DOI 10.52209/1609-1825_2022_3_241 UDC 621.879

Development of the Schematic Diagram and Calculation of the Hydraulic Control System of the Excavator in the Software Environment "FluidSIM – Fluid Modeling Program"

[1]**KUANYSHULY Zharashan,** *doctoral student, zkuanyshuly@gmail.com,*
[2]***SULEYEV Bakhtiyar,** *PhD, Director of Department, culeev_bahtiyar@mail.ru,*
[2]**KURMASHEVA Bakyt,** *Cand. of Tech. Sci., Dean, happiness_b@mail.ru,*
[3]**SAKHAPOV Rustem,** *Dr. of Tech. Sci., Head of Department, rusakhapov@gmail.com,*
[1]**BALABEKOVA Kyrmyzy,** *PhD, Associate Professor, 06_03_92@mail.ru,*
[1]*L.N. Gumilyov Eurasian National University, Kazakhstan, Nur-Sultan, Satpayev Street, 2,*
[2]*NPJSC «Abylkas Saginov Karaganda Technical University», Kazakhstan, Karaganda, N. Nazarbayev Avenue, 56,*
[3]*Kazan State University of Architecture and Engineering, Russia, Tatarstan, Kazan, Zelenaya Street, 1,*
**corresponding author.*

Abstract. *The purpose of the research presented in the article was to develop a basic hydraulic scheme of the excavator control system equipped with satellite systems for monitoring the position of equipment. The article substantiates the relevance of the research, examines the existing satellite positioning systems used to accurately determine the location of working equipment and machinery in general. The principle of operation of the excavator and its design features are described, taking into account the operation of the machine using location detection systems. The scheme of the hydraulic control system of the excavator in the software environment Festo FluidSIM is developed. Graphical data for modeling the operation of a hydraulic cylinder are presented. The main elements of the hydraulic drive of the excavator are calculated, on the basis of which the hydraulic cylinder of the working equipment is selected.*

Keywords: *excavator, bucket, working body, positioning system, rotary platform, hydraulic drive, hydraulic line, working fluid, hydraulic cylinder, piston rod, hydraulic motor, pressure.*

Introduction, literary review

It is extremely important to ensure the accuracy of the work during the operation of the excavator. In practice, this largely depends on the skill and qualifications of the operator. The excavator operator must accurately set the angle of attack of the boom and handle.

Modern machines use a satellite global positioning system for this. Today, three main satellite positioning systems are used to ensure operation – GPS, GLONASS, Beidou, DORIS, and Galileo [1]. Due to the low coverage of the DORIS and Galileo systems, their large-scale application has not found a place.

The key devices of the car navigation system is a tracker. The tracker acts as a device for receiving and transmitting data. It contains a GLONASS/GPS/GSM terminal that performs the functions of determining coordinates using a satellite receiver. Figure 1 shows an excavator with a satellite system.

The development of excavator control systems is reflected in the works of foreign and domestic scientists, among them is the work [2], which provides information about the excavator stability control system. The task of the system is to predict the probability of overturning the machine in difficult working conditions. Receiving information from the machine control system, artificial intelligence introduces motion correction.

In the article [3], a mathematical model has been developed that explains the operation of the bearing of the excavator platform rotation mechanism. Based on the model, the resistance forces acting on the operation of the rotation mechanism are determined, which makes it possible to predict the operation of the bearing.

The author [4] proposes the development of three machine learning algorithms for the excavator control process. This process is carried out by using various global positioning sensors and memory systems.

The development [5] is aimed at solving the control of the digging depth of the machine, in order to prevent damage to the pipes. With the help of radar, a signal is generated, which is received by the

Figure 1 – GPS control system

excavator control module and monitors the operation of the hydraulic cylinder.

A special place is occupied by the developments of domestic scientists, which are aimed at modernizing existing and developing new machine designs [6, 7, 8, 9, 10].

From the literature analysis, it can be concluded that the most relevant direction in ensuring the accuracy of the machine is the use of global positioning systems that ensure the accuracy of the installation of working equipment up to 0.5 cm.

To this end, it is necessary to develop a schematic diagram of the hydraulic drive of the control system and calculate its elements.

To achieve this goal, it is necessary to solve a number of tasks, namely:

- develop a schematic diagram in a software environment;
- check the operability of the circuit using the program and get graphical data;
- to calculate the main elements of the drive.

