Approaches to reduction of dynamic loads arising in truck-mounted hydraulic lifts

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Abstract. The article addresses approaches to reduction of dynamic loads arising in truck-mounted hydraulic lifts. Lifts are widely used to perform assembly and painting work in the course of construction. Dynamic loads, arising in the process of their operation, reduce performance and operational safety of lifts. The co-authors focused their research efforts on hinge mechanisms installed in truck-mounted hydraulic lifts. Hydraulic lift booms have hydraulic drives that ensure a uniformly continuous pace of hydraulic cylinder rod extension, but rotation speeds of the booms do not coincide, thus, causing them to move up by fits. This phenomenon triggers dynamic loads that arise in booms and make workers feel uncomfortable when on the platform. The co-authors provide motion equations for upper and lower booms of a lift. Having solved these equations, the co-authors obtained rational values of loads applied to the booms. Dependencies between varying values of the force in a hydraulic cylinder rod and the boom swing angle, as well as between the boom swing angle and the boom lifting angle are to be identified to reduce dynamic loads. These dependencies enable the co-authors to tailor the pump output. The co-authors suggest a rational system of proportional hydraulic cylinder control over acceleration or the force. Dependencies, obtained by the co-authors, can be applied to fine-tune the proportional distributor to make booms move smoothly, to reduce dynamic loads and to ensure a comfortable working environment for workers on the platform.

1. Introduction

Truck-mounted hydraulic lifts are construction machines that serve as mechanical aids in the process of construction. The number of accidents, involving hydraulic lifts, is driven by the growing volume of construction work. Worst accidents deal with the low reliability of hydraulic systems. Hydraulic lifts are equipped with one, two or more hinge booms. Levers and hydraulic cylinders are used to change the angle between them. The platform, attached to the top of the upper boom, is moved by changing the angle between top and bottom booms and by rotating the turntable [1]. Construction operations, involving hydraulic lifts, are performed by workers at some distance from the earth surface. Several accidents and injuries occurred due to the insufficient reliability of hydraulic systems [2]. Therefore, reliability improvement and development of recommendations for reduction of dynamic loads in truck-mounted hydraulic lifts have gained relevance [3, 4]. The following problems, dealing with the dynamic behaviour of hydraulic machines, arise: the temperature differential, demonstrated by the fluid inside different elements of the hydraulic system; the lack of an adequate description of the dynamic behaviour of hydraulic drive elements, which is needed to design a dynamic circuit composed of a hydraulic drive, a mechanical drive and metal constructions [5].
2. Results

Let us take a closer look at the behaviour of booms and hydraulic cylinders in motion. Research and analyses have shown that the rational choice of a swing angle, hydraulic cylinder rod pace, force and pressure values inside the hydraulic system can reduce dynamic loads. The resulting load, applied to the mechanism, is the total of dynamic and static loads. The hydraulic drive of a truck-mounted lift has a fixed capacity pump. Since the lifting speed depends on the swing angle of booms, it’s important to identify the influence of speed variations on the dynamic behaviour in motion. Open-loop fluid power drive systems, installed in truck-mounted lifts, have a significant impact on changes in dynamic loads due to the irregular boom lifting pace.

The pump capacity is invariable; that’s why the pace of the hydraulic cylinder extension in the course of boom lifting is constant; it depends on the diameter of the hydraulic cylinder responsible for lifting the boom, whereas the boom lifting (rotation) speed depends on the boom angle. Therefore, it’s important to know the dependencies that describe the kinematics of booms.

We use the design, demonstrated in Figure 1, as the basic one, and determine the parameters of lift booms.

![Figure 1. Design model.](image)

Boom angle $\alpha$ (Figure 1) can vary from 0 to 90°, while $\beta$ varies from 0 to 180°; therefore, the equation describing the motion of booms can be written as:

\[
\begin{align*}
  x &= a \cos \alpha + b \sin \theta \\
  y &= a \sin \alpha + b \cos \theta.
\end{align*}
\] (1)

If $\beta > 180°$, then:

\[
\begin{align*}
  \lambda + \beta &= 90° + \nu \\
  \lambda + \beta - 90° &= \nu
\end{align*}
\] (2)

Angle $t = \beta - 180°$, therefore:

\[
\begin{align*}
  x &= a \cos \alpha + b \sin t \\
  y &= a \sin \alpha + b \cos t.
\end{align*}
\] (3)

Let us identify dependence between the change in angle $\alpha$ and the change in the position of a hydraulic cylinder rod (Figure 2).
Figure 2. Dependence between the change in angle $\alpha$ and the change in the position of a hydraulic cylinder rod.

