# ALGORITHM FOR OPTIMIZING THE HYDRAULIC CYLINDER PLACEMENT FOR MULTI-SCISSOR LIFT PLATFORMS

**Cornel CIUPAN, Emilia CIUPAN, Mihai CIUPAN**

***Abstract:*** *There are many applications that use scissor-type mechanisms for lifting platforms or robots. The platform stroke is greatly amplified compared to the actuator stroke, which is why the driving force is much greater than the load. The size of the drive system is chosen based on the maximum force and therefore it is important that this is minimized. The paper analyzes the influence of the actuator placement, in order to reduce the forces and optimize the drive system. The optimization algorithm can be applied to platforms with two or more scissors and consists of the following steps: determining the dimensions and number of scissors, kinematic analysis to determine the actuator motion law, and finally optimizing the actuator connection points.*

***Key words:*** *scissor platform, multi-scissor mechanism, optimization algorithm, lifting force.*

## 1. INTRODUCTION

### 1.1 Scissor platform

Lifting work platforms are mechanical devices used for height vertical elevating, 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] [2].

These AWP platforms use mechanical systems of foldable crossed levers, called scissor mechanisms, which act to lift the platform only vertically. The platform can be raised and lowered with hydraulic or pneumatic cylinders, or with other electro-mechanical systems [3].

Scissor mechanisms are used for multiple applications [3][4]:
− Lifting tables for large loads (over 10000 N) and low heights (2-5 m).
− Lifting tables for medium loads (1000-5000 N) and high heights (10-15 m).
− Robots and other handling systems [5].

The choice of the scissor mechanism configuration is made depending on the functional requirements of the platform.

Dang & Nguyen [3] developed mathematical models to investigate load and stability, using parameterized dimensions of double scissor platforms.

Paper [6] presents research on the single scissor lift about two problems: the influence of the mounting position of the hydraulic cylinder on its required actuation force, and cylinder stroke in order to meet the required lifting height of the load.

The article [4] focuses on the stability of an automotive lift's design when moving with a load, based on a kinematic and kinetostatic analysis.

Article [7] presents research on optimizing the energy consumption of a hydraulic scissor lift with reduced capacity.

The stability of the scissor mechanism used in moving platforms was studied in the paper [8].

In order to design a platform with scissors, the structure of the platform must be determined, the positioning of the scissors at the base of the platform and at the moving table, the hydraulic control parts and the driving of the hydraulic cylinder. The most important mechanism is the scissor lift one, whose force directly influences the performance of the entire equipment and, together with the positioning of the hydraulic cylinder, determines lifting height of the platform [6].

## 1.2 Problem to solve

Figure 1 shows a platform with (k+1) identical scissor mechanisms. Each mechanism n is made up of two arms $A_{n-1} - B_n$, respectively $B_{n-1} - A_n$. The two arms of length $2\ell$ have a central joint $O_n$.

The height H of the platform is given by the length $\ell$ and the opening angle $\alpha$ of the scissors.

The algorithm for determining the number k of scissors depending on the platform dimensions, the lifting height and the range of variation of the angle $\alpha$ was presented in the paper [1]. The same paper also presented the equations for determining the forces in the joints.

In this paper, the mechanism by which the platform is raised and lowered with an actuator placed between joints C and D is studied. A trapezoidal motion law of the platform is imposed, and the motion law of the actuator is determined to achieve the desired movement of the platform.
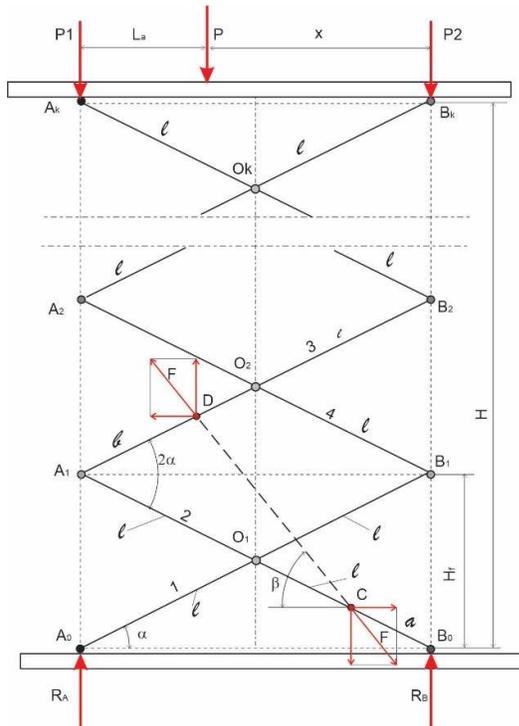


**Fig. 1.** Diagram of a platform with k scissors

Due to the high forces that occur, especially when the platform is at its minimum height ($\alpha=\alpha_{min}$), hydraulic cylinders are used. In the case of a hydraulic cylinder, the stroke c is less than its length in the rod retracted position. The variation of the force at the cylinder rod is studied depending on the placement of joints C on segment $O_1B_0$, and of joint D on segment $A_1B_2$.