The scientific novelty of the work lies in the developed scheme of the hydraulic drive of the excavator control, based on the data received from the hydraulic distributor with electronic control.

The practical usefulness of the conducted research lies in the development of an excavator control system based on data obtained from the Festo FluidSIM software environment and the calculation carried out.

Materials and methods of research, research results

In order to develop the functioning scheme of the hydraulic drive of the excavator, the Festo FluidSIM software was used. A schematic diagram of a hydraulic drive has been developed in the software environment, the elements are collected from the data library of the software product.

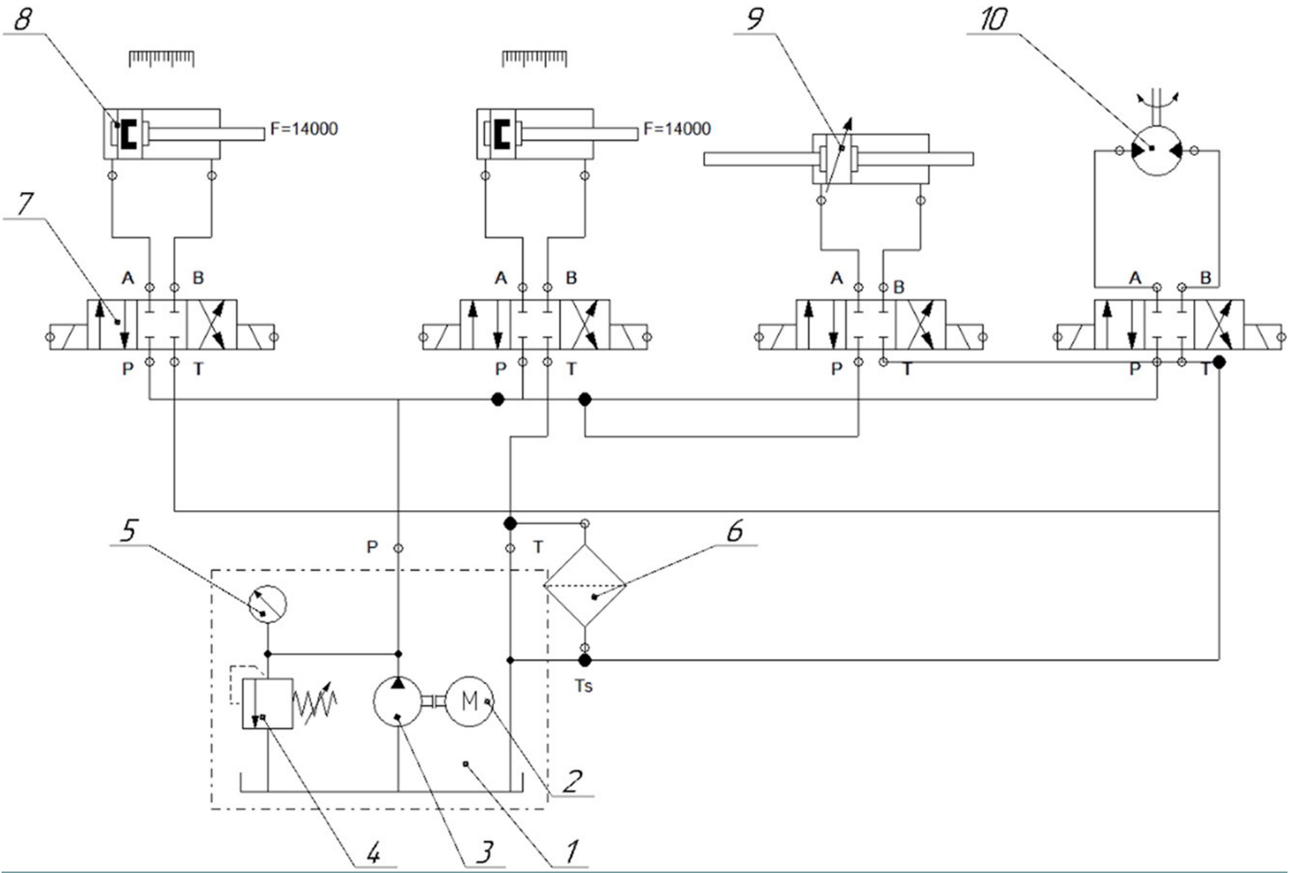
Designing a hydraulic drive system is a rather complex process that requires quite extensive knowledge. The advantages of a hydraulic drive are the physical characteristics of the fluid. These primarily include the non-compressibility of a liquid body, which allows, according to Newton's third law, to provide exactly the force that was spent on its compression. To ensure accurate positioning of the excavator's working equipment, it is necessary to use elements of the global positioning system. To do this, it is necessary to provide in the schematic diagram of the hydraulic drive (Figure 2) the presence of a controlled hydraulic distributor. The scheme provides an electromagnetic hydraulic three-position distributor.

