DOI:10.58168/SAS2025_258-265
УДК 630*3+811.111

REDUCING THE DYNAMIC LOADING AND ENERGY CAPACITY OF A LOG TRUCK HYDRAULIC MANIPULATOR USING A PNEUMO-HYDRAULIC DAMPING DEVICE

СНИЖЕНИЕ ДИНАМИЧЕСКОЙ НАГРУЖЕННОСТИ И ЭНЕРГОЕМКОСТИ ГИДРОМАНИПУЛЯТОРА АВТОСОРТИМЕНТОВОЗА ЗА СЧЕТ ПНЕВМОГИДРАВЛИЧЕСКОГО ДЕМПФИРУЮЩЕГО УСТРОЙСТВА

Путятин П.А., аспирант
ФГБОУ ВО «Воронежский государственный лесотехнический университет им. Г.Ф. Морозова», Воронеж, Россия.

Putyatin P.A., postgraduate student
FSBEI HE «Voronezh State University of Forestry and Technologies named after G.F. Morozov», Voronezh, Russia.

Abstract.

As a result of analyzing current and emerging solutions in the field of hydraulic drives for technological equipment, it has been established that mathematical modeling of operating processes is one of the key tools in the design and research of machines. This study is aimed at reducing energy consumption and minimizing dynamic loads in the boom lifting mechanism of a log truck manipulator. To achieve this, an energy-efficient hydraulic drive is proposed, with a model that accounts for the volumetric stiffness of the system. As part of the boom mechanism upgrade, the design includes the installation of a pair of twin hydraulic cylinders, one of which is connected to a hydraulic accumulator.

A distinctive feature of the system is that the accumulator operates independently, without being connected to the pump for recharging. Once fully charged by the recovery-mode hydraulic cylinder, it connects to a discharge valve and distributor through a system of check valves, allowing the pump to switch to idle mode, thereby reducing energy losses.

Keywords: hydraulic manipulator, boom lifting mechanism, energy efficiency, dynamic load reduction, hydraulic accumulator, mathematical modeling, pneumo-hydraulic damper.

Аннотация.

В ходе анализа современных и перспективных решений в области гидроприводов для технологического оборудования установлено, что одним из ключевых инструментов в процессе проектирования и исследования машин является математическое моделирование рабочих процессов**.** Настоящая работа направлена на снижение энергопотребления и уменьшение динамических нагрузок**,** возникающих в механизме подъема стрелы манипулятора сортиментовоза. Для этого предлагается использовать энергосберегающий гидропривод**,** модель которого учитывает объёмную жёсткость системы**.** В рамках модернизации конструкции стрелы гидроманипулятора предлагается внедрение пары сдвоенных гидроцилиндров**,** при этом один из них соединяется **с** гидроаккумулятором**.** При этом важным отличием является то, что гидроаккумулятор функционирует автономно**,** без подключения к насосу для зарядки.

После полного заряда от гидроцилиндра, работающего в режиме рекуперации, он соединяется с разгрузочным клапаном и распределителем через систему обратных клапанов**,** что позволяет перевести насос на режим холостого хода и сократить потери энергии.

Ключевые слова: гидравлический манипулятор, механизм подъёма стрелы, энергоэффективность, снижение динамической нагрузки, гидроаккумулятор, математическое моделирование, пневмогидравлический демпфер.

The performance of logging operations is significantly influenced by the operational reliability and condition of the machinery employed during material handling tasks. Research presented in sources [1–2] explores an advanced concept of a regenerative hydraulic drive system designed for timber manipulators. Through the application of mathematical and simulation-based modeling, the study reveals how variables such as time affect the volume of compressed air, as well as pressure and temperature within the pneumatic accumulator. After three full cycles of operation by both pneumatic cylinders, the pressure reaches approximately 2.3 MPa. During continuous air usage, pressure fluctuations remain minimal, not exceeding 0.4 MPa. It was also determined that repeated compression in pneumatic cylinders can lead to extremely high internal temperatures –exceeding 1000 K – with an average operating temperature ranging from 200 to 300 °C. These elevated thermal conditions are recognized as a major drawback of the pneumatic energy recovery systems under consideration.

An important task is to minimize overloads in hydraulic systems that occur during sudden changes in operating modes, which leads to premature wear of components and a decrease in machine life. This problem is especially relevant for manipulator mechanisms, the design of which provides hydraulic cylinders that are exposed to shock loads when working with wood.