## 2. THE KINEMATIC ANALYSIS

The height of the platform varies with the angle $\alpha$ and is determined by the equation (1).

$$H = 2k \cdot l \cdot sin\ \alpha \qquad (1)$$

The velocity and acceleration of the platform are obtained by differentiating equation (1):

$$v = 2k \cdot l \cdot cos\ \alpha \qquad (2)$$
$$a = -2k \cdot l \cdot sin\ \alpha \qquad (3)$$

Figure 2 shows the equation of the platform motion, in which the following were noted:
− $t_1$, the time for the platform to rise from the minimum height $H_{min}$ to the maximum height $H_{max}$.
− $t_a/t_f$, acceleration/braking time corresponding to the acceleration stroke $H_a$/braking stroke $H_f$.
− $t_c$, the displacement time at constant speed, corresponding to the stroke $H_c$.
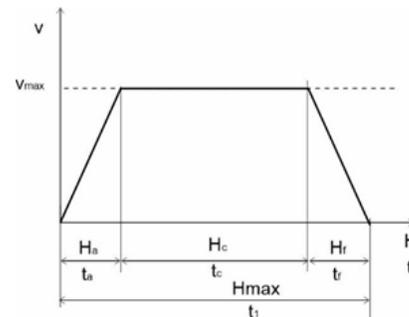


**Fig. 2.** The law of motion of the platform

Knowing the maximum platform lifting speed, the acceleration a or the acceleration stroke $H_a$ and applying the equation of motion in figure 2, the lifting/lowering times and the expression of the platform stroke h(t) are obtained by equations (4) and (5).

$$t_a = t_f = \frac{v_{max}}{a} = \frac{2H_a}{v_{max}}$$
$$t_c = \frac{H_{max} - 2H_a}{v_{max}} \qquad (4)$$

$$t_1 = t_c + 2t_a$$

$$h(t) = \begin{cases} H_{min} + 0.5 \cdot t^2, \ t \le t_a \\ h(t_a) + v_{max} \cdot (t - t_a), \ t \le t_c \\ h(t_c) + v_{max} \cdot (t - t_c) - 0.5(t - t_c), \ t \le t_1 \end{cases} \quad (5)$$

The angle α can be determined as a function of time t based on relation (1):

$$\sin \alpha(t) = \frac{h(t)}{2k \cdot l} \quad (6)$$

The angle β is determined as follows:

$$\tan \beta = \frac{2l + b - a}{2l - a - b} \tan(\alpha) \quad (7)$$

The cosine theorem is applied to triangle $A_1CD$:

$$CD^2 = (2l - a)^2 + b^2 - 2(2l - a)b \cdot \cos 2\alpha \quad (8)$$

Since the length of the segment CD is given by the size of the hydraulic motor (retracted length $CD(\alpha_{min})$ and stroke X(t)) from equations (7) and (8), the motion law for controlling the hydraulic cylinder is obtained by relation (9).

$$X(t) = CD(\alpha(t)) - CD(\alpha_{min}) \quad (9)$$

## 3. THE ALGORITHM

The algorithm for optimizing the hydraulic cylinder placement for multi-scissor lift platforms consists of the next three steps:
1. Establish the dimensions of the platform, the phase in which the dimensions of the main component elements are determined.
2. Establish the platform's and the actuator's law of motion through kinematic analysis.
3. Optimize the actuator placement in order to minimize its force.

The calculation of the platform dimensions (figure 3) is done based on the main input data, using the algorithm presented in paper [1].