When drawing up a hydraulic circuit, it is necessary:

- reduce pressure losses to a minimum;
- arrange the elements in such a way as to exclude mutual influence;
- provide for the presence of safety valves in the system;
- choose the working fluid according to the purpose and operating conditions of the machine;
- use the device in the drive according to the specifications.

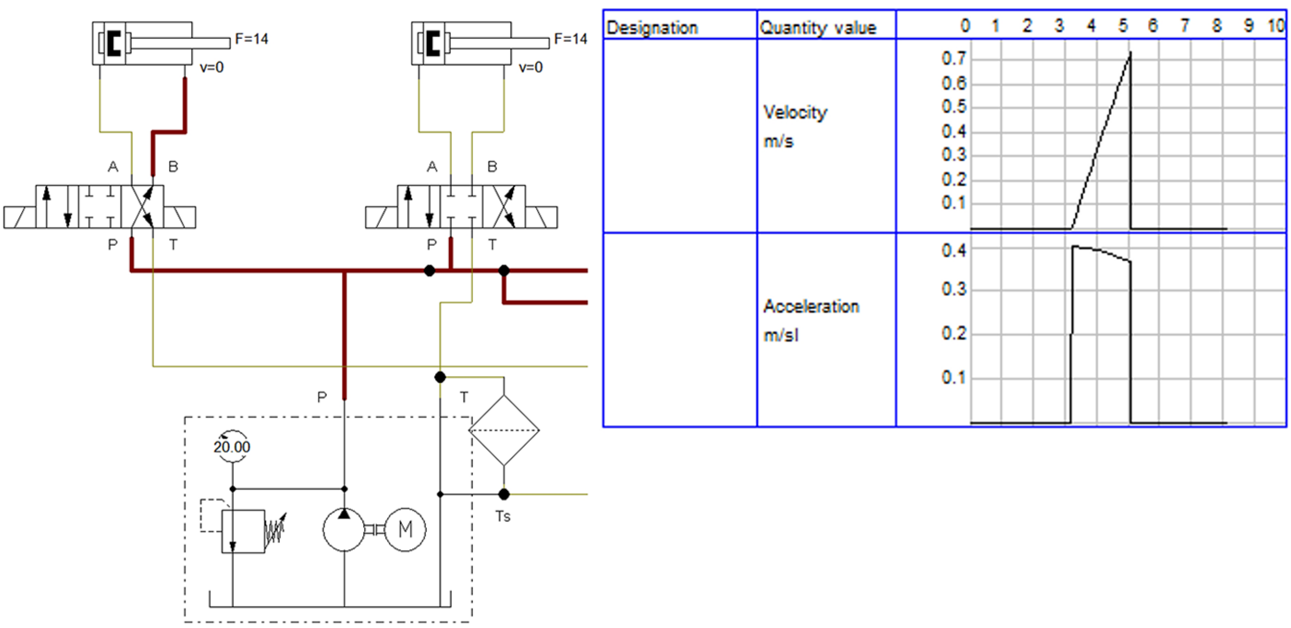
Figure 3a shows the flow diagram of the fluid inside, and the graph of the change in the speed of the rod and acceleration is shown in Figure 3b.

As can be seen from Figure 3b, the speed of movement of the rod increases until the end of the



1 – tank; 2 – drive motor; 3 – hydraulic pump of the NSH type; 4 – pressure reducing valve; 5 – pressure gauge; 6 – filter; 7 – hydraulic three–position distributor; 8 – hydraulic cylinders for lifting and lowering the handle; 9 – hydraulic cylinder of double-acting bucket; 10 – hydraulic motor for driving the rotary platform

Figure 2 – Schematic diagram of the hydraulic drive



a b

Figure 3 – Fluid flow diagram

movement, while the acceleration of the movement is uniform, primarily due to the fact that it is necessary to ensure uniform acceleration.