Figure 1 presents the suggested hydrokinematic layout of the boom lifting mechanism, enhanced with an energy-efficient component. The redesigned lifting system for the forest manipulator includes the following elements: hydraulic reservoir (1), pump (2), control valve or hydraulic distributor (3), and hydraulic cylinder (4), which is connected to the distributor via pipelines (6 and 7). The structure also comprises boom sections (5) and a hydraulic energy recovery cylinder (8), positioned parallel to cylinder (4) between the boom (5) and the rotary support column (9). The piston cavity of the hydraulic recovery cylinder 8 is connected by a hydraulic line 10 through a pressure the non-return valve 11 is connected to the hydraulic accumulator 12, and through the connecting non-return valve 13 to the stem cavity of the same cylinder 8. In addition, the piston and stem cavities of the hydraulic recovery cylinder 8 are connected through a hydraulic line 14 and a suction non-return valve 15 to the hydraulic tank 1. The discharge and automatic assembly 16 contains a non-return valve 17, discharge 18 and safety 19 valves. A filter 20 and a check valve 21 are installed to drain the working fluid. A new technical solution is that in order to reduce pressure surges during starting and braking modes between hydraulic lines 6 and 7, instead of an inefficient and unreliable hydromechanical damper with a spring-loaded massive plunger and check valves, a new damper is installed, including a body 22 made of non-magnetic material, two movable pistons 23 and 25 and a fixed partition 24 made of magnetic material, facing each other with the poles of the same name. There is a throttle opening in the center of the fixed partition 24. In addition, in the new hydraulic drive boom lifting mechanism, the accumulator 12 is disconnected from pump 2 due to additional check valves 26 and 27 and bypass hydraulic line 28, so that the pump does not use energy to recharge the accumulator.

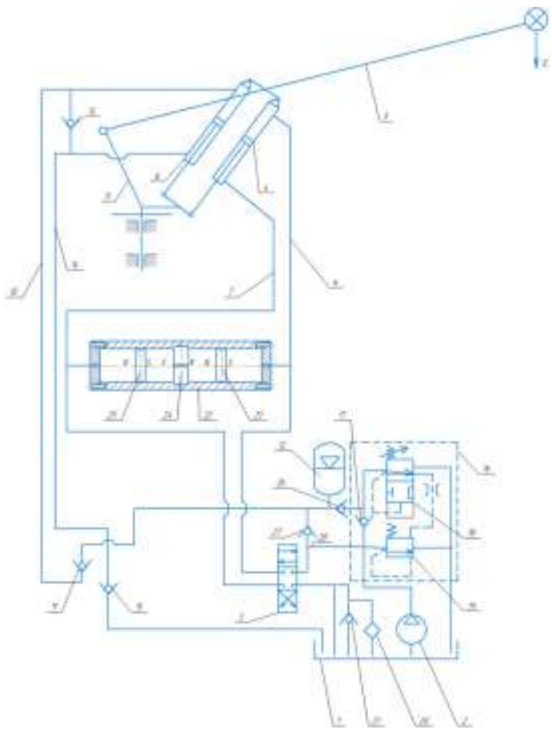


Figure 1. Hydrokinematic diagram of the boom lifting mechanism of a forest manipulator with an elastic damping energy-saving device

