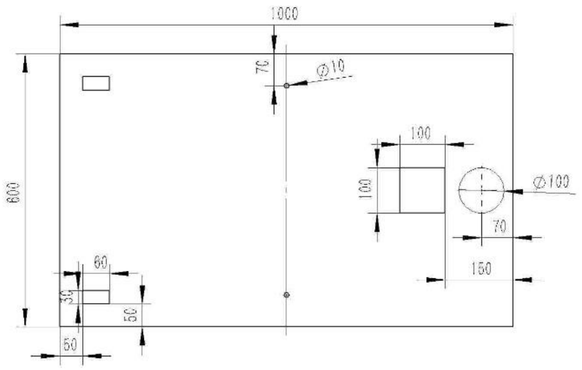

Figure 6. Specific force position with hydraulic cylinder

˜Modeling for finite element analysis

Model before setting hydraulic cylinders

The number of nodes and elements used in finite element analysis is 500 and 1000 respectively.

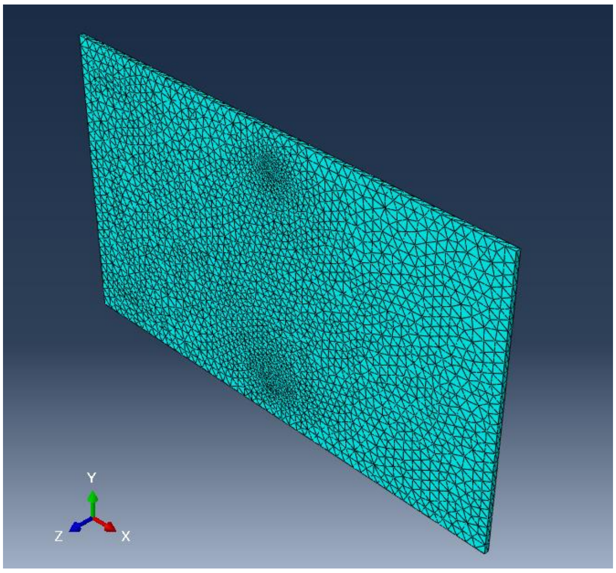

Figure 7. Model before mounting hydraulic cylinders

Model after setting hydraulic cylinders

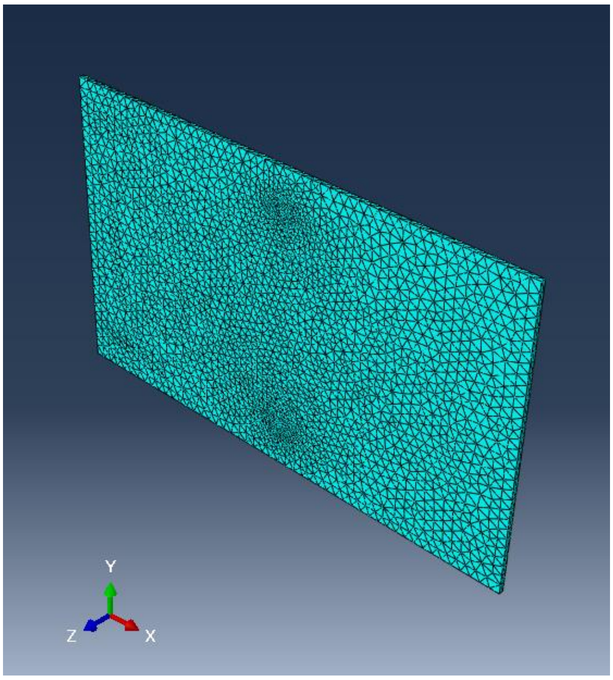

Figure 8. Model after mounting hydraulic cylinders

˜Stress analysis of the worktable

The number of nodes and elements used in finite element analysis is 500 and 1000 respectively, the stress analysis results obtained by using ABAQUS program are as follows.

Stress analysis before setting hydraulic cylinders

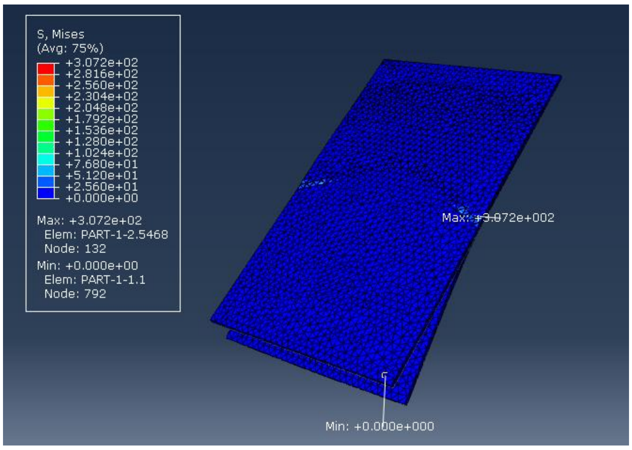

Figure 9. Stress distributions without hydraulic cylinders

The maximum stress appears on the contact surface of caster and worktable and its value is 307.2Mpa. It's bigger than the permissible stress of carbon steel 220Mpa, which does not satisfy the strength condition.