Calculate the drive elements. According to the obtained graphical data of modeling the operation of the hydraulic drive, it is necessary to determine the useful power of the reciprocating hydraulic motor (hydraulic cylinder). The obtained data provide an opportunity to obtain the necessary theoretical force in the hydraulic cylinder to ensure the operation of the working equipment

$$N_{\text{гдв}} = T \cdot \vartheta = 23000 \cdot 0.05 = 1.4\, kW, \quad (1)$$

where $N_{\text{ГДВ}}$ – is the power of the hydraulic motor, kW;

T – is the force on the rod N;

ϑ – is the speed of movement of the rod m/sec.

The useful power of the pump is determined based on the power of the hydraulic motor, taking into account the loss of energy during its transfer from the pump to the hydraulic motor according to formula 2.

$$N_{\text{нп}} = k_{\text{зу}} \cdot k_{\text{зс}} \cdot \sum N_{\text{гдв}} = 1.2 \cdot 1.3 \cdot (1.4 + 18.8) = \\ = 31{,}512\, kW, \quad (2)$$

where $N_{\text{нп}}$ – useful power of the pump, kW;

$k_{\text{зу}}$ – is the coefficient of force margin, $k_{\text{зу}}$=1,1…1,2;

$k_{\text{зс}}$ – speed margin coefficient, $k_{\text{зс}}$=1,1…1,3;

$\sum N_{\text{ГДВ}}$ – total power of hydraulic motors

$$Q_{\text{н}} = \frac{N_{\text{нп}}}{p_{\text{ном}}} = \frac{31512}{20 \cdot 10^6} = 0.0015561 \ \text{m}^3/\text{sec} \quad (3)$$

where $p_{\text{ном}}$ – the nominal pressure in the hydraulic system adopted by us according to standart is equal to 20 MPa.

$$q_{\text{н}} = \frac{N_{\text{нп}}}{p_{\text{ном}} \cdot \eta_{\text{н}}} = \frac{31512}{20 \cdot 10^6 \cdot 16.7} = 0.0000943473\, \text{m}^3/\text{rnd} \quad (4)$$

where $\eta_{\text{н}}$ – the rotation speed of the pump shaft is rpm, in our case, the pump shaft will rotate from the power take-off shaft of the base machine equal to 1000 rpm or 16.7 rpm. The rated rotational speeds set by GOST 12446-80 are as follows: 480, 600, 750, 960, 1200, 1500, 1920.

The calculated values of the internal diameters of the suction, pressure and drain hydraulic lines are determined from the equation of continuity of the fluid flow, taking into account the dimensions according to formula 5.

$$d_p = \sqrt{\frac{4 \cdot Q_{\text{НД}}}{\pi \vartheta_{\text{ж}}}} = \sqrt{\frac{4 \cdot 0.0014362}{3.14 \cdot 1.12}} = 0.04, \quad (5)$$

where $\vartheta_{\text{ж}}$ – the speed of fluid movement in the hydraulic line m / s is equal to 1.2; 2; 5, in the suction, drain and pressure lines, respectively.

In accordance with the principle of imposing losses known from hydraulics, the pressure loss in the hydraulic line is determined by the formula 6

$$\Delta p = \Delta p_l + \Delta p_M, \quad (6)$$

where Δp_l – pressure loss along the length of the hydraulic line MPa;

Δp_M – pressure loss in local resistances of MPa.

Pressure losses along the length of the hydroline (track) are determined by the Darcy-Weisbach formula 7.

$$\Delta p_l = \lambda \frac{l}{d} \cdot \frac{\vartheta_{\text{ж}}^2}{2} \cdot \rho \cdot 10^{-6} = 0.038 \frac{3.5}{0.04} \cdot \frac{1.2^2}{2} \cdot \\ \cdot 865 \cdot 10^{-6} = 0.002\, MPa, \quad (7)$$

where λ – coefficient of travel losses (Darcy coefficient);

ρ – s the density of the working fluid.

The coefficient of travel losses depends on the mode of fluid movement, it is determined by the formulas recommended in hydraulics for laminar motion 8, for turbulent motion 9.

