Experimental studies of a throughput of the distribution systems of planetary hydraulic motors

A Voloshina\textsuperscript{1,5}, A Panchenko\textsuperscript{1}, O Titova\textsuperscript{2}, V Pashchenko\textsuperscript{3} and A Zasiadko\textsuperscript{4}

\textsuperscript{1}Department of Mechatronic Systems and Transport Technologies, Dmytro Motorny Tavria State Agrotechnological University, B. Khmelnytsky ave. 18, Melitopol, Ukraine
\textsuperscript{2}Department of Foreign Languages, Dmytro Motorny Tavria State Agrotechnological University, B. Khmelnytsky ave. 18, Melitopol, Ukraine
\textsuperscript{3}Department of Tactics, National Academy of the National Guard of Ukraine Zakhysnykov, Ukrainy sq., 3, Kharkiv, Ukraine
\textsuperscript{4}Department Berdyansk college of the Tavria State Agrotechnological University, Eastern ave. 23, Berdyansk, Ukraine

\textsuperscript{5}Email: voloshina2012@gmail.com

Abstract. As a result of the study, an experimental test bench was developed for testing high-torque hydraulic motors. A methodology for experimental studies of a unified series of planetary hydraulic motors has been developed. It has been established that an increase in the throughput of a hydraulic motor with a modernized distributed system makes it possible to increase the hydromechanical efficiency of the modernized hydraulic motor by 11 to 14\%, the volumetric efficiency by 2 to 4\%, and the overall efficiency by 7 to 9\%. The increase in the values of the hydromechanical, volumetric and overall efficiency of the modernized hydraulic motor explains the increase in the throughput of its distributed system. It has been established that the torque of the developed serial hydraulic motor is 300 to 325 min\(^{-1}\), which is a sign of the rigid characteristics of this hydraulic motor. The stability of the torque (within 1.5\%) developed by the modernized hydraulic motor 370 to 375 Н \cdot m in the frequency range of 75 to 450 min\(^{-1}\) is confirmed by its rigid characteristic.

1. Introduction

High-torque low-speed gerotor [1, 2], orbital [3] and planetary [4] hydraulic motors are most commonly used to drive active working bodies and running systems of road, construction, agricultural and other self-propelled equipment. One of the main units causing a decrease in the functional parameters of hydraulic motors is a working fluid distribution system that creates a rotating hydraulic field necessary for the movement of the inner rotor of these hydraulic machines [5, 6]. The main disadvantage of the distribution system is the fluctuations in the flow of the working fluid supplied to the hydraulic motor, caused by the unevenness of its throughput [6].

The throughput of the distribution system of the planetary hydraulic motor is understood as the total area of overlap of its working windows. Irrational design of the elements of the distribution system leads to fluctuations in the overlap area and a change in the output characteristics of the hydraulic motor as a whole, which is confirmed by parametric studies [5, 6]. Therefore, conducting experimental studies of planetary hydraulic motors in order to determine the effect of the throughput of their distribution systems on changing the functional parameters of planetary hydraulic motors is an
urgent task.

2. Analysis of recent studies and publications

A mechatronic system of active control of dynamic spatial positioning of the executive body is considered [7]. A method for designing hydraulic mechatronic systems with elements of multicriteria optimization has been developed, which makes it possible to design a mechatronic system with given output characteristics [8]. The dynamic model of the drive is proposed [9]. The dynamic processes occurring in mechatronic systems with planetary hydraulic motors are investigated in order to predict changes in their output characteristics [10]. The parameters of variation are substantiated, which determine the change in the output characteristics of the hydraulic motor, depending on the design features of its system of rotors and the distribution system. Regression equations are obtained that describe the change in the output characteristics of the hydraulic motor during operation, for a given range of changes in its operating parameters [11]. A methodology for experimental research and construction of control characteristics is proposed [12]. Experimental studies of mechatronic systems with volumetric hydraulic machines were not considered.