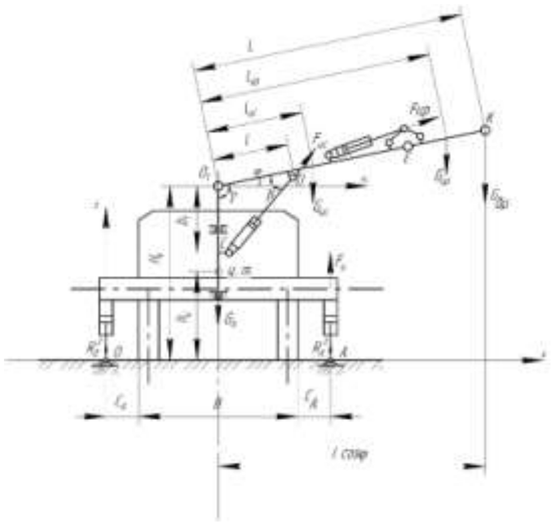


Figure 2. Calculation scheme of the manipulator

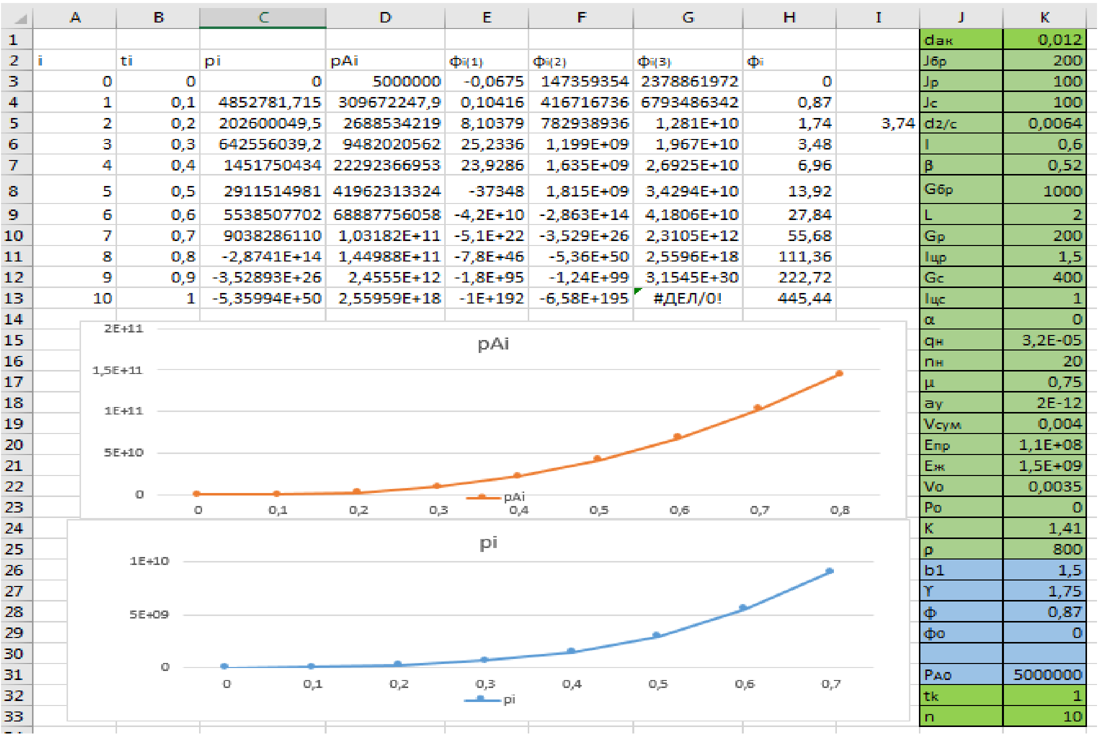
To compile a mathematical model, a design scheme has been developed for a new boom lifting mechanism for a forest hydraulic manipulator during operation (Figure 2).

1) The developed mathematical model comprises three differential equations. The first one describes the motion of the boom during the lifting of a load: the left-hand side of this equation represents the dynamic moment caused by the inertial forces of the boom assembly and the load, while the right-hand side accounts for the driving torque produced by the boom's hydraulic cylinder, reduced by the resisting torque generated by the gravitational forces acting on the boom, the handle, and the load;

2) The flow equation of the working fluid, on the left side is the performance (supply) of the gear pump driven by the engine of the base machine, and on the right side is the flow rate of the boom hydraulic cylinder when the rod is extended, the flow rate for charging the hydraulic accumulator, the flow rate for leakage through the gaps between the pistons and the sleeves of the hydraulic cylinders and the flow rate for deformation of elastic elements (hydraulic accumulator, damper, RVD)

3) The third equation characterizes the operating process of the hydraulic accumulator. It incorporates several key parameters: the pre-charge pressure of the accumulator set at 5 MPa, its effective working volume ranging between 4 and 5 cubic meters, the cumulative volume of the elastic components within the hydraulic system (in cubic meters), and the reduced modulus of elasticity that reflects the combined compressibility of both the working fluid and the system’s elastic elements.

Initial simulations carried out in the MathCad software enabled the calculation of dynamic characteristics for the energy-efficient hydraulic system powering the boom lifting mechanism. As illustrated in Figure 3, the pressure behavior of the working fluid was analyzed both within the hydraulic circuit and the pneumatic accumulator. Integrating an energy-efficient damping component into the hydraulic system of the lifting mechanism resulted in a noticeable reduction in peak pressure within the piston chamber’s hydraulic line during transitional operating phases—by approximately 1.5 to 1.6 times.



