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A study on the vector method for the design of a scissor lifts

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ABSTRACT: Scissor lifts have become a staple in various industries. The choice of a lift table system configuration is crucial as it directly impacts the system's functionality and the type of objects it can handle. This paper uses the vector method to explore the mathematical model of the configuration and load calculation for a scissor lift, focusing on the design parameters. The aim is to improve the performance of scissor lift systems, including lifting height, loading, and stability. A 2D-model of the system was created and simulated in the Working Model software to confirm the precision of the suggested approach. The simulation results show that by making adjustments to the mounting positions of cylinders, the elevation of the platform and reactions on the joints of the components can be calculated. This calculation helps to enhance the system's performance. In addition, the findings also demonstrate the practical importance in the calculation process and dimensional design of scissor lifts.

KEYWORDS: table scissor lift, parametric method, kinematic analysis, cylinder's orientation.

I. INTRODUCTION

A lift table is a device that raises and lowers objects, including people, using a scissors mechanism. The lifting height, weight lifting equipment, and lifting equipment according to drive devices are the three main criteria used when choosing lift devices. There have been numerous scissor lift layouts that focus on cylinder arrangement. These dimensions are crucial to the movement of the platform because they relate to the lifts' working area and cylinder operation.

Numerous studies have been undertaken to assess the functional capacity of devices in accordance with the aforementioned criteria. In their study, Solmazyiğit et al. [1] introduced a design for a scissor lift mechanism capable of effectively lifting weights weighing up to 25 tonnes, which was then fabricated and tested with positive results. The structural stability of a multi-layer scissor lift was assessed by Pan et al. [2] by a falling arrest test. This test aimed to verify the system's tip-over safety during the lowering process. In a separate investigation conducted by Dong et al. [3], it was shown that the tip-over potential of the scissor lift system is contingent upon the velocity of the cylinder. Additionally, the research findings suggest that the stability of the system is diminished in cases when connecting joints experience significant wear or when the structure itself sustains damage.

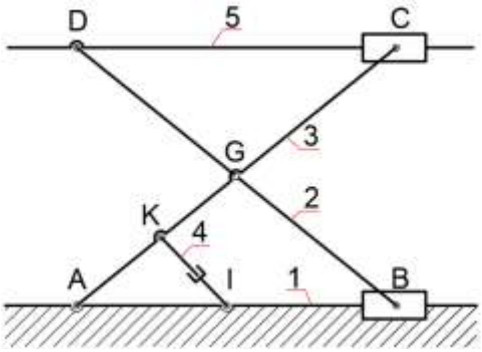

Figure 1 Diagram of the mechanism
1. Ground frame; 2. Inner frame; 3. Outer frame; 4. Cylinder; 5. Plat form

In addition to conducting empirical production and testing on physical devices, there are also studies that concentrate on theoretical models for the purpose of assessing the performance of lifting systems and determining the most optimised design. In their study, Spackman [4] used mathematical methodologies to examine the operational principles behind n-layer scissor lifts. The research not only examined the responses of the scissor members, but also addressed many design considerations pertaining to the positioning of actuators, the strength of the members, and the stiffness of the structure. In their study, Kosucki et al. (5) proposed the use of a volumetric controller as a means to effectively manage the rotational velocity of the cylinders. The study discusses the

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potential expansion of volumetric control for operating low-power drive systems, highlighting its notable benefits including a straightforward structure and cost-effectiveness. In their study, Karagülle et al. [6] used finite element analysis (FEA) to investigate the internal loads exerted on individual components of a single-layer system. The research was conducted on a three-dimensional model that was constructed using Solidworks software. Several studies have emphasised the use of simulation software for evaluating the performance of the system, while others have employed calculations of component lift strength to ascertain suitable design parameters [7, 8]. Nevertheless, the existing literature on the arrangement of cylinders and the development of a precise equation for calculating thrust force is limited, with only a limited number of publications addressing this topic. A study proposes applying the parametric dimension technique in designing double-stage scissor lifts with the cylinders arrange on parallel arms [9].

The present work involves the analysis of a scissors lift model, which is configured as shown in Figure 1. By using this model, it becomes feasible to compute the suitable dimensions for the system. The study's results are visually represented using graphic charts, which illustrate the correlation between platform operational factors and cylinder properties. Through the process of doing calculations, it becomes feasible to get a conclusion pertaining to the optimal dimension selection for the design and production of comparable devices.

