Saving hydraulic drive of the grapple slewing gear in timber transport machines and improvement of its work processes

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Abstract. The research analysis of dynamics of technological machine work processes has been carried out. The aim of the work is improvement of work processes of the grapple slewing gear in forest transport machines by justification of energy saving hydraulic drive parameters. It enables to reduce dynamic loading and power consumption of the carried-out technological process. The computer program including the design data of new power-saving hydraulic drive of the grapple slewing gear affecting the efficiency of working processes is developed on the basis of a mathematical model of work process. As a result of computer experiments it is established that the energy-saving hydraulic drive with optimum parameters reduces the maximum pressure of actuating fluid during column braking. The pressure becomes equal to 3MPa. Recovery energy when turning the column is 25% of the spent energy. Amplitude of load swinging with a frequency of 0.8–1.5 Hz with the sharp change of the column movement mode decreases in 2–3 times.

1. Introduction

In the forestry industry, manipulator-type machines are in great demand. These machines [1] have rather strict requirements to: the grapple radius, the load moment, the final angle of rotation and the moment of column rotation, the maximum height of the load, and productivity.

The current loads on the hydraulic system, climatic conditions [2], and the specificity of the developed soils are taken into account. The priorities in creating high-quality machines are their reliability and durability under dynamic overloads. Grapples used in logging remain an important link, which the technological process depends on. Improving these machines will always be relevant [3].

A typical drawback of forest manipulators is the large dynamic loads in transient conditions and swinging of grips when hovering over a bunch of assortments and stacking the load in a predetermined position. It is necessary to combat the limitation of peak overflows of actuating fluid pressure. Reducing dynamic loading and energy intensity can be achieved in various ways: from upgrading existing structures to developing new types of devices. Safety valves, throttles, dampers are used as inhibiting fluid flow devices. A common drawback of these devices is limitation of fluctuations in the actuating fluid pressure. It occurs due to its flow from one cavity to another through the throttle holes. In this case, hydraulic energy is converted into heat, which leads to overheating of the liquid and loss of energy. The energy-saving hydraulic drive has technical advantages over compatibles [4]: the limitation of fluctuations in the pressure of the actuating fluid occurs due to the accumulation of energy during braking conditions and its return to the system during reverse movement.
Studies of the work process dynamics of harvesting machines were considered in the papers of famous scientists. Nesmianov I. A. and Khavronin V.P. [5] considered the dynamics of the hydraulic drive of the loading manipulator with elastic-damping bonds in the hydraulic system. Alexandrov V.A. [6] considered the emergency braking modes of the manipulator boom when working with loads, and the loading of the gripper mechanism. This process is accompanied by an additional dynamic load on the machine, which once again emphasizes the need to reduce it Posmetyev V.I. studied energy-saving hydraulic drives with a subsystem of energy storage of compressed air [1, 7, 8]. However, the use of compressed air in the recurrence system causes a negative effect of heat-mass transfer and the appearance of moisture, freezing of motor elements with the expansion of compressed air [9].

The authors developed a mechanism for turning the column of a grapple [10]. In the proposed design of the rotation mechanism, the energy-saving hydraulic drive not only accumulates the energy of inertia at the end of the column rotation and returns it during the reverse stroke, but also dampens dangerous peaks of pressure of the actuating fluid during transient conditions. An important advantage over compatibles [8] is that the recovery system uses actuating fluid instead of compressed air. The provided unloading and safety valves reliably protect the hydraulic drive from high pressure surges of the actuating fluid. At the same time, energy costs for technological operations are reduced, and productivity is increased. Up to now, the dynamics of hydraulic mechanisms (including the rotation mechanisms of the manipulator) [11], which would take into account the actual pattern of changes in the driving forces developed by the hydraulic drive, has been studied insufficiently.

The aim of the work is to improve the work processes of the grapple rotation mechanism of timber transport machines by substantiating the parameters of energy-saving hydraulic drive. It enables to reduce dynamic loading and energy intensity of the technological process.

The scientific novelty of the research lies in the fact that the mathematical models of the manipulator’s working processes and the computer program take into account the design parameters of the new rotator mechanism of the manipulator [10]. New dependences of the change in the actuating fluid pressure and the swinging amplitude of the load are revealed. They differ in consideration of the parameters of a new energy-saving drive. The parameters of an energy-saving drive are justified, differing in optimal values calculated according to the criteria for reducing dynamic loading, energy intensity and amplitude of load swinging in operating modes.