The rod pace is identified according to (4):

$$v = \frac{Q}{A}$$

(4)

where $Q$ is the fluid flow rate inside the hydraulic cylinder in square meters per second; $A$ is the piston surface area, identified according to (5):

$$A = \frac{\pi D^2}{4}$$

(5)

where $D$ is the hydraulic cylinder diameter in square meters.

Let us identify the relation between the rod pace and the angular speed of the boom (Figure 3).

Figure 3. Relation between the rod pace and the angular speed of the boom.

The direction of the rod pace changes as the hydraulic cylinder extends; pace direction depends on the swing angle of the hydraulic cylinder (see Figure 3). Initially angle $\beta'$, as demonstrated in Figure 3, is unaltered; however, further extension of the hydraulic cylinder causes the angle to change $\beta=\beta'+q$, while the speed of angular boom rotation can be calculated using formula (6):
ω = \frac{v_0}{x \cdot c}. \quad (6)

Angle \( v \) is the angle between speed \( v_{Hz} \) and speed \( v_0 \); it will be equal to \( v=90^\circ + \alpha - \beta \), then speed \( v_0 \) can be calculated using the formula:

\[ V_0 = V_{Hz} \cdot \cos \varphi. \quad (7) \]

The speed of booms, installed in truck-mounted lifts, changes depending on the angle of swing, and speed \( v_{max} \) is attained if angle \( \alpha = 80^\circ \).

Let us analyze the motion of the first boom as the most heavily loaded element. We will consider two motion modes; they are acceleration and continuous motion:

\[ M_d = J_{boom} \cdot \ddot{a} = P_{n}(t)h_1 - (m_1h_1 + m_2h_2)g - c\varphi \quad (8) \]

where \( J_{boom} \) is the moment of inertia, \( m_1 \) is the mass of the first boom; \( m_2 \) is the mass of the second boom and the platform; \( \ddot{a}, a \) stand for the boom acceleration and displacement; \( c \) is flexural rigidity of the boom, being a cantilevered beam resting on two supports.

The moment arising during the displacement of booms is calculated according to the following formula:

\[ M = G_{l_1} + G_{l_2} + Qgl_3 \quad (9) \]

where \( G \) is the mass of the \( i \)-th boom in kilograms, \( l \) is the boom length in meters.

The force arising in the hydraulic cylinder is:

\[ F_{Hz} = PA_n \quad (10) \]

where \( A_n \) is the piston area, \( A_n = \frac{\pi D^2}{4} \).

Figure 4 shows dependence between the force changing in the hydraulic cylinder rod and the swing angle of a hinge boom.

![Figure 4. Dependence between the force arising in the rod and boom swing angle \( \alpha \).](image)

The analysis has proven that the load change, caused by the changing swing angle, represents a parabola, if the load is applied to the hydraulic cylinder rod (11):

\[ F = \alpha^2 + 48\alpha + 84. \quad (11) \]

Rod pace and angular speed are determined with regard for the swing angle (6), and \( \omega \) is calculated according to the following formula:

\[ \omega = \frac{V_{turn}}{R} \quad (12) \]
where $\omega$ is angular speed, $\frac{1}{c}$, $R$ is rotation radius in meters.

Figure 5 shows dependence between angular speed $\omega$ and swing angle $\alpha$.

![Figure 5. Dependence between angular speed $\omega$ and angle $\alpha$.](image)

3. Conclusion
The research results have evidenced dependence between the boom swing angle and the force in the rod which rises the hinge boom of a lift. Dependencies, obtained by the co-authors, will make it possible to rationally adjust the non-controllable pump output. It has been identified that any reduction of dynamic loads, arising in lifts, requires installation of controllable pumps or a system of proportional control over acceleration or forces in a hydraulic cylinder.

The analysis of various options has led the co-authors to the conclusion that the application of a system of proportional control over the force can ensure more reliable operation of a truck-mounted hinge lift and operational comfort on the platform. Besides, this measure can extend the service life of the metal construction of a lift boom and rationally fine-tune the extension pace of a hydraulic cylinder rod.

References
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