II. KINEMATIC ANALYSIS

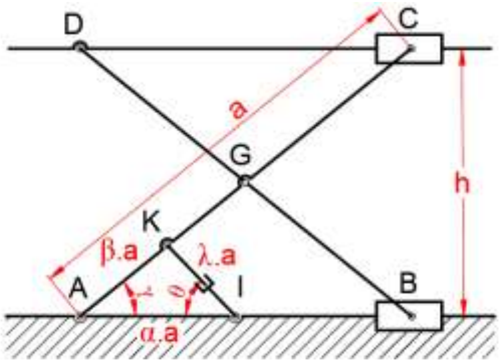

Figure 2 Table scissor lift with symbolic parameter

The movement of a scissor lift with different dimensions can be studied, and it can be concluded that the designate dimensions in Figure 2 have the most influence on the lift structure (in both movement and strength calculation). When the cylinder's length changes from l_{min} to l_{max}, the platform rises from the lowest (h_{min}) to the highest (h_{max}). However, this variable (h) is also affected by the frame length (AC, BD) and the angle between frames. As a result, it is difficult for designers to select the precise dimensions from the layout to simulate system movement.

Assign parameters for assembling dimensions $AC=a; AI=\alpha.a; AK=\beta.a; IK=\lambda.a$ (Where $\alpha>0, 0<\beta<1, \lambda_{max}>\lambda>\lambda_{min}>0$ is the cylinder length ratio compared to one frame) the system is parameterized as shown in Figure 2.

During operation, the cylinder's length changes from min to max to raise the platform's height from h_{min} to h_{max}, respectively. These expressions establish this height: When cylinder extends, platform height h can be calculated using following equation:

$$h = a\sin\gamma = a\sqrt{1-\cos^2\gamma} \tag{1}$$

The angle γ between frames is determine based on the relationship of the triagle AIK:

$$\cos\gamma = \frac{\alpha^2+\beta^2-\lambda^2}{2\alpha\beta} \tag{2}$$

Substitute Eq. (2) into Eq. (1); the height of the platform can be determined by the layout dimensions of the structure:

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$$h = a\sqrt{1-(\frac{\alpha^2+\beta^2-\lambda^2}{2\alpha\beta})^2}$$
$$= a\sqrt{(1+\frac{\alpha^2+\beta^2-\lambda^2}{2\alpha\beta})(1-\frac{\alpha^2+\beta^2-\lambda^2}{2\alpha\beta})}$$
$$= a\sqrt{(\frac{2\alpha\beta+\alpha^2+\beta^2-\lambda^2}{2\alpha\beta})(\frac{2\alpha\beta-\alpha^2-\beta^2}{2\alpha\beta}}$$
$$= a\sqrt{\left[\frac{(\alpha+\beta)^2-\lambda^2}{2\alpha\beta}\right]\left[\frac{\lambda^2-(\alpha-\beta)^2}{2\alpha\beta}\right]}$$
$$= a\frac{\sqrt{[(\alpha+\beta)^2-\lambda^2][\lambda^2-(\alpha-\beta)^2]}}{2\alpha\beta} \quad (3)$$

III. FORCE ANALYSIS

Throughout the functioning of the system, the forces exerted on the joints of a mechanism exhibit fluctuations in both magnitude and direction. According to the illustration shown in Figure 3, it is essential that the loading force denoted as W be precisely positioned at point P inside the system. Point P is situated between hinges C and D at the lowest level of the platform. However, when the platform ascends, the proximity between point C and point D increases, while the distance between point D and point P stays constant. The aforementioned phenomenon will have an impact on the equilibrium state of the structure as well as the amount of the force exerted on the frames. Nevertheless, a significant portion of recent scholarly investigations pertaining to scissor systems have mostly centred upon the development of a conceptual model for conducting simulations, without putting forward any approaches for assessing stability or improving frame dimensions.

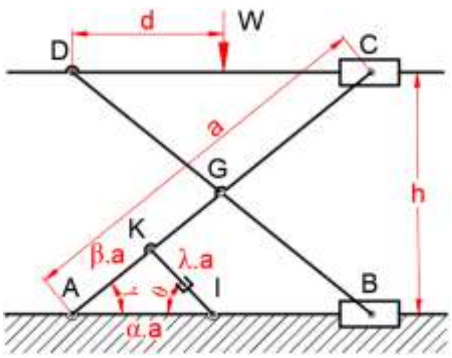

Figure 3 Location of load W when the platform worked

Given the assumption that the platform is elevated at a sufficiently moderate rate, so that the influence of acceleration may be disregarded. The computation of responses on the structure may be given in the following phases, considering that the load on the system and the weight of the cylinder are much lower than the weight of the frame.