Research on this topic is very important for science. It solves the most common problems of power unit failure of modern manipulator-type machines. Achieving this goal will contribute to the possibility of equipping manipulator-type machines with less metal-intensive drive elements designed for lower pressures, providing energy saving, reducing the swing amplitude of the load and pressure peaks in the hydraulic system, affecting the wear resistance of the equipment.

2. Materials and methods

The developed mechanism for turning the column of the grapple [10] is taken as the object of the study. The experiments were carried out on its example. A computer program “Program for modeling the energy-saving hydraulic drive of the boom manipulator” was compiled in Object Pascal language in the Borland Delphi 7.0 integrated programming environment to conduct computer experiments with the model. The main limitations of the program: operating pressure of the hydraulic system from 2 to 30 MPa, time resolution 2×10^-6 s. The optimal step of numerical integration is determined by repeatedly conducting experiments with a step that sequentially decreases 2 times and stopping at the step after which the simulation results are practically unchanged. These results are 1-2%.

The program provides the output of schematic images of the manipulator and the load in three projections with the deviation of the load from the equilibrium position in the tangential and radial directions, graphs of pressure dependences in the left and right cavities of the hydraulic cylinders and grip fluctuations with a bundle of assortments.

First, an experiment without a air-charged accumulator with instant locking of the entrances to the swing hydraulic cylinders with diameters of 60-140 mm used on existing constructions of LV-210 and LV-184 manipulators was conducted. Next, the experiment was carried out when breaking the rotation
mechanism of the column with the connection of the air-charged accumulator, which recorded a pressure increase.

Two parameters of the pneumatic-hydraulic accumulator were selected based on computer experiments, which significantly affect the efficiency of energy-saving hydraulic drive. These are working volume of the pneumatic accumulator $V_{PD}$ and gas charging pressure $P_{PDA0}$.

The optimization criteria were: the energy stored by the pneumatic-hydraulic accumulator for one operating cycle of the $Ec$ manipulator; maximum pressure surge of the actuating fluid in the hydraulic drive $Pm$ over the working cycle; maximum deviation of the load in the tangential direction during the work cycle when it swings $Atm$; the maximum energy of pneumatic-hydraulic accumulator with the given parameters $Eo$. Computer experiments were carried out to calculate the criteria. When optimizing the accumulator parameters, each factor varied as follows: $V_{PD}$ was 2, 6 and 10 dm$^3$; $P_{PDA0}$ 3, 10 and 20 MPa.

3. Results
As a result of computer experiments, theoretical dependences of the actuating fluid pressure $P_p$ on time $t$ were obtained (figure 1). As you might have expected, the use of an energy-saving hydraulic drive enables to significantly reduce pressure surges in the hydraulic system. Figure 1a shows that a sharp braking of the rotary column leads to a pressure burst of up to 33 MPa, which is 13 MPa higher than the working pressure (20 MPa). An energy-saving hydraulic actuator can almost completely eliminate them, a pressure surge is 3 MPa (figure 1b).

![Figure 1. Graphs of theoretical dependences of the actuating fluid pressure $P_p$ on time $t$: without (a) and using (b) accumulator.](image)

It is necessary to maximize $Ec$ and $Eo$, and minimize $Pm$ and $Atm$ during optimization. Graphs of analytical dependencies were constructed for visual analysis of the obtained patterns during optimization of parameters. These analytical dependencies concern optimization criteria from the parameters of hydraulic-pneumatic accumulator (figure 2). Figure 2a shows the dependence of the
operating energy $E_c$ on the working volume $V_{PGA}$ and gas charging pressure $P_{PGA0}$ of the battery. Figure 2b shows the dependence of the pressure surge on $V_{PGA}, P_{PGA0}$. Figure 2c shows the dependence of the amplitude of load swing $A_{tm}$ on $V_{PGA}, P_{PGA0}$. Figure 2d is the dependence of the accumulated energy $E_o$ on $V_{PGA}, P_{PGA0}$.

Comparing the regenerative energy with the total energy expended in the rotation of the column, it was found that its share is approximately 25%. In the considered recovery system, an actuating fluid was used. In contrast to a recirculation system with compressed air [9], the negative effects of heat transfer are not observed in this system. The maximum amplitude of the load swinging in the tangential direction $A_{tm}$ is less than 0.25 m. Equipping the manipulator with an energy-saving hydraulic actuator allows reducing the load swinging amplitude (with a frequency of 0.8–1.5 Hz) by a factor of 2–3 with a sharp change in the movement mode of the rotary column. For diameters of hydraulic cylinders of 60–140 mm the working volume of the battery is 6–10 dm$^3$, and the gas charging pressure is 2–6 MPa.