The kinematic analysis (figure 4) has the role of generating platform motion law h(t), using a trapezoidal motion law with acceleration, constant speed and braking phases (figure 2). Also in this step, the motion law of the scissors is determined by the scissors angle α(t):

$$\alpha(t) = arcsin\left(\frac{h(t)}{2k \cdot l}\right) \quad (10)$$

The last step aims to establish points C and D for actuator placement in order to minimize the driving force (figure 5).

| Step 1 - Sizes | |
|---|---|
| *Input data* | |
| Platform length | $Lp$ |
| Max. platform height | $H_{max}$ |
| Min. platform height | $H_{min}$ |
| Scissors angle | $\alpha_{min}$ |
| | $\alpha_{max}$ |
| Maximum load | $P$ |
| *Calculations* | |
| Scissor length | $2l' = \dfrac{L_p}{sin(\alpha_{min})}$ |
| Number of scissors | $k' = \dfrac{H_{max}}{2l' \cdot sin(\alpha_{max})}$ |
| Setting | $k$ |
| | $l$ |

**Fig. 3.** Algorithm - Step 1

| Step 2 - Kinematical analysis | |
|---|---|
| *Input data* | |
| Maximum speed | $v_{max}$ |
| Acceleration or acceleration stroke | $a$ |
| | $H_a$ |
| *Calculations* | |
| Lifting times | $t_a, t_c, t_1$ |
| Platform stroke | $h(t)$ |
| Scissors angle | $\alpha(t)$ |

**Fig. 4.** Algorithm - Step 2

| Step 3 - Optimization | |
|---|---|
| *Input data* | |
| $CB_0$ segment boundaries | $a_{min}$ - $a_{max}$ |
| $DA_1$ segment boundaries | $b_{min}$ - $b_{max}$ |
| *Calculations* | |
| CD length | $CD(t)$ |
| Check cylinder stroke | $X = CD_{max} - CD_{min}$ |
| | $X < CD_{min} + R$ |
| Cylinder stroke | $X(t)$ |
| Cylinder force | $F(t)$ |
| Setting a, b for minimum F | $a$ |
| | $b$ |

**Fig. 5.** Algorithm - Step 3

In the first phase, the limits of variation of the lengths a and b are established. These determine the position of the hydraulic motor. Then, the values a and b are checked for which it is possible to place the hydraulic cylinder depending on its stroke:

$$CD_{min} = \frac{CD_{max} + Rs - X}{2} \qquad (11)$$

where:

$$CD_{min} = CD(\alpha_{min})$$
$$CD_{max} = CD(\alpha_{max})$$
$$X = CD_{max} - CD_{min}$$

$Rs$ is the cylinder retracted stroke.

The force at the hydraulic motor rod can be determined from the equality between the work produced by lifting the load P and the work produced by the driving force:

$$F(t) = P \frac{h(t) - h(t-1)}{X(t) - X(t-1)} \qquad (12)$$

The alternative that offers the lowest force F at the beginning of the movement is chosen because this determines the cylinder diameter and the hydraulic system pressure. The algorithm can also be used in the case of an electric drive with a screw-nut mechanism.

## 3. CASE STUDY

The application of the algorithm is presented in the case of a hydraulic platform with the following input data: platform length L=2.1 m, maximum height $H_{max}$=5 m, minimum height: $H_{min}$=1.3 m, scissors angle: $\alpha_{min}$=10° and $\alpha_{max}$=60°, maximum load P=1000 N.

By applying step 1 of the algorithm, the following data are obtained: k=3, $\ell$=1 m, $H_{max}$=5.2 m, $H_{min}$=1.25 m, $\alpha_{min}$=12°, $\alpha_{max}$=60°.

Based on the data from step 1, with $v_{max}$=0.1 m/s and $H_a$=0.5 m, the platform's motion law is determined in step 2 of the algorithm, by applying equations (4) and (5) (figure 6).
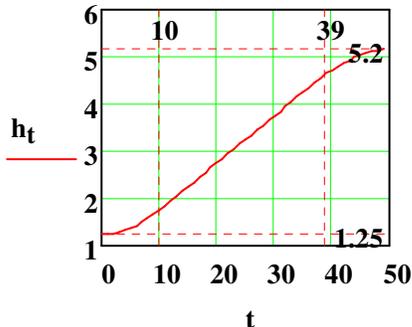


**Fig. 6.** Platform motion h(t) [m]

The law of variation of the angle $\alpha$ was determined based on relation (6) (figure 7).