i	ti	pi	pAi	φi(1)	φi(2)	φi(3)	φi	
0	0	0	5000000	-0,0675	147359354	2378861972	0	
1	0,1	4852781,715	309672247,9	0,10416	416716736	6793486342	0,87	
2	0,2	202600049,5	2688534219	8,10379	782938936	1,281E+10	1,74	3,74
3	0,3	642556039,2	9482020562	25,2336	1,199E+09	1,967E+10	3,48	
4	0,4	1451750434	22292366953	23,9286	1,635E+09	2,6925E+10	6,96	
5	0,5	2911514981	41962313324	-37348	1,815E+09	3,4294E+10	13,92	
6	0,6	5538507702	68887756058	-4,2E+10	-2,863E+14	4,1806E+10	27,84	
7	0,7	9038286110	1,03182E+11	-5,1E+22	-3,529E+26	2,3105E+12	55,68	
8	0,8	-2,8741E+14	1,44988E+11	-7,8E+46	-5,36E+50	2,5596E+18	111,36	
9	0,9	-3,52893E+26	2,4555E+12	-1,8E+95	-1,24E+99	3,1545E+30	222,72	
10	1	-5,35994E+50	2,55959E+18	-1E+192	-6,58E+195	#ДЕЛ/0!	445,44	

dак	0,012
Jбр	200
Jр	100
Jс	100
dz/c	0,0064
l	0,6
β	0,52
Gбр	1000
L	2
Gр	200
lцр	1,5
Gс	400
lцс	1
α	0
qн	3,2E-05
nн	20
μ	0,75
aу	2E-12
Vсум	0,004
Eпр	1,1E+08
Eж	1,5E+09
Vо	0,0035
Pо	0
K	1,41
ρ	800
b1	1,5
Υ	1,75
φ	0,87
φо	0
PAо	5000000
tk	1
n	10

Figure 3. Fragment of the Exel program for determining the dynamic characteristics of an energy-efficient hydraulic drive

References

1. Posmetev V. I., Nikonov V. O., Posmetev V. V. Investigation of the energy-saving hydraulic drive of a multifunctional automobile with a subsystem of accumulation of compressed air energy // IOP Conference Series: Materials Science and Engineering. – IOP Publishing, 2018. – T. 441. – №. 1. – C. 012041.doi: 10.1088 / 1757-899x / 441/1/012041, (2018).
2. Lagerev, A.V. Modeling of work processes in a throttle-controlled hydraulic drive of manipulative systems of mobile machines with separate movement of links / A.V. Lagerev, I.A. Lagerev // Scientific and technical bulletin of Bryansk State University. - 2018. - No. 4. –pp. 355-379. – URL: https://cyberleninka.ru/article/n/modelirovanie-rabochih-protsessov-v-drosselno-reguliruemom-gidroprivode-manipulyatsionnyh-sistem-mobilnyh-mashin-pri-razdelnom.
3. Popikov, P.I. Substantiation of the layout and parameters of the hydraulic drive of the lifting mechanism of the forest manipulator / P.I. Popikov, I.D. Evsikov // Current directions of scientific research of the XXI century: theory and practice. 2019. Vol. 7, No. 3 (46). pp. 226-231.
4. Evsikov, I.D. Substantiation of the axioms of the formalized model of the arrow movement of a forest manipulator / I.D. Evsikov, P.I. Popikov, N.S. Kamalova // Voronezh Scientific and Technical Bulletin. - 2020. - Vol. 2, No. 2 (32). - pp. 4-10. – URL: http://vestnikvglta.ru/arhiv/2020/2-32-2020/4-10.pdf.

Список литературы

1. Posmetev V. I., Nikonov V. O., Posmetev V. V. Investigation of the energy-saving hydraulic drive of a multifunctional automobile with a subsystem of accumulation of compressed air energy // IOP Conference Series: Materials Science and Engineering. – IOP Publishing, 2018. – T. 441. – №. 1. – C. 012041.doi: 10.1088 / 1757-899x / 441/1/012041, (2018).
2. Лагерев, А.В. Моделирование рабочих процессов в дроссельно-регулируемом гидроприводе манипуляционных систем мобильных машин при раздельном движении звеньев / А.В. Лагерев, И.А. Лагерев // научно-технический вестник брянского государственного университета. – 2018. -

№4. –с. 355-379. – URL: https://cyberleninka.ru/article/n/modelirovanie-rabochih-protsessov-v-drosselno-reguliruemom-gidroprivode-manipulyatsionnyh-sistem-mobilnyh-mashin-pri-razdelnom.

3. Попиков, П.И. Обоснование компоновки и параметров гидропривода механизма подъема лесного манипулятора / П.И. Попиков, И.Д. Евсиков // Актуальные направления научных исследований XXI века: теория и практика. - 2019. - Т. 7, № 3 (46). - С. 226-231.

4. Евсиков, И.Д. Обоснование аксиом формализованной модели движения стрелы лесного манипулятора / И.Д. Евсиков, П.И. Попиков, Н.С. Камалова // Воронежский научно-технический вестник. - 2020. - Т. 2, № 2 (32). - С. 4-10. – URL: http://vestnikvglta.ru/arhiv/2020/2-32-2020/4-10.pdf.