In Figure 4, it can be seen that the scissor structure is detached from both the moving platform 5 and the ground platform 1.

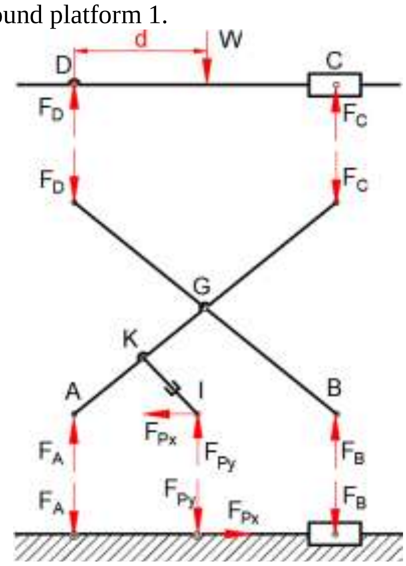

Figure 4 Separating component frames to determine reactions in the mechanism

The determination of the reactions at supports C and D may be achieved by using moment equilibrium equations, as shown by the provided figure.

$$\sum M_D = 0 \Leftrightarrow F_C.CD - W.d = 0 \Rightarrow F_C = \frac{W.d}{CD} = \frac{W.d}{a\cos\gamma} \quad (4)$$

$$\sum F_y = 0 \Leftrightarrow F_C + F_D - W = 0 \Rightarrow F_D = W - F_C = \frac{W.a\cos\gamma - W.d}{a\cos\gamma} \quad (5)$$

Second, release the connection at joints G, and separate these reactions into directional components $F_x$and F_y(see Figure 5):

Balancing the moment in BD frame:

$$\sum M_B = 0 \Leftrightarrow F_D.a\cos\gamma - F_{Gy}.\frac{a\cos\gamma}{2} = 0 \Rightarrow \frac{F_{Gy}}{2} = F_D = \frac{W.a\cos\gamma - W.d}{a\cos\gamma} \quad (6)$$

$$\sum F_x = 0 \Leftrightarrow F_{Gx} = 0$$

Apply the moment equilibrium equation for AC frame:

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$$\sum M_A = 0 \Leftrightarrow F_C.a\cos\gamma + F_{Gy}.\frac{a\cos\gamma}{2} - F_P.r = 0 \Leftrightarrow F_C.a\cos\gamma + F_{Gy}.\frac{a\cos\gamma}{2} - F_P.\alpha.a.\sin\theta = 0 \quad (7)$$

From (4), (5) and (6), (7) become:

$$W.a\cos\gamma - F_P.\alpha.a.\sin\theta = 0 \Longrightarrow F_P = \frac{W\cos\gamma}{\alpha.\sin\theta} \quad (8)$$

The angle θ between cylinder IK and ground frames is determine based on the relationship of the triagle AIK:

$$\cos\theta = \frac{\alpha^2 + \lambda^2 - \beta^2}{2\alpha\lambda} \quad (9)$$

Then:

$$\sin\theta = \sqrt{1 - \cos^2\theta} = \sqrt{1 - (\frac{\alpha^2 + \lambda^2 - \beta^2}{2\alpha\lambda})^2} = \frac{\sqrt{(2\alpha\lambda + \alpha^2 + \lambda^2 - \beta^2)(2\alpha\lambda - \alpha^2 - \lambda^2 + \beta}}{2\alpha\lambda} = \frac{\sqrt{((\alpha + \lambda)^2 - \beta^2)(\beta^2 - (\alpha - \lambda)^2)}}{2\alpha\lambda} \quad (10)$$

To find the acting force of the cylinder when applied the force W, substitude (10) into (9):

$$F_P = \frac{W\cos\gamma}{\alpha.\sin\theta} = \frac{W\cos\gamma}{\alpha.\frac{\sqrt{((\alpha+\lambda)^2-\beta^2)(\beta^2-(\alpha-\lambda)^2)}}{2\alpha\lambda}} = \frac{2.W.\lambda.\cos\gamma}{\sqrt{((\alpha + \lambda)^2 - \beta^2)(\beta^2 - (\alpha - \lambda)^2)}} \quad (11)$$