The conditions for static equilibrium of the mobile complex were established [13]. An engineering method for determining radial compliance is proposed, taking into account the radial clearance and contact deformations of parts [14]. Using nonlinear models and the method of analyzing the response surface, the parameters of thin-walled structures have been substantiated [15], studies have been carried out to develop adequate models for analyzing the response of thin-walled structures to a load [16]. The dependences of the contact pressure on the external forces that act on them [17] are considered, the distribution of contact pressures is determined [18], the regularities of the distribution of contact pressure are investigated [20]. Issues related to research in the design and operation of hydraulic machines with cycloidal rotors were not considered.

It is known [1, 3, 8, 11] that in mechatronic systems with a hydraulic drive, gerotor [1, 2], orbital [3, 5] and planetary [4, 6] hydraulic machines with cycloidal rotors are mainly used. The proposed theoretical method for predicting the characteristics of an engine with constant difference orbital piston engines [21]. Experiments have been carried out to confirm the theoretical model [22]. Numerical modeling, modeling and forecasting of the production depth were carried out, which as a result is compared with the results of experimental studies [23]. The implemented method for determining the reliability of a hydraulic motor by modeling changes in the technical state of internal and external rotors [24] analyzes the performance of the orbital engine and conduct experimental research [25]. A comprehensive study of a hydrostatic unit with a low speed of rotation of an orbital rotor in a hydrostatic transmission system is presented. Using the actual parametric values, the general dynamic model is confirmed experimentally [26]. Issues related to experimental study of planetary hydraulic machines were not considered.

Calculation formulas are proposed and a comparative assessment is carried out according to the criterion of the channel cross-section of a hydraulic machine with a planetary rotor with a central gear wheel in the shape of a wave and floating satellites [27]. The systematization and comparative analysis of the schemes of mechanisms of planetary rotary hydraulic machines [28]. Cavitation phenomena occurring in the working fluid distribution zone have been investigated [29]. Promising methods for the production and application of carbon nanoparticles in tribology [30] were reviewed, the results of tribosystems testing with the use of liquid crystal additives [31] are given, experimental studies are considered, taking into account the effect of an electrostatic field on the working fluid of a volumetric hydraulic drive [32]. The values of pressure loss, flow rate and velocity distribution over the cross-section of the pipeline in a straight section and in a turn have been determined [33]. A comparison of the use of the SST turbulence model taking into account the curvature of streamlines and flow rotation [34] is presented, the application of the RANS approach using the corrected SST turbulence model is considered, which allows one to determine all the main characteristics of the vortex flow [35]. A 3D model has been proposed that takes into account the dynamically changing volume of the working
fluid in the working chambers [36], mathematical expressions are given to assess the flow rate of the working fluid [37] in gerotor hydraulic machines. It should be noted that the operation of the rotors of a gerotor pump differs fundamentally from the operation of the rotors of a planetary (orbital) hydraulic motor. For functioning of the planetary hydraulic motor, a rotating hydraulic field of the working fluid created by the distribution system is required [6, 38]. The cyclic rotation of the hydraulic field depends on the number of working chambers formed by the external and internal rotors and is characterized by the kinematic diagram of the distribution system [6]. The kinematic diagrams of the distribution systems of planetary hydraulic motors have been substantiated [6], a technique has been developed for displacing the distribution windows of a movable distributor, which makes it possible to reduce fluctuations in the flow of the working fluid (throughput), and as a result, to improve the output characteristics of the planetary hydraulic motor [39]. The influence of the shape of distribution windows on the output characteristics of a planetary hydraulic motor, which can be made in the form of a segment [38], a circle [4] and a groove [40], has been investigated. Experimental studies of the throughput of the distribution system have not been carried out.

When carrying out parametric studies of the influence of the distribution system of the planetary hydraulic motor, a number of assumptions and limitations were made [4, 6, 38, 40]. Therefore, comparative experimental research of hydraulic motors with serial and modernized distribution systems is one of the most important and urgent tasks.