Indicators value

№	Indicator	Value
1	Reynolds number	
	for the suction hydraulic line	4800
	for the drain hydraulic line	6000
	for pressure hydroline	4000
2	The loss coefficient	
	for the suction hydraulic line	0,038
	for the drain hydraulic line	0,035
	for pressure hydraulic line	0,039
3	The pressure loss along the length, MPa	
	in the suction hydraulic line	0,002
	in the drain hydraulic line	0,15
	in the pressure hydraulic line	0,16
4	Pressure losses in local resistances are determined by the Weisbach formula, MPa	
	in the suction hydraulic line	0,00031
	in the drain hydraulic line	0,00173
	in the pressure hydraulic line	0,0054

$$\lambda = \frac{0.3164}{R_e^{0.25}} = \frac{0.3164}{4800^{0.25}} = 0.038, \quad (8)$$

where R_e – the Reynolds number determined by the formula 9. The Reynolds number for a hydroline is determined in order to establish the flow regime. The value obtained in this way can characterize a laminar or turbulent flow regime.

$$R_e = \frac{\vartheta_ж \cdot d}{\upsilon} = \frac{1.2 \cdot 0.04}{10^{-5}} = 4800, \quad (9)$$

where υ – the kinematic viscosity coefficient of the liquid for the liquid υ=10 cSt=10-5 m²/s.

Based on the formulas presented above, the calculation was made, the values obtained are summarized in Table.

Discussion of the results obtained, conclusion

Based on the conducted research and the process of modeling the operation of the hydraulic cylinder in the Festo FluidSIM software environment, a schematic diagram of the hydraulic control system of the excavator was developed, graphical data describing the operating mode of the working equipment were obtained, based on them, the hydraulic calculation of the main elements was carried out.

Based on the presented data obtained by modeling and calculating the operation of the hydraulic system, the calculated values of which are presented in Table, we accept a standard hydraulic cylinder with a diameter of 110 mm, a stem diameter of 50 mm and a piston stroke of 250 to 800 mm.

REFERENCES

1. Serapinas B.B. Global positioning systems. – Moscow: IKF «Catalog». – 2002. – 106 p.
2. Shigematsu Kosuke, Tsubouchi Takashi, Sarata Shigeru Tip-over prevention system based on motion prediction for teleoperated excavator // Advanced robotics – 2021. – T. 35. – No. 23. – p. 1438-1449 DOI:10.1080/01691864.2021.2004223
3. Jovanovic Vesna, Janosevic Dragoslav, Pavlovic Jovan, Analysis of the influence of the digging position on the loading of the slewing platform bearing in hydraulic excavators // Facta universitatis-series mechanical engineering – 2021. – T.19. – No. 4. – p. 705-718. DOI:10.22190/FUME190225020J
4. Shi Yupeng, Xia Yimin, Luo Lianglin e.t.c. Working stage identification of excavators based on control signals of operating handles // Automation in construction. – 2021. T. 130. – 103873. doi.org/10.1016/j.autcon.2021.103873
5. Yajima Ryosuke, Katsuma Shinya, Suzuki Makot, Matsushita Fumiya, Hamasaki Shunsuke, Chun Pang-jo, Nagatani Keiji, Yamauchi Genki, Hashimoto Takeshi, Yamashita Atsushi, Asama Hajime, Ozawa Kazumasa Development of an excavator-avoidance system for buried pipes // Advanced robotics – 2021. – T. 35. – No. 23. – pp. 1468-1483. DOI: 10.1080/01691864.2021.2007167
6. Sazambaeva B.T., Togizbaeva B.B., Masanov G.K., Balabekova K.G. Utility model patent, No. 5564. IPC class E02F3 / 40, application number (21) 2020 / 0616.2 (22) 13.11.2020. Model of a working body with a mechanical drive for cutting asphalt
7. Sazambaeva B.T., Togizbaeva B.B., Makhanov, Sarsenbaev B. To the calculation of multipurpose working bodies of hydraulic excavators // Computer modeling of multipurpose working equipment of a single bucket excavator // Scientific journal «Mechanics and Technologies». – 2018. – vol. 3. – pp. 60-63.
8. Sazambaeva B.T., Togizbaeva B.B., Kenzhebaeva A.S. Patent for utility model No. 3767. Working equipment of the excavator Application date (21) 2018 / 0454.2, published (22) 22.06.2018.
9. B.D. Suleev, A.B. Kenesbek, B.B. Togizbayeva, K.G. Balabekova. Mathematical modeling of the additional working body of the excavator // BULLETIN of L.N. Gumilyov ENU. Technical Science and Technology Series – 2021. – No. 3. pp. 74-83. DOI: 10.32523/2616-7263-2021-136-3-74-83.
10. B.D. Suleyev. Design and calculation of hydraulic driven cutting working bodies for the construction of slit-foundation // The Bulletin of KazATC – 2018. – Vol. 106, No. 3. pp. 77-83.