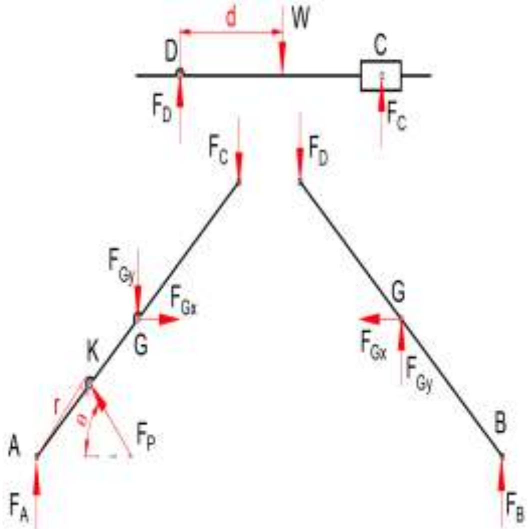

Figure 5 Release the connection at joints G

IV. RESULTS

In order to confirm the precision of the computation methodology, a total of five two-dimensional physical models were generated using the Working Model programme. These models were used to assess the reactions occurring at the joints, as seen in Figure 6.

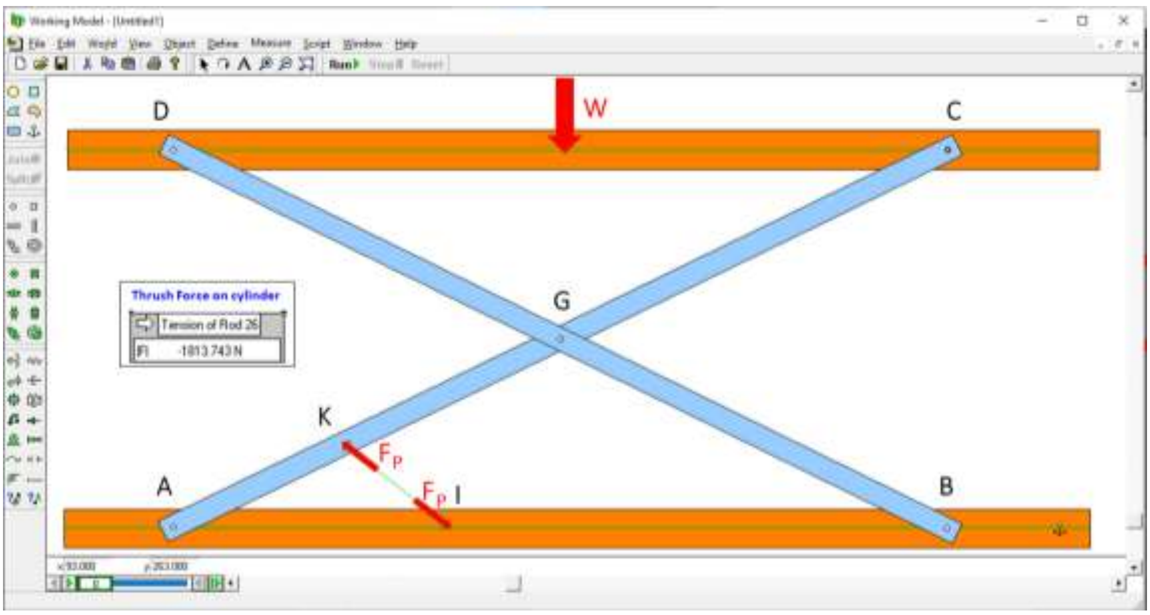

Figure 6 Export reactions at joints using Working Model

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The obtained results from this step are then compared with the results calculated using equations, as presented in Table 1.

Table 1 Bảng so sánhkếtquảtínhtoánvàmôphỏngcơcấubànnâng

$a = 0.8m; W = 800N; \lambda_{max} = 0.25$	$F_1[N]$	$F_2[N]$	D [%]
$\alpha = 0.4$ $\beta = 0.4$	1694,226	1695,195	0,057217
$\alpha = 0.4$ $\beta = 0.5$	1754,161	1755,543	0,078759
$\alpha = 0.5$ $\beta = 0.4$	1754,161	1754,387	0,012859
$\alpha = 0.5$ $\beta = 0.6$	1487,089	1488,415	0,08919
$\alpha = 0.6$ $\beta = 0.5$	1487,089	1489,06	0,132563

With $F_1$is reaction obtained by calculation; $F_2$is reaction measured from Working model and $D = \left|\frac{F_2 - F_1}{F_1}\right|.100\%$ is the difference between the two methods.