3. Statement of the objective and tasks of the study
To conduct experimental studies, in order to determine the influence of the throughput of the distribution system of the planetary hydraulic motor on the change in its functional parameters, it is necessary:
- to develop a test bench for testing high-torque low-speed planetary-type hydraulic motors;
- to develop a methodology for conducting study of the influence of the throughput of the distribution system of a planetary hydraulic motor on the change in its output characteristics experimental studies of the influence of the distribution system of a planetary hydraulic motor on the change in its output characteristics;
- to study the influence of the throughput of the distribution system of a planetary hydraulic motor on the change in its output characteristics.

4. The basic part of the study
Earlier parametric studies [4, 6, 39] determining the influence of the transmission capacity of the distribution system of a planetary hydraulic motor on the change in its functional parameters are associated with a number of assumptions and limitations. Therefore, in order to confirm and correct the previously obtained results of parametric studies, comparative bench tests of planetary hydraulic motors with serial and modernized distribution systems should be conducted.

The developed test bench for testing planetary hydraulic motors (Figure 1, a) consists of four main units: a pumping station (Figure 1, b), a loading device (Figure 1, c), a unit for measuring the flow rate and changing the direction of the working fluid flow (Figure 1, d) and the control panel (Figure 1, f). This test bench allows testing a family of unified series of planetary hydraulic motors with a power of 6.5; 11; 22 and 33 kW, respectively. The pumping station consists (Figure 1, b) of a frame with a tank for working fluid with a thermometer, an axial piston variable pump with a working volume of 89 cm$^3$ with a drive motor, a feed pump and three safety (overflow) valves. For the conditioning of the working fluid, the pumping station has two fine filters, two heat exchangers, two pressure gauges and shut-off valves.

The loading device (Figure 1, c) is designed to simulate the load on the hydraulic motor shaft by braking and is a powder brake placed on the frame together with the tested hydraulic motor. When measuring the output characteristics of the hydraulic motor under test, two pressure gauges are used to control the pressure and a tachometer with a pulse sensor to determine the angular velocity.

The unit for measuring the flow rate and changing the direction of the flow of the working fluid (Figure 1, d) is designed to measure the amount of working fluid passed through the hydraulic motor
and for reversing the activation of hydraulic motors during testing. It consists of a frame with two electrically controlled distributors, two calibrated axial piston hydraulic motors with tachometers and impulse sensors with discs, and two fine filters.

![Figure 1](image-url)

**Figure 1.** Experimental test bench for testing planetary hydraulic motors: a – general view; b – pumping station; c – load device; d – unit for measuring the flow rate and changing the direction of the flow of the working fluid; f – control panel.

The control panel (Figure 1, f) is designed to control the electrical elements of the test bench according to the corresponding algorithm: drive motors, flow distributors, tachometers, powder brakes, etc.

Test bench studies were carried out on a serial and modernized PRG-22 series hydraulic motors with a working volume of 160 cm³. The modernization of the hydraulic motor consisted in changing
the geometric and functional parameters of the movable and stationary distributors, other parts of the hydraulic motor remained serial. The studies were carried out for planetary hydraulic motors with a kinematic distribution system 7/6 [6]. The number of distribution windows of the movable distributor is 12 (6 working and 6 discharge windows), and the number of distribution ports of the fixed distributor is 14 (7 delivery ports and 7 drain windows). In the serial distribution system, 3 discharge windows are used as additional working ones, and the gap between the windows of the movable and fixed distributor is 0°51'. In the modernized distribution system of the hydraulic motor, 2 unloading windows are used as additional working ones, and the gap between the distribution windows is 0° [39].

The throughput of the distribution systems of the tested hydraulic motors was determined by the total flow area of the working windows of the system under consideration. For a serial hydraulic motor, the flow area of the working windows ranges from 222 to 226 mm², while the average area was 223 mm². For a modernized hydraulic motor, the flow area of the working windows is constant and equal to 226 mm².

