Calculation for variations in resistance force during trailer unloading device operation

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Abstract. Transportation tasks can make up to 20% of the labor expenditures associated with growing, harvesting, and shipping agricultural commodities, and their expenses can reach up to 35.40 percent of the entire cost of production. In addition, labor-intensive loading and unloading procedures involve packed and piece items. Employing mobile loading equipment that can travel straight across the field is the foundation for mechanizing the loading and transfer of packed, packaged, and piece items. Conflicting needs for the loading and transport systems of such units lead to insufficient serial unit efficiency metrics, most notably productivity and resource intensity. The article comprehensively studied the changes in the resistance force and their equations in the working process of the lifting-tipping device trailers.

1 Introduction

A number of works have been carried out by our country's and foreign scientists in order to improve the durability, reliability and operational characteristics of trailers and their elements, to improve their construction, and to improve their main parameters that determine their working capabilities, and these works are still ongoing. Among the scientists of our country O.V. Lebedev, A.D. Glushenko, A.A. Shermuhamedov, Sh.P. Alimuhamedov, G.K. Annakulova, A.A. Togaev, F.M. Matmurodov, B.J. Astanovs and foreign countries T.M. Bashta, V.I. Malik-Gayzakov, E.A. Slivinsky, A.G. Denisov, E.N. Khrestoporov, P.R. Bartosh, I.G. Selevenchik, P.N. Kishkevich, A.V Solamadze, Y. Efe, M. Akhin, Z. Kamiński, K. Heybrouk, K. Maehata and others carried out scientific work. General calculation rules of the hydraulic system of lifting devices A.A. Shermuhamedov, I.I. Usmanov, R.T Salimdzhanov and A.A Togaev's scientific work [1]. F.M. Matmurodov and F. U. Yuldashev in here scientific work [2, 3] studied the kinematic and dynamic parameters of the overturning devices of the cotton picking machine. Research on kinematic, static and dynamic calculations of the truck-dumper lifting device A.A. Shermuhamedov and his students [4, 5, 6, 7, 8].

Determining the resistance forces acting on the device during the operation of the trailer unloading device and their variation is of great importance in the design of trailers. This is

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because the basic dimensions and parameters of the trailer design elements are determined by the resistance forces acting on them.

An analysis of the available technical literature, published scientific papers, and Internet data shows that this issue has not been fully researched.

2 Methods

The unloading device of trailers consists of hydraulic and mechanical systems. The hydraulic cylinders resting on the frames $A$ of the frame are affected by the hydraulic cylinder platform, which is interconnected by the base point $B$, which tends to rotate around the base $C$, which connects the platform to the frame. As a result, the platform turns at a certain angle and performs the process of unloading loads from the trailer (Figure 1).

Fig. 1. Scheme for calculating the resistance forces acting on the device.

The amount of total resistance applied to the device during the lifting of the platform varies according to the following factors:

1. Due to the decrease in the mass of the load as a result of the load spilling from the platform;
2. Due to the fact that part of the total resistance force acting on the device passes through the platform support to the frame;
3. Due to the change in the coordinates of the center of gravity.

Since the angle of inclination of the platform during the operation of the device ($\alpha$) simultaneously affects all factors that lead to a change in the total resistance of the device, it is a complex variable during the operation of the device, which determines the static resistance ($F_{res}$) function.

$F_{res}$ - is the static resistance of the platform (including load),

$$F_{res} = (m_1 + m_2) \cdot g$$

If we denote the variable resistance force by $F_{\alpha}$:

$$F_{\alpha} = F_{res}(\alpha)$$

In the process of unloading loads from trailers (platform turning angle $\alpha > 0$), the device is affected by the mass resistance force, which is the sum of the mass of the load - $m_1$, the mass of the platform (including body) $m_2$ and the masses of the moving parts of the hydraulic cylinder - $m_3$. The variable resistance force ($F_{\alpha}$) during the overturning process can be
determined as follows, taking into account the frictional forces on the bases (A and C) of the moving parts of the device:

\[ F_\alpha = \frac{(m_1+m_2+m_3)g \cdot \cos \alpha}{K^n \cdot K_C^n} \]  

(1)

here: \( \alpha \) - is the angle of rotation of the platform, \( g \) - is the acceleration of free fall; \( K \) - is the efficiency of the base C; \( K_A \) - is the efficiency of the base A; \( n \) - is the number of bases.

Equation (1) is a mathematical expression for determining the variable resistance force acting on a trailer unloading device during operation.