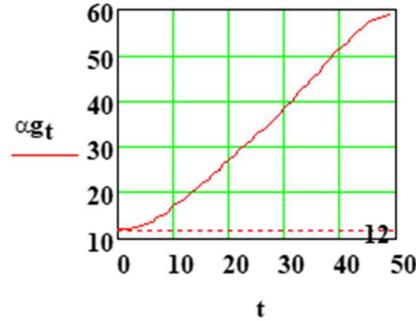**Fig. 7.** Scissor angle α(t) [°]

The length of the segment CD was calculated using the relation (8) (see figure 8).
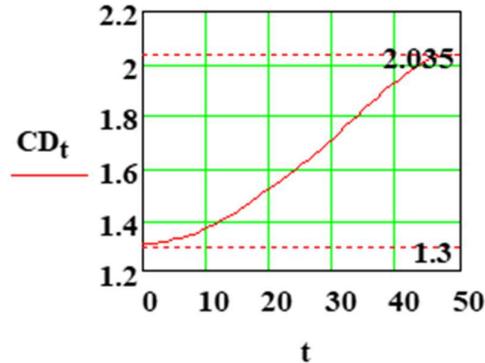


**Fig. 8.** CD length CD(t) [m]

Choosing the positions of points C and D by a=$\ell$/4 and b= $\ell$/2, the force F at the hydraulic motor rod (figure 9) and the amplification factor Af (figure 10) have resulted, in relation to the load P.
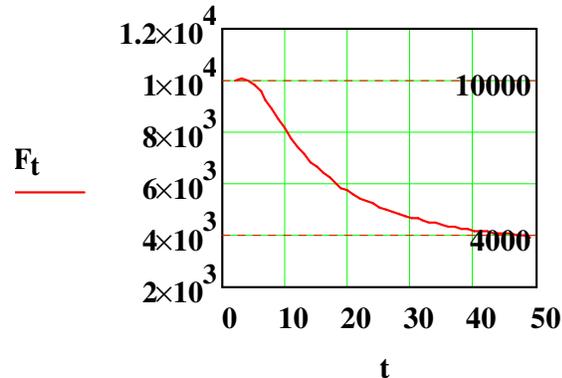


**Fig. 9.** Cylinder Force [N]

It is found that the maximum force $F_{max}$ occurs at the beginning of the platform lifting stroke, i.e. at the angle $\alpha_{min}$. For the points of

application of the established force (a= ℓ/4, b= ℓ/2), it is found that the driving force is 10 times greater than the load P.
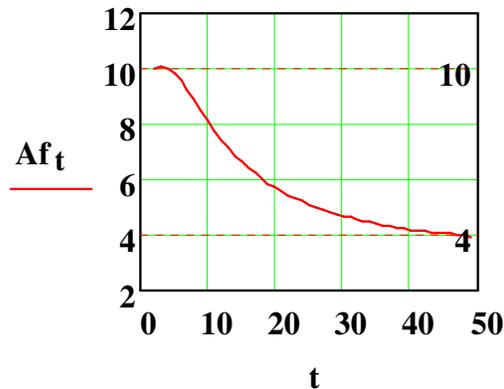
$Af_t$



**Fig. 10.** Force amplification factor

To optimize the connection points of the hydraulic cylinder to the platform, the values in table 1 were chosen for segments a and b. The values highlighted in table 1 meet the requirement imposed by equation (10).

*Table 1*

**Length for segments a and b**

| i, j | $a_i$ | $b_j$ |
|------|-------|-------|
| 1 | ℓ/5 | ℓ/5 |
| 2 | ℓ/4 | ℓ/4 |
| 3 | ℓ/3 | ℓ3 |
| 4 | ℓ/2 | ℓ/2 |
| 5 | 2ℓ/3 | 2ℓ/3 |
| 6 | ℓ | ℓ |

In figure 11 the variation of force F is shown as a function of time t and the position of point C by a=$a_i$.

$F_{t,1}$

$F_{t,i}$

$F_{t,5}$



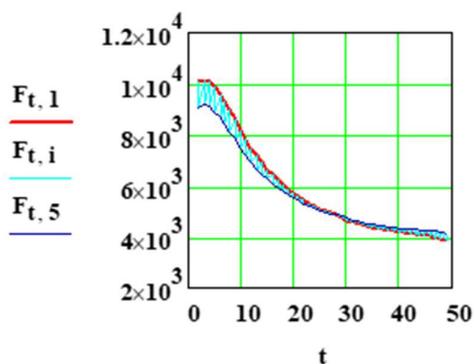**Fig. 11.** Cylinder Force b= ℓ/2, a= ℓ/5,…, 2ℓ/3