The required value of the flow rate of the working fluid passing through the hydraulic motor is equal to 50, 70, 90 and 110 l/min, respectively, was set using a variable pump when the test hydraulic motor was idling (no load). The required load was set using the test bench brake in the range of 25...400 N·m with a step of 25 N·m.

The main factors that determine the change in the functional parameters of the planetary hydraulic motor in the study of the distribution system are: the rotational speed of the hydraulic motor shaft, the pressure difference and the gap between the distribution windows of the movable and fixed distributors [4, 6, 38, 40]. The study of changes in the functional parameters of the serial and modernized hydraulic motors was evaluated based on the results of comparative tests of these hydraulic motors.

The mechanical, volumetric and overall efficiency of the tested hydraulic motor was determined according to the standard method according to the results of measuring the pressure drop, torque, rotation frequency of the hydraulic motor shaft and the flow rate of the working fluid.

As a result of the research, the dependences of the efficiency of the tested hydraulic motor on the frequency of rotation of its shaft were determined (Figure 2). It has been established that the nature of the patterns of change in the efficiency of serial and modernized hydraulic motors in the entire range of change in rotational speeds is similar.

With an increase in the speed of the hydraulic motor shaft to 300 min⁻¹, the hydromechanical efficiency (Figure 2, a) of both hydraulic motors increases, taking the value 0.75 to 0.81 for the serial (curve 1) and 0.89 to 0.92 for the modernized (curve 2) hydraulic motors. The maximum value of the hydromechanical efficiency of both hydraulic motors is in the range of rotation frequencies of its shaft 150 to 450 min⁻¹. An increase in the rotation frequency of the hydraulic motor shaft to 670 min⁻¹ leads to a significant decrease in its hydromechanical efficiency to values of 0.65 for the serial and 0.75 for the modernized hydraulic motors. The hydromechanical efficiency of a hydraulic motor (Figure 2, a) with a modernized distribution system (curve 2) is 11 to 14% higher than that of a hydraulic motor with a serial distribution system (curve 1).

The volumetric efficiency of a hydraulic motor (Figure 2, b) with an upgraded distribution system (curve 2) is 2 to 4% higher than that of a hydraulic motor with a serial distribution system (curve 1) and remains practically unchanged over the entire range of speed variation.

The change in the overall efficiency from the rotational speed (Figure 2, s) has the same character as the dependence of the hydromechanical efficiency, which is explained by low volumetric losses. The overall efficiency of a hydraulic motor with a modernized distribution system (curve 2) is 7 to 9% higher than that of a hydraulic motor with a serial system distribution (curve 1).

The increase in the value of the hydromechanical, volumetric and overall efficiency of the modernized hydraulic motor is explained by the throughput of its distribution system.

Studies of changes in the output characteristics of a planetary hydraulic motor (Figure 3) have established that the nature of the change in torque depending on the rotation frequency (Figure 3, a) for serial and modernized hydraulic motors are similar. In the rotation frequency range from 75 to 550
min⁻¹, the torque developed by the serial hydraulic motor is 300 to 325 N·m (curve 1) and changes insignificantly (within 8%), which is a sign of the rigid characteristics of this hydraulic motor. The stability of the torque (within 1.5%) developed by the modernized hydraulic motor 370 to 375 N·m (curve 2) in the rotation frequency range of 75 to 450 min⁻¹ confirms its rigid characteristic. The stiffness of the characteristics of a hydraulic motor is understood as its ability to provide stable torque readings over a wide range of speed changes, especially at low rpm.

Figure 2. Dependence of efficiency on the frequency of rotation of the output shaft of the hydraulic motor at the nominal pressure: a – hydromechanical; b – volumetric; c – general; 1 – serial hydraulic motor; 2 – modernized hydraulic motor.

Figure 3. Change in the output characteristics of the planetary hydraulic motor: a – the dependence of the torque on the rotational speed of the output shaft of the hydraulic motor; b – dependence of the speed of rotation of the output shaft of the hydraulic motor on the flow rate of the working fluid; 1 – serial hydraulic motor; 2 – modernized hydraulic motor.