The first two models depict the outcomes of the same construction, with cylinder lengths of 0.2 m, correspondingly. The subsequent models illustrate formations characterized by randomly oriented cylinders. The calculation model's accuracy in identifying the reactions in the mechanism is shown by the observed deviations of less than 0.06%. This suggests that it is possible to precisely ascertain the design parameters without the need of constructing or simulating the system in three-dimensional virtual models, a process that may be time-intensive.

For detailed analyses, constraints such as the range of frame angular movement are applied (γ_{min} = 5° and γ_{max} = 75°), the operational length of the cylinder (10 mm for zero-stroke and 20 mm for full-stroke, corresponding to λ_{min} = 0.125 and λ_{max} = 0.25 for the given model with a = 0.8 m), and the maximum thrust force F_p = 3 kN. Based on this information, two graphs of lifting eficiency ΔH and the maximum loading for the cylinder at full-stroke (highest position) are constructed, as presented in Figure 7.

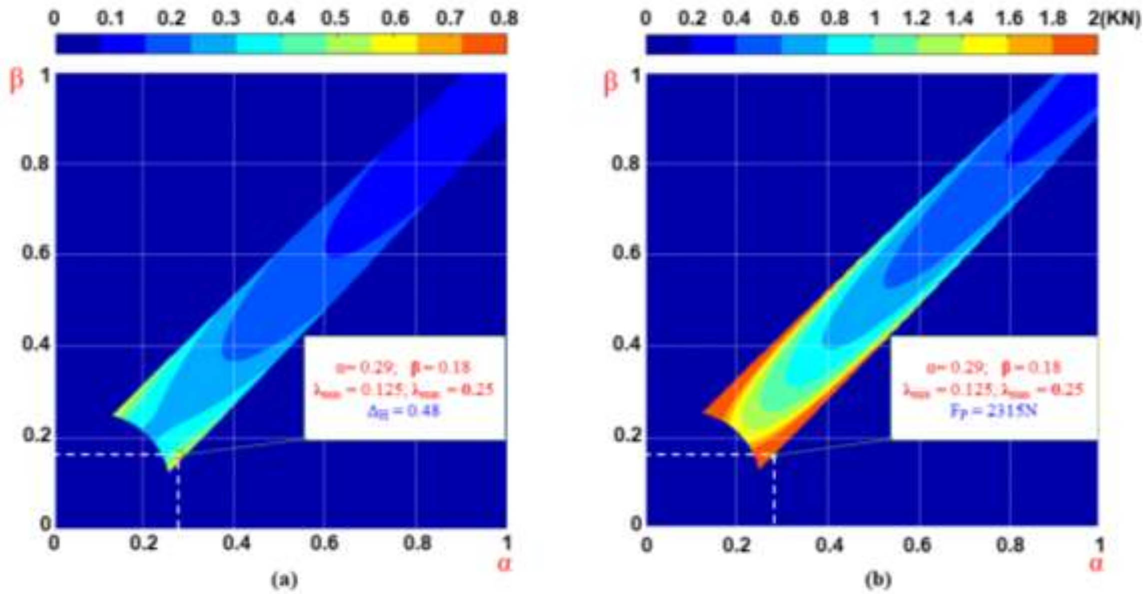

Figure 7 Graphs constructed from the given data (α,β); a) lifting eficiency ΔH, and b) maximum thrust force F_P. The graph also indicates that to achieve the highest efficiency for the cylinder, the cylinder orientation must be selected as α = 0.29 and β = 0.18 with ΔH=0.48m and $F_P = 2315N$

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V. CONCLUSION

The present research examines the suitability of using the parametric approach in the design of table scissor lifts. The study's findings are presented in the following manner:

• Through the use of basic dimensional characteristics, one may ascertain crucial data pertaining to table scissor lifts, including the height of the platform, the thrust force exerted by the cylinder, and the loading inside the revolution joints. This feature facilitates simplified component selection, eliminating the need for intricate 3D modelling or empirical testing.

• The use of the parametric approach enables the effective identification of the suitable cylinder, taking into consideration the design characteristics and the specified criteria.

• Through the examination of the responses and spatial orientation of the lift, it becomes feasible to enhance the configuration of the system, resulting in decreased expenses and reduced computational duration.

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