When the device rises and forms a certain angle with the frame during operation, to maintain equilibrium on the platform (along with the load), its center of gravity moves from point \( B \) to point \( O \) and to this point the resistance force \( (F_\alpha) \) changes depending on the angle of rotation \( (\alpha) \) affects.

Since the hydraulic cylinder acts on the platform through point \( B \), the force \( F_\alpha \) must be reduced from point \( O \) to point \( B \) to determine the force acting on the lifting device. To do this, using the equation for maintaining the equilibrium position of the platform at the angle of inclination \( \alpha = 0 \) and the slope, it is possible to determine the interdependence of the resistance forces acting on the points \( O \) and \( B \) as follows (Figure 1):

\[ F_0 \cdot BC = F_\alpha \cdot O_1 C \]

hence - \( F_{0 \text{res}} \) as follows:

\[ F_{0 \text{res}} = \frac{F_\alpha \cdot O_1 C}{BC} \]

if is, \( O_1 C = \frac{BC}{\cos \alpha} \)

\[ F_{0 \text{res}} = \frac{F_\alpha}{\cos \alpha} \]  

(2)

will be.

Expression (2) is the equation for bringing the force of resistance acting on the center of gravity of the platform at \( \alpha > 0 \) to the center of gravity at \( \alpha = 0 \).

Identify the components of the resistance force acting on the device during operation. The resistance force acting on the device during operation \( (F_{0 \text{res}}) \) consists of the normal force acting on the hydraulic cylinder \( (F_0) \), perpendicular to the platform) and the longitudinal force \( (F_2) \) acting on its support along the platform surface.

The resistance force \( (F_0) \) acting on the hydraulic cylinder during the operation of the device is determined as follows:

\[ F_0 = F_{0 \text{res}} \cdot \cos \alpha = \frac{F_\alpha \cdot \cos \alpha}{\cos \alpha} = F_\alpha \]  

(3)

It can be seen from expression (3) that the force \( F_\alpha \) acts on the hydraulic cylinder independently of the angle of rotation \( \alpha \), and the calculation of the hydraulic cylinder is carried out on the force \( F_0 = F_\alpha \).

The resistance force \( (F_2) \) acting on the platform is determined as follows:

\[ F_2 = F_{0 \text{res}} \cdot \sin \alpha = \frac{F_\alpha \cdot \sin \alpha}{\cos \alpha} = F_\alpha \cdot \tan \alpha \]

Also, the normal force \( (F_0) \) consists of a force \( (F_1) \) directed along the axis of the hydraulic cylinder rod and a force resisting its movement \( (F_1') \) and a force resisting the rotation of the hydraulic cylinder. \( F_1' \) force acts in a direction perpendicular to the stock axis.

The forces \( F_1 \) and \( F_1' \) on the triangle \( ABB_1 \) are determined as shown in Figure 1.

If we denote \( AB = a \), \( BB_1 = b \) and \( AB_1 = H \) the forces \( F_1 \) and \( F_1' \) can be defined as follows:

\[ F_1 = F_0 \cdot \cos \alpha = F_\alpha \cdot \cos \left[ \text{arcsin} \left( \frac{b \cdot \sin (180^\circ - 0.5 \cdot \alpha)}{\sqrt{a^2 + b^2 - 2ab \cdot \cos (180^\circ - 0.5 \cdot \alpha)}} \right) \right] \]

\[ F_1' = F_0 \cdot \sin \alpha = F_\alpha \cdot \sin \left[ \text{arcsin} \left( \frac{b \cdot \sin (180^\circ - 0.5 \cdot \alpha)}{\sqrt{a^2 + b^2 - 2ab \cdot \cos (180^\circ - 0.5 \cdot \alpha)}} \right) \right] \]  

(4)
It is known that during unloading, loads slide from the platform to each other or to the supporting surfaces, and the variation of resistance forces during these processes varies.

Determination of variable resistance force for reciprocating sliding loads. As the sliding loads are shed during the process, part of the load passes through the base to the frame, and the total resistance changes due to changes in the center of gravity of the load.

In this case:

$$F_\alpha = F_0 = \frac{(m_1+m_2+m_3)g \cdot cosa}{K^n \cdot K_1^n}$$  \hspace{1cm} (5)

will be.