The increased stability of the torque developed by the modernized hydraulic motor and the 14% increase in the absolute value of the torque is explained by the rational design of the structure of the elements of the distribution system of this hydraulic motor. 

Analysis of the dependence of the change in the speed of the hydraulic motor shaft on the flow rate of the working fluid (Figure 3, b) shows that these parameters, both for the serial (curve 1) and for the modernized (curve 2) hydraulic motors, are in a linear relationship and with an increase in the flow
rate of the working fluid increase. Modernization of the distribution system has practically no effect on the change in the considered dependencies.

Thus, studies of the influence of the distribution system of a planetary hydraulic motor on the change in its output characteristics have established that elimination of the pulsation of the working fluid flow and an increase in the throughput of a hydraulic motor with a modernized distribution system makes it possible to increase the hydromechanical efficiency of a modernized hydraulic motor by 11 to 14%, volumetric efficiency by 2 to 4%, and the total – by 7 to 9%.

5. Conclusions

As a result of the study, an experimental test bench was developed for testing high-torque hydraulic motors, which allows testing a family of unified series of planetary hydraulic motors with a power of 6.5; 11; 22 and 33 kW, respectively. A methodology for experimental studies of a unified series of planetary hydraulic motors has been developed.

The maximum value of the hydromechanical efficiency of both hydraulic motors is in the range of rotation frequencies of its shaft 150 to 450 min\(^{-1}\). The hydromechanical efficiency of a hydraulic motor with a modernized distribution system is 11 to 14% higher than that of a hydraulic motor with a serial distribution system.

The volumetric efficiency of a hydraulic motor with a modernized distribution system is 2 to 4% higher than that of a hydraulic motor with a serial distribution system and remains practically unchanged over the entire range of speed variation. The overall efficiency of a hydraulic motor with a modernized distribution system is 7 to 9% higher than that of a hydraulic motor with a serial distribution system. The increase in the values of the hydromechanical, volumetric and general efficiency of the modernized hydraulic motor is accounted for by the increase in the throughput of its distribution system.

Studies of changes in the output characteristics of a planetary hydraulic motor (Figure 3) have established that in the range of rotation frequencies of 75 to 550 min\(^{-1}\), the torque developed by a serial hydraulic motor is 300 to 325 Н⋅m and changes slightly (within 8%), which is a sign of a rigid characteristics of this hydraulic motor. The stability of the torque (within 1.5%) developed by the modernized hydraulic motor 370 to 375 Н⋅m in the range of rotation speeds of 75 ÷ 450 min\(^{-1}\) confirms its tough characteristic.

References

[1] Gamez-Montero P, Codina E and Castilla R 2019 A Review of Gerotor Technology in Hydraulic Machines Energies 12 (12) 2423

[2] Strmcnik E and Majdic F 2018 The Pressure and Efficiency Characteristic of Hydraulic Gerotor Motor with the Floating Outer Ring Tehnicki vjesnik-technical gazette 2 (25) 609–515

[3] Panchenko A, Voloshina A, Milaeva I and Luzan P 2019 Operating Conditions’ Influence on the Change of Functional Characteristics for Mechatronic Systems with Orbital Hydraulic Motors Modern Development Paths of Agricultural Production. Springer 169-176

[4] Voloshina A, Panchenko A, Boltyansky O and Titova O 2019 Improvement of Manufacture Workability for Distribution Systems of Planetary Hydraulic Machines Lecture Notes in Mechanical Engineering, Springer 732-741

[5] Panchenko A, Voloshina A, Milaeva I, Panchenko I and Titova O 2018 The Influence of the form Error after Rotor Manufacturing on the Output Characteristics of an Orbital Hydraulic Motor International Journal of Engineering and Technology 7 (4.3) 1–5 - убрать

