Reduction of dynamic loads on the hydraulic drive of forest boom lifter

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Abstract. The article is devoted to the reduction of dynamic loads on hydraulic drive by optimization of hydraulic cylinder for boom lifting and parameters of new damping device. A mathematical model of the working process of the boom lifting mechanism of serial hydraulic manipulator LV-184A has been solved. The optimal position of the hydraulic cylinder, in which the fluid pressure is reduced from 12.4 MPa to 11.3 MPa, has been found. It takes into account the forces of inertia and compliance of hydraulic drive. Connecting a new damper reduces the maximum pressure in the piston cavity of the hydraulic cylinder by 47%. The minimum of maximum values of the working fluid pressure is achieved when the damper throttle channel diameters are in the range of 4.0–4.5 mm. The aim (reduction of dynamic loads) is achieved by optimizing the configuration of the boom lift cylinders and the parameters of new damper. It significantly increases reliability of hydraulic drive elements and efficiency of manipulator-type machines in forestry complex.

1. Introduction

At present, forest manipulators are widely used in timber harvesting in the timber industry complex of Russia. Due to their versatility and economic efficiency, the manipulators are used in loading and unloading machines used in logging or thinning operations. Hydraulic manipulators are used to work with round wood in assortment and tree-length logging [1, 2]. Manipulators of the Velikie Luki Machine-Building Plant of TOK-70.1, ASM-1V.1, ASK-18A brands, installed on KAMAZ-65115, MAZ-6312V9 vehicles -429-012, KAMAZ-43118, are widely used in timber transport operations. Maikop Machine Building Plant produces hydraulic manipulators of LV-184 A-10, LV-185-14A, MM-100, LV-190-05 brands. They are used for the same purpose and can be installed behind the cab of a car or on the rear overhang of a subframe as a part of a road train. LV-184A model is the lightest in the payload class (52 kN) among the products of Maikop Machine Building Plant. The manipulator is produced in crane (LV-184A.OO.OOO) and forest versions (LV-184A.SYU.00-03). It is designed to work in special vehicles, as well as tracked and wheeled tractors of 30-50 kN traction class and stationary installations. In the forest version, the boom lifter of the manipulator is equipped with a hydraulic cylinder, a full-revolving rotator and a clamping gripper for logs. Other manipulators of various modifications fundamentally differ only in the load moment and handling radius. The scope and purpose of the machines are the same, only more powerful manipulators are placed on a more energy-saturated and heavy base.
High dynamic loading and premature failure of hydraulic equipment occur during the operation of hydraulic manipulators with long logs [2-4]. Therefore, new developments are needed to improve the hydraulic system. It can increase the technical level of forest manipulators. The dynamic load on the structure of forest manipulators largely depends on the location of lifting hydraulic cylinders of the boom (the most loaded mechanism) [5]. It also depends on the responsiveness of the hydraulic drive because different damping devices have been used in the design of models produced in the Russian Federation recently [6]. However, the used dampers are installed in the lower cover of the hydraulic cylinder. They dampen peak pressures only at the extreme position of the piston with the fully retracted rod.

Analysis of the literature showed that hydraulic dampers in foreign technique equipped with a hydraulic drive are also widely used to reduce dynamic loads and accumulate energy [7] when damping vibration. The article [8] presents the results of research on the choice of design parameters of the traction mechanism of ESH 20.90 walking excavator using an additional elastic damping device. Based on the solution of the inverse dynamic problem, taking into account the oscillatory movements, it was found that the elastic damping device makes it possible to reduce the dynamic loads in the starting mode and the duration of their impact. It significantly increases the logarithmic decrease in elastic oscillations. A dynamic model of a hydraulic damper with a safety valve is presented [9], taking into account the effect of the percentage of air on the oil compressibility. It was found that mixing oil with air reduces the resistance force of the damper and the equivalent damping. It is significantly reduced in disturbances with low amplitude and lower frequency. The dynamic characteristics of energy-saving hydraulic damper with simultaneous vibration damping have been studied [10]. With vibration excitation, the flow of hydraulic oil inside the damper cylinder is converted into mechanical energy from the rotation of the output shaft of the hydraulic motor. A hydraulic motor drives an electromagnetic generator. The maximum power collected by an electromagnetic generator with preliminary harmonic excitation with amplitude of 0.02 m and frequency of 0.8 Hz was 435.1 W.