It is found that force F varies inversely proportional to a. It is important to reduce the force F at the beginning of the stroke when it is maximum (figure 12).
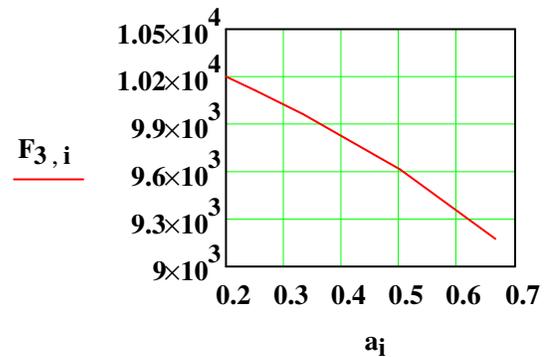
$F_{3,i}$



**Fig. 12.** Cylinder Force F(t,$a_i$), t=3 s

It is found that at the moment t=3 s the force is reduced by approximately 10% with the increase of the segment a from ℓ/5 to 2ℓ/3 (figure 13).
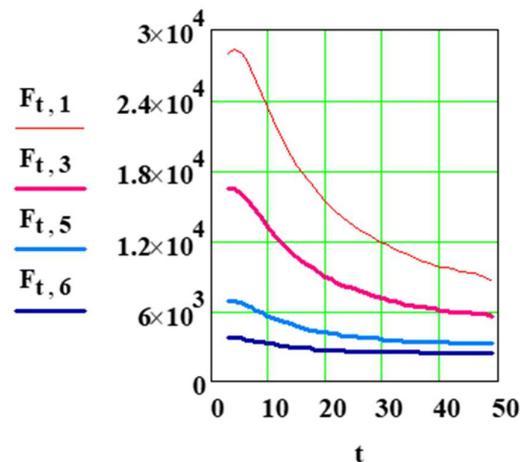
$F_{t,1}$

$F_{t,3}$

$F_{t,5}$

$F_{t,6}$



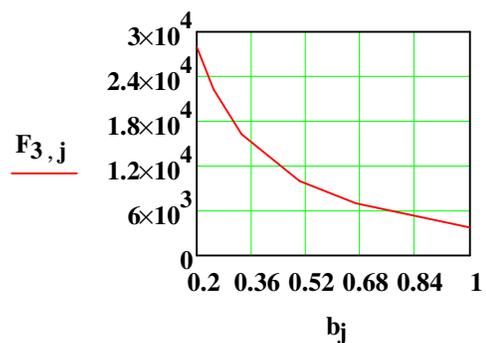**Fig. 13.** Cylinder Force F(t,$b_j$), t=3s

$F_{3,j}$



**Fig. 14.** Cylinder Force F(t,$b_j$), t=3s

The evolution of force F was analyzed with the change in length b=$b_j$ (figure 14). It is found that the force F decreases with the approach of point C to the joint $O_2$. It is found that at the moment t=3 s the force is reduced to 25% if b increases from ℓ/5 to ℓ (figure 13).

## 4. CONCLUSIONS

The algorithm is useful for the design and optimization of hydraulic k-scissors platforms. The algorithm has been implemented in a MATHCAD program that can be used in all phases of the design.

In order to be able to use the algorithm in the case of any multi-scissor type mechanisms, regardless of the type of drive (hydraulic or electric), it was decided to determine the force based on the equality between the work performed by the driving force and that of the load.

The optimization aims to reduce the maximum force. This occurs at the beginning of the platform lifting movement from the minimum height.

This research shows that the size of segment b has a much greater influence than segment a. This is the reason why it is recommended that point C be placed as close as possible to point $O_2$ at the beginning of step 3. Then, the optimal position of points B and C should be sought considering the type and dimensions of the hydraulic cylinders that would be suitable for the given application.

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### Algoritm pentru optimizarea plasării cilindrului hidraulic pentru platformele elevatoare multi-foarfece

Sunt cunoscute multiple aplicații care folosesc mecanisme de tip foarfecă pentru ridicarea unor platforme sau pentru roboți. Cursa platformei este mult amplificată în raport cu cursa actuatorului fapt pentru care forța motoare este mult mai mare decât sarcina. Mărimea sistemului de acționare se alege pe baza forței maxime și de aceea este important ca aceasta să fie minimizată. Lucrarea analizează influența amplasării actuatorului, în scopul reducerii forțelor și a optimizării sistemului de acționare. Algoritmul de optimizare poate fi aplicat la platforme cu două sau mai multe foarfeci și constă din următorii pași: stabilirea dimensiunilor și a numărului de foarfeci, analiza cinematică pentru determinarea legii de mișcare a actuatorului, iar în final de optimizare a punctelor de conectare a actuatorului.

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