Stress analysis after setting hydraulic cylinders

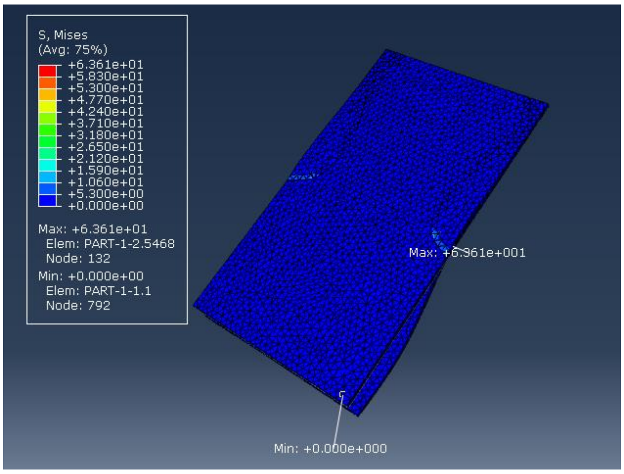

Figure 10. Stress distributions with hydraulic cylinders

The maximum stress is still present on the contact surface between the caster and the worktable, its value is 63.3Mpa. It is less than the permissible stress of carbon steel 220Mpa, to satisfy the strength condition.

Table 6. Stress analysis

	Without hydraulic cylinder	With hydraulic cylinder
Maximum stress (Mpa)	307.2	63.6
Error(%)	39.6	71.1

˜Deformation analysis of worktable

The number of nodes and elements used in finite element analysis is 500 and 1000 respectively, the stress analysis results obtained by using ABAQUS program are as follows.

Deformation analysis before setting hydraulic cylinders

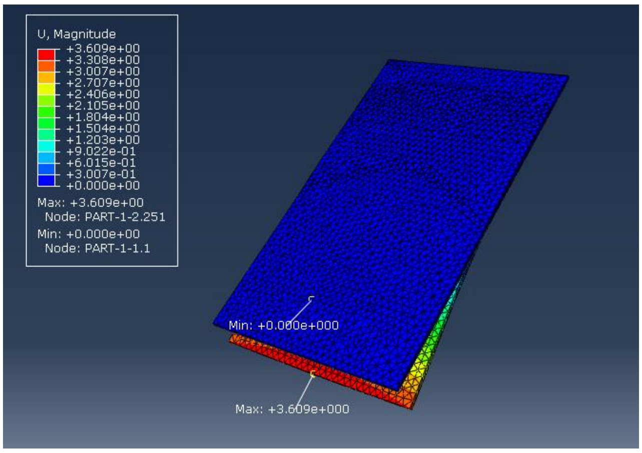

Figure 11. Deformation distributions without hydraulic cylinders

Here, the maximum deformation appears on the edge of the worktable, which is 3.6mm.

Deformation analysis after setting hydraulic cylinders

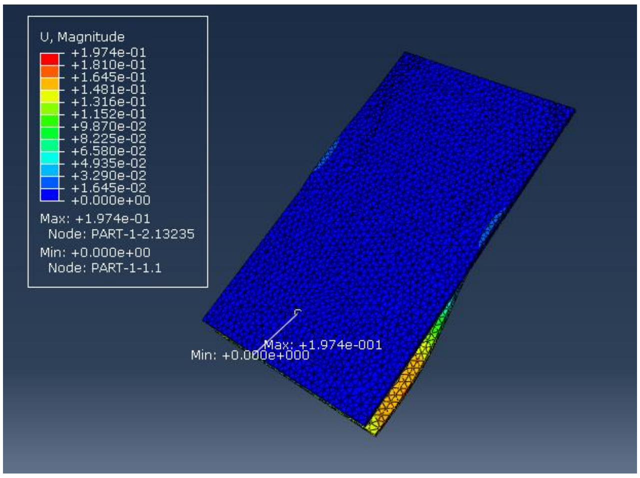

Figure 12. Deformation distributions with hydraulic cylinders

The maximum deformation appears where the object is, with a value of $0.2mm$.

Table 7. Deformation analysis

	Without hydraulic cylinder	With hydraulic cylinder	Error(%)
Maximum deformation (mm)	3.6	0.2	94.4

II. CONCLUSION

In this paper, one method was proposed to overcome the defects of poor stability, the unstable half part of the worktable which has no support in the highest position so that it cannot withstand heavy things. The finite element method was used to propose this method which can improve the rigidity and stability of the scissor lift worktable, reduce the maximum stress, and efficiently utilize the worktable space. First, the position at which the deformation is maximized and the stress of that position was analyzed, a hydraulic cylinder was mounted to increase the stability of the scissor lift. Next, the ABAQUS program was used to analyze and compare the deformation of worktable with and without hydraulic cylinder. As a result, the maximum stress without supporting the hydraulic cylinder is $307.2Mpa$ which does not satisfy the strength condition, and the maximum deformation is $3.6mm$. After mounting the hydraulic cylinder, the deformation is 0.2mm and the maximum stress value is $63.6Mpa$ which satisfies the strength condition. Through the analysis, it can be seen that the maximum stress value of the table decreased by 79.3% and the maximum deformation value decreased by 94.4% after mounting the hydraulic cylinder. These results greatly improve the stability of the scissor lifting mechanism and provide a theoretical basis for effectively using all the space of the worktable.

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