During the process, the mass \((m_1)\) of the load in expression (5) changes as follows, for the upper half of the load as follows:

$$m_1 = \frac{\rho \cdot B \cdot [2 \cdot A \cdot L^2 \cdot \tan(90^\circ - \varphi_0 + \alpha)]}{2}$$  \hspace{1cm} (6)

and for the lower half of the load:

$$m_1 = \frac{0.5 \cdot \rho \cdot B \cdot L^2}{\tan(90^\circ - \varphi_0 + \alpha)}$$  \hspace{1cm} (7)

3 Results

Substituting the value of \(m_1\) in expression (6) and (7) into expression (5) and defining the boundary conditions, the following system of equations is formed:

$$F_0 = F_\alpha = \begin{cases} \frac{[(0.5 \cdot \rho \cdot B \cdot [2 \cdot A \cdot L^2 \cdot \tan(90^\circ - \varphi_0 + \alpha))] + m_2 + m_3 \cdot g \cdot cosa}{K^n \cdot K_1^n}, & 0^\circ < \alpha \leq \varphi_0 - \arctg \frac{A}{L} \\ \frac{(m_2+m_3) \cdot g \cdot cosa}{K^n \cdot K_1^n}, & \varphi < \alpha < 45^\circ \end{cases}$$

$$F_2 = \begin{cases} \frac{[(0.5 \cdot \rho \cdot B \cdot [2 \cdot A \cdot L^2 \cdot \tan(90^\circ - \varphi_0 + \alpha))] + m_2 + m_3 \cdot g \cdot cosa \cdot \tan \alpha}{K^n \cdot K_1^n}, & 0^\circ < \alpha \leq \varphi_0 - \arctg \frac{A}{L} \\ \frac{(m_2+m_3) \cdot g \cdot cosa \cdot \tan \alpha}{K^n \cdot K_1^n}, & \varphi < \alpha < 45^\circ \end{cases}$$

here: \(\rho\) - is the density of the load; \(\varphi_0\) - is the natural slope angle of the load at rest; \(\varphi\) - is the angle of friction of the load on the slide; \(B\) - is the length of the load; \(L\) - is the width of the load; \(A\) - is the height of the load.

This system of equations takes into account the decrease in the angle of rotation of the sliding load mass depending on the value of \(a\), the passage of part of the load through the base, the change in the center of gravity of the load, the density of loads, friction in the supports and the natural angle of inclination indicates the change in resistance force during the process.

Determination of variable resistance force for sliding loads sliding on base surfaces. In trailers, the masses of the loads sliding along the supporting surfaces are almost constant during the process, and they are shed suddenly at the end of the process. However, in this process, part of the load passes through the base to the frame and the resistance also changes due to the change in the center of gravity of the load.

This change can be expressed as follows:

$$F_\alpha = F_{0 \, res} \cdot cosa$$

from it:

$$F_{0 \, res} = \frac{F_\alpha}{cos \alpha} = \frac{(m_1 + m_2 + m_3) \cdot g \cdot cosa}{K^n \cdot K_1^n \cdot cosa} = \frac{(m_1 + m_2 + m_3) \cdot g}{K^n \cdot K_1^n}$$
The components of the force $F_{0\,\text{res}}$ are defined as follows:

\[
F_0 = F_{0\,\text{res}} \cdot \cos \alpha = \frac{(m_1 + m_2 + m_3)g \cdot \cos \alpha}{K^n - K_1^n} \quad 0 \leq \alpha \leq \varphi,
\]

\[
F_2 = F_{0\,\text{res}} \cdot \sin \alpha = \frac{(m_1 + m_2 + m_3)g \cdot \sin \alpha}{K^n - K_1^n} \quad 0 \leq \alpha \leq \varphi
\]

These equations show that the angle of rotation of the load sliding on the base surface decreases with respect to the value of $\alpha$, part of the load passes through the base to the frame and the resistance of the load changes during the process, taking into account the center of gravity.

Here: $\varphi$ - is the friction angle of the loads on the base surface.

**Fig. 2.** Diagram of change of resistance force ($F_0$) acting on the device on the angle of rotation of the platform ($\alpha$), wheat on the left and cotton on the right.

**4 Conclusion**

The general rules of calculation of the hydraulic system of the unloading devices of trailers are given in the scientific works of A. A. Shermukhamedov and Kh. Baynazarov [1, 4, 5, 6, 7, 8]. In his scientific work F. Matmurodov studied of kinematic and dynamic parameters on the lifting equipment of a cotton picking machine [2]. F. Yuldashev research to determine the basic parameters of the car self-propelled lifting device [3]. The analysis of the available technical literature, published scientific works and internet data shows that this issue has not been fully researched [9, 10, 11, 12, 13].
The following conclusions can be drawn from the research:

- The resistance force $F_\alpha$ acting on the center of gravity of the platform at $\alpha > 0$ is increased by $\frac{1}{\arccos \alpha}$ times the force $F_{0\text{res}}$ applied to the center of gravity at $\alpha = 0$.

- The force acting on the hydraulic cylinder during the overturning process is $F_0 = F_\alpha$

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