«FluidSIM – Fluidics Simulation Program» бағдарламалық ортасында гидравликалық жетектің принципиалды сұлбасын әзірлеу және экскаватордың гидравликалық басқару жүйесін есептеу

[1]***КУАНЫШУЛЫ Жарасхан,*** *докторант, zkuanyshuly@gmail.com,*
[2]****СУЛЕЕВ Бахтияр Даниярович,*** *PhD, департамент директоры, culeev_bahtiyar@mail.ru,*
[2]***КУРМАШЕВА Бакыт Куанышевна,*** *т.ғ.к., декан, happiness_b@mail.ru,*
[3]***САХАПОВ Рустэм Лукманович,*** *т.ғ.д., кафедра меңгерушісі, rusakhapov@gmail.com,*
[1]***БАЛАБЕКОВА Кырмызы Гинаятовна,*** *PhD, қауымдастырылған профессор, 06_03_92@mail.ru,*
[1]*Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Қазақстан, Нұр-Сұлтан, Сәтпаев көшесі, 2,*
[2]*«Әбілқас Сағынов атындағы Қарағанды техникалық университеті» КеАҚ, Қазақстан, Қарағанды, Н. Назарбаев даңғылы, 56,*
[3]*Қазан мемлекеттік сәулет және құрылыс университеті, Ресей, Татарстан, Қазан, Зеленая көшесі, 1,*
**автор-корреспондент.*

Аңдатпа. *Мақаланың мақсаты – спутниктік жүйелерімен жабдықталған экскаватордың басқару жүйесінің гидравликалық схемасын әзірлеу. Мақалада зерттеулердің өзектілігі негізделген, экскаватордың жұмыс жабдығымен жалпы техниканың нақты орналасқан жерін анықтау үшін пайдаланатын қолданыстағы спутниктік позициялау жүйелері қарастырылған. Экскаватордың жұмыс принципі және оның құрылымдық ерекшеліктері орналасқан жерді анықтау жүйелерін қолдана отырып, машинаның жұмысын қамтамасыз етуді* *ескере отырып сипатталған. Festo FluidSim бағдарламалық ортасында экскаватордың гидравликалық басқару жүйесінің схемасы жасалды. Гидравликалық цилиндрдің жұмысын модельдеудің графикалық деректері ұсынылған. Экскаватордың гидравликалық жетегінің негізгі элементтері есептелді, оның негізінде жұмыс жабдығының гидравликалық цилиндрі таңдалды.*

***Кілт сөздер:** экскаватор, шөміш, жұмыс мүшесі, позициялау жүйесі, айналмалы платформа, гидравликалық жетек, гидравликалық желі, жұмыс сұйықтығы, гидравликалық цилиндр, өзек, гидравликалық қозғалтқыш, қысым.*

Разработка принципиальной схемы и расчет гидравлической системы управления экскаватора в програмной среде «FluidSIM – Fluidics Simulation Program»

*[1]**КУАНЫШУЛЫ Жарасхан,** докторант, zkuanyshuly@gmail.com,*
*[2]***СУЛЕЕВ Бахтияр Даниярович,** PhD, директор департамента, culeev_bahtiyar@mail.ru,*
*[2]**КУРМАШЕВА Бакыт Куанышевна,** к.т.н., декан, happiness_b@mail.ru,*
*[3]**САХАПОВ Рустэм Лукманович,** д.т.н., зав. кафедрой, rusakhapov@gmail.com,*
*[1]**БАЛАБЕКОВА Кырмызы Гинаятовна,** PhD, ассоциированный профессор, 06_03_92@mail.ru,*
[1]Евразийский национальный университет имени Л.Н. Гумилева, Казахстан, Нур-Султан, ул. Сатпаева, 2,
[2]НАО «Карагандинский технический университет имени Абылкаса Сагинова», Казахстан, Караганда, пр. Н. Назарбаева, 56,
[3]Казанский государственный архитектурно-строительный университет, Россия, Татарстан, Казань, ул. Зеленая, 1,