However, existing dampers cannot be used in hydraulic drives of forest manipulators without additional research and design changes taking into account operating conditions.

The aim of the study was to reduce the dynamic loads on the hydraulic drive of the boom lifting mechanism of forest manipulator. It is made by optimizing the configuration of hydraulic cylinder and parameters of the new damping device.

The novelty of the research is combined method of reducing dynamic loads which is used for the first time in the world. It simultaneously includes optimization of kinematic diagram of the boom lifting mechanism and the parameters of the damper. The design of the damper is protected by an invention patent.

2. Materials and methods
A new design damper is connected to the hydraulic system of the boom lifter between the piston and rod cavities of the hydraulic cylinder to reduce dynamic loads. Unlike existing designs, it enables to damp vibrations of the working fluid when the hydraulic cylinder piston stops not only in the extreme, but also at intermediate positions [11].

The modernized hydraulic manipulator LV-184 A, produced by OJSC (Open Joint Stock Company) Maikop Machine Building Plant was chosen as the object of the study. It is installed on the chassis of a serial truck. A design diagram is drawn up to determine the optimal location of the lifting cylinder of the boom (figure 1).
Figure 1. Design diagram of the boom lifting mechanism.

The system of differential equations for the flow rate of the working fluid in the hydraulic drive and boom movement, taking into account the influence of inertia forces and hydraulic drive flexibility, has the form:

\[ QK_i = \frac{\pi d^2}{4} b \sin \beta \frac{d\varphi}{dt} - a_i P + K_w \frac{dP}{dt}, \]

\[ (J_b + m_l^2) \frac{d^2\varphi}{dt^2} = \frac{\pi d^2}{4} P b \sin \beta - g(m_l + m_t^l) \cos \varphi, \]

where

\[ Q \] − rated pump flow, m³/s;
\[ t \] − time, s;
\[ J_b \] − moment of boom group inertia relative to the joint O, kg·m²;
\[ m \] − mass of tree lengths, kg;
\[ l \] − OS boom length, m;
\[ g \] − gravity acceleration (9.8 m/s²);
\[ a_i \] − coefficient taking into account fluid leakage, m⁵/Ns;
\[ P \] − hydraulic pressure (current value), Pa;
\[ K_w \] − hydraulic drive compliance coefficient, m⁵/Pa (determined by empirical dependence);
\[ d \] − inner...
diameter of the hydraulic cylinder, m; $\varphi$ – current angle of the boom, degrees; $m_b$ – weight of the boom group, kg; $l$ – length of the segment from $O$ joint to the mass center of the boom group, m; $K_t$ – increase coefficient in the flow of the working fluid to the $Q$ value; $S_i$, $S_f$ – standard initial and final lengths of the hydraulic cylinder, m; are specified in the source data; $S$ – current length of hydraulic cylinder, m; $\varphi_i$ – initial angle of boom rotation, degrees; $\varphi_f$ – final angle of rotation of an arrow, degrees.

The design diagram of the damper with its basic geometric parameters is shown in figure 2.

The differential equation of plunger motion in a new damper has the form:

$$\ddot{x}_d = \frac{1}{m_d} \left( P \frac{\pi (D^2 - d_p^2)}{4} + P \frac{\pi d_p^2}{4} - P \frac{\pi (D^2 - d_{sh}^2)}{4} - P \frac{\pi d_{sh}^2}{4} - \dot{x}_d k_d \right),$$

where $x_d$ – plunger displacement in the body due to different values of acting forces, m; $m_d$ – damper piston mass, kg; $k_d$ – coefficient of viscous friction of the plunger when moving in damper; $d_k$ – diameters of the throttling channel, m; $d_p$ – diameter of the piston cavity, m; $d_{sh}$ – diameter of the rod cavity, m; $D$ – diameter of the plunger, m; $H$ – length of the plunger, m.

The computer program "Program for modeling the damper of the hydraulic system of the manipulator of a timber truck train" in Object Pascal language in the Borland Delphi 7.0 integrated programming environments was used to solve the mathematical model of the working process of the hydraulic drive of the boom lifter. The certificate of official registration of the computer program No. 2008613263 was received.