4. Conclusion

Thus, the novelty of the research was development and implementation of a mathematical model in the form of computer program in which design data of the new turning mechanism protected by the patent for invention No. 2610848. No research has been conducted previously. New dependences of pressure changes in actuating fluid and amplitude of load swinging, taking into account reasonable parameters of the energy saving drive, have been revealed. The best values are calculated by the criteria of dynamic load reduction, power consumption and amplitude of load swinging in operating modes. Dynamic loading of the hydraulic manipulator and power consumption of work processes considerably decrease during the application of energy saving hydraulic actuator. At the same time metal consumption and soil specific pressure of the loaded machine decreases. Thereby soil cover

![Figure 2. Response surfaces to the optimization of $V_{PGA}, P_{PGA0}$ parameters of air-charged accumulator: a – dependence of $E_c$ on the parameters ($V_{PGA}, P_{PGA0}$); b – dependence of $P_{m}$ on the parameters ($V_{PGA}, P_{PGA0}$); c – dependence of $A_{tm}$ on the parameters ($V_{PGA}, P_{PGA0}$); d – dependence of $E_{o}$ on the parameters ($V_{PGA}, P_{PGA0}$).]
damage decreases. Decrease in power consumption, in its turn, enables to cut fuel consumption and emission of gases in the environment. The conducted research promotes improvement of work processes of energy-saving hydraulic drive of the grapple slew ing gear in timber transport machines and can be used in the design of new nodes and mechanisms.

References
[1] Posmetyev V I, Bartenev I M, Malyukova M A and Malyukov S V 2019 Energy saving of hydraulic drives of machines due to increase of effectiveness of hydraulic cylinders cuffs according to the results of simulation modeling IOP Conf. Series Materials Science and Engineering 483 012107 doi: 10.1088/1757-899x/483/1/012107
[2] Morales D O, Westerberg S, La Hera P X, Mettin U, Freidovich L and Shiriaev A S 2014 Increasing the level of automation in the forestry logging process with crane trajectory planning and control J. Field Robot. 31(3) 343 doi: 10.1002/rob.21496
[3] Chetverikova I V and Popikov P I 2016 Improving the effectiveness of road log trucks with hydraulic manipulators for the combined methods of delivery of wood in terms the North-West of Russia Actual Areas of Research of the XXI century: Theory and Practice 4(5-4) 173 [in Russian]
[4] Posmetyev V I and Nikonov V O 2017 Justification of the scheme of perspective design of recuperative hydraulic actuator of the forest cars, 1st Int.Conf. Innovative Processes and Technologies in the Modern World. (Ufa, Russia) (Ufa: Autonomous non-profit organization "Research Center for Information and Legal Technologies") pp 108-112 [in Russian]
[5] Nesmianov I A and Khavronin V P 2016 Dynamics of the hydraulic drive of the loading manipulator with elastic damping connections in the hydraulic system Modern Technics and Technologies 3 9614 http://technology.snauka.ru/en/2016/03/9614
[6] Alexandrov B A, Shol H R, Timokhov R C and Gasymov GW 2016 Loading of the filling-packing machine in the braking mode during the tree lifting by the Modern Knowledge-Intensive Technologies 2(2) 205
[7] Posmetev V I, Nikonov V O and Posmetev V V 2018 Investigation of the energy-saving hydraulic drive of a multifunctional automobile with a subsystem of accumulation of compressed air energy IOP Conf. Series Materials Science and Engineering 441 012041 doi: 10.1088/1757-899x/441/1/012041
[8] Posmetyev V I 2018 Perspective design of hydraulic actuator with gears of recovery of energy in forest cars with the trailer Voronezh Scientific and Technical Bulletin 3, 3(25) 4 [in Russian]
[9] Zhao P Y, Chen Y L and Zhou H 2017 Imulation analysis of potential energy recovery system of hydraulic hybrid excavator. Int. J. Precis. Eng. Man. 18 (11) 1575 https://doi.org/10.1007/s12541-017-0187-0
[10] Popikov P I, Klubnichkin V E, Bukhtoyarov L D and Chetverikova I V, RF Patent No 2610848 (16 February 2017)
[11] Nersesyan M A and Borisov VA 2019 Automation and management in technical systems Automation and Management in Technical Systems 7,1 28 [in Russian]