**автор-корреспондент.*

***Аннотация.** Целью исследований, представленных в статье, является разработка принципиальной гидравлической схемы системы управления экскаватора, оснащенного спутниковыми системами контроля положения техники. В статье обоснована актуальность проведённых исследований, рассмотрены существующие системы спутникового позиционирования, применяемые для точного определения местоположения рабочего оборудования и техники в целом. Описан принцип работы экскаватора и его конструктивные особенности с учетом обеспечения работы машины при помощи систем определения местоположения. Разработана схема гидравлической системы управления экскаватором в программной среде Festo FluidSim. Представлены графические данные моделирования работы гидроцилиндра. Рассчитаны основные элементы гидравлического привода экскаватора, на основе которой подобран гидроцилиндр рабочего оборудования.*

***Ключевые слова:** экскаватор, ковш, рабочий орган, система позиционирования, поворотная платформа, гидравлический привод, гидролиния, рабочая жидкость, гидроцилиндр, шток, гидродвигатель, давление.*

REFERENCES

1. Serapinas B.B. Global positioning systems. – Moscow: IKF «Catalog». – 2002. – 106 p.
2. Shigematsu Kosuke, Tsubouchi Takashi, Sarata Shigeru Tip-over prevention system based on motion prediction for teleoperated excavator // Advanced robotics – 2021. – T. 35. – No. 23. – p. 1438-1449 DOI:10.1080/01691864.2021.2004223
3. Jovanovic Vesna, Janosevic Dragoslav, Pavlovic Jovan, Analysis of the influence of the digging position on the loading of the slewing platform bearing in hydraulic excavators // Facta universitatis-series mechanical engineering – 2021. – T.19. – No. 4. – p. 705-718. DOI:10.22190/FUME190225020J
4. Shi Yupeng, Xia Yimin, Luo Lianglin e.t.c. Working stage identification of excavators based on control signals of operating handles // Automation in construction. – 2021. T. 130. – 103873. doi.org/10.1016/j.autcon.2021.103873
5. Yajima Ryosuke, Katsuma Shinya, Suzuki Makot, Matsushita Fumiya, Hamasaki Shunsuke, Chun Pang-jo, Nagatani Keiji, Yamauchi Genki, Hashimoto Takeshi, Yamashita Atsushi, Asama Hajime, Ozawa Kazumasa Development of an excavator-avoidance system for buried pipes // Advanced robotics – 2021. – T. 35. – No. 23. – pp. 1468-1483. DOI: 10.1080/01691864.2021.2007167
6. Sazambaeva B.T., Togizbaeva B.B., Masanov G.K., Balabekova K.G. Utility model patent, No. 5564. IPC class E02F3 / 40, application number (21) 2020 / 0616.2 (22) 13.11.2020. Model of a working body with a mechanical drive for cutting asphalt
7. Sazambaeva B.T., Togizbaeva B.B., Makhanov, Sarsenbaev B. To the calculation of multipurpose working bodies of hydraulic excavators // Computer modeling of multipurpose working equipment of a single bucket excavator // Scientific journal «Mechanics and Technologies». – 2018. – vol. 3. – pp. 60-63.
8. Sazambaeva B.T., Togizbaeva B.B., Kenzhebaeva A.S. Patent for utility model No. 3767. Working equipment of the excavator Application date (21) 2018 / 0454.2, published (22) 22.06.2018.
9. B.D. Suleev, A.B. Kenesbek, B.B. Togizbayeva, K.G. Balabekova. Mathematical modeling of the additional working body of the excavator // BULLETIN of L.N. Gumilyov ENU. Technical Science and Technology Series – 2021. – No. 3. pp. 74-83. DOI: 10.32523/2616-7263-2021-136-3-74-83.
10. B.D. Suleyev. Design and calculation of hydraulic driven cutting working bodies for the construction of slit-foundation // The Bulletin of KazATC – 2018. – Vol. 106, No. 3. pp. 77-83.