Two computer experiments were carried out to assess the effect of the damper on pressure jumps in the hydraulic lines of the hydraulic cylinder. The first experiment was conducted without a connected damper. In the second experiment, the mathematical model of the hydraulic subsystem contained damper with typical parameters. For the basic experiment, the following values of the input parameters were chosen: $P = 20$ MPa; $Q = 1.33 \cdot 10^3$ m$^3$/s; $m = 600$ kg; $m_b = 250$ kg; $K_t = 100 000$ N·m·s/rad; $l = 6.115$ m; $l_i = 0.45$ m; $d = 0.1$ m; $m_d = 1$ kg; $H = 0.045$ m; $d_p = 0.042$ m; $d_{sh} = 0.035$ m; $D = 0.065$ m.

The effectiveness of the damper is determined by the diameter of the throttling channels of the plunger. A series of 21 computer experiments was carried out to study the influence of the throttle channel diameter on the dynamic load of the hydraulic drive of the boom lifter. In the experiments the throttle channel diameter was changed from 0 to 10 mm with a step of 0.5 mm.

3. Results and discussion

Calculations using a computer program showed that for the upgraded LV-184A hydraulic manipulator, the optimal position of the hydraulic cylinder, taking into account the forces of inertia and the
flexibility of the hydraulic drive, is achieved when the distance of the joint for connecting the hydraulic cylinder to the boom to the joint for connecting the boom to the swing column is 0.9 m. Without taking them into account, the optimum was achieved at a distance of 0.66 m. The working fluid pressure was reduced from 12.4 MPa to 11.3 MPa while maintaining the specified load moment, which significantly increases the reliability of the hydraulic drive elements and the machine as a whole.

The dependences of the pressure of the working fluid in the piston and rod cavities of the hydraulic cylinder on time in transient modes when the piston stops in intermediate positions are obtained (figure 3). Connecting a damper reduces peak pressure in the pressure hydraulic line of the piston cavity of the hydraulic cylinder by 47%, and the pressure hydraulic line in the rod cavity – by 25%. The use of a damper enables to smooth out pressure jumps in the hydraulic system, in addition, in transient modes, high-frequency pressure fluctuations are excluded, which cause fatigue destruction of metal structures of manipulator elements.

![Graphs](image_url)

**Figure 3.** Graphs of smoothing high-frequency pressure fluctuations when using piston dampers (a) and in rod (b) cavities.

As a result of computer experiments, the dependences of the maximum values of $P_{\text{max}}$, pressure in the cavities of the piston and rod of the lifting cylinder of the boom on the diameter of the damper throttle channel $d_k$ were obtained (figure 4).

The minimum pressure values $P_p$ are achieved at diameters $d_k$ in the range of 4.0–4.5 mm. It depends on the maximum pressure of the working fluid $P_p$ in the piston cavity of the hydraulic cylinder on the diameter of the damper throttle channel $d_k$. The minimum peak pressure values $P_{sh}$ are for diameters $d_k$ in the range 2.0–2.5 mm. It depends on the maximum pressure in the rod cavity of the hydraulic cylinder $P_{sh}$ on the diameter $d_k$. High values of the maximum pressure values $P_p$ and $P_{sh}$ are observed with a small diameter $d_k$, since the working fluid does not have time to flow through the throttling channels.
Figure 4. The diameter effect of the throttling channels on the peak pressure in the hydraulic system.

4. Conclusion
For the first time in the world, we are using a combined method of reducing dynamic loads (the goal of the study is achieved). At the same time, optimization of the kinematic diagram of the boom lifter and parameters of the new damper, the design of which is protected by an invention patent, is carried out.

The use of a new damper makes it possible to smooth out pressure surges in the hydraulic system. In addition, high-frequency pressure fluctuations in transient processes, which cause fatigue failure of the metal structures of the manipulator elements, are eliminated. When a damper is connected, the maximum pressure in the piston cavity of the hydraulic cylinder is reduced by 47%. The minimum values of the maximum working fluid pressures are reached when the damper throttling channel diameters are in the range of 4.0–4.5 mm. The maximum pressure decreases by 25% in the rod cavity of the hydraulic cylinder. The minimum of maximum pressure values is get when the diameters of the damper throttling channel are in the range of 2.0–2.5 mm.

Thus, it becomes possible to reduce the dynamic load of manipulator hydraulic drive. It highly increases the efficiency of manipulator-type machines in forestry complex and related industries.

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