[6] Voloshina A, Panchenko A, Boltyansky O, Panchenko I and Titova O 2018 Justification of the Kinematic Diagrams for the Distribution System of a Planetary Hydraulic Motor International Journal of Engineering and Technology 7 (4.3) 6–11

[7] Strutinsky V and Demyanenko A 2016 The development of mechatronic active control system of tool spatial position of parallel kinematics machine tool Journal of Theoretical and Applied Mechanics 54 (3) 757–768
[8] Voloshina A, Panchenko A, Panchenko I, Titova O and Caldare A 2020 Design of Hydraulic Mechatronic Systems with Specified Output Characteristics Advances in Design, Simulation and Manufacturing III DSMIE 2020 Lecture Notes in Mechanical Engineering 42-51
[9] Strutynskyi S 2018 Defining the dynamic accuracy of positioning of spatial drive systems through consistent analysis of processes of different range of performance, Naukovyi Visnyk NHU 3 64-73
[10] Panchenko A, Voloshina A, Titova O, Panchenko I and Zasiadko A 2020 The Study of Dynamic Processes of Mechatronic Systems with Planetary Hydraulic Motors Advanced Manufacturing Processes II. Lecture Notes in Mechanical Engineering 56–64
[11] Voloshina A, Panchenko A, Titova O, Milaeva I and Pastushenko A 2020 Prediction of Changes in the Output Characteristics for the Planetary Hydraulic Motor Advanced Manufacturing Processes II. Lecture Notes in Mechanical Engineering 84–93
[12] Korohodskyi V, Kryshtopa.S, Migal V, Rogovyi A and others 2020 Determining the Characteristics for the Rational Adjusting of an Fuel-air Mixture Composition in a Two-stroke Engine with Internal Carburation. Eastern-European Journal of Enterprise Technologies 2(5) 39-52
[13] Strutynsky V, Hurzhi A and Kozlov L 2019 Determination of static equilibrium conditions of mobile terrestrial complex with lever-type manipulator Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu 5 79-86
[14] Gaydamaka A, Kulik G, Frantsuzov V, Hrechka I and others 2019 Devising an engineering procedure for calculating the ductility of a roller bearing under a no-central radial load Eastern-European Journal of Enterprise Technologies 3 7(99) 6-10
[15] Bondarenko M, Tkachuk M, Grabovskiy A and Hrechka I 2019 Substantiation of Thin-Walled Structures Parameters Using Nonlinear Models and Method of Response Surface Analysis International Journal of Engineering 44 32–43
[16] Atroshenko O, Tkachuk M, Martynenko O, Tkachuk M and others 2019 The Study of Multi-component Loading Effect on Thin-Walled Structures with Bolted Connections Eastern-European Journal of Enterprise Technologies 1 7(97) 15–25
[17] Tkachuk M, Grabovskiy A, Tkachuk M, Saverska M and I. Hrechka 2020 A semi-analytical method for analys of contact interaction between structural elements along aligned surfaces Eastern-European Journal of Enterprise Technologies 1 7(103) 16–25
[18] Marchenko A, Tkachuk M, Kravchenko S, Tkachuk M, and Parsadanov I 2020 Experimental Tests of Discrete Strengthened Elements of Machine-Building Structures. Advanced Manufacturing Processes Lecture Notes in Mechanical Engineering 559–569
[19] Tkachuk M, Grabovskiy A, Tkachuk M, Hrechka I and others 2019 Investigation of multiple contact interaction of elements of shearing dies Eastern-European Journal of Enterprise Technologies 4 7(100) 6–15
[20] Rogovyi A, Khovanskyy S, Grechka I and Pitel J 2019 The Wall Erosion in a Vortex Chamber Supercharger Due to Pumping Abrasive Mediums Design, Simulation, Manufacturing: The Innovation Exchange 682–691
[21] Maiti R and Nagao M 1999 Prediction of starting torque characteristics of epitrochoid generated orbital rotary piston hydraulic motors JSME international journal series c-mechanical systems machine elements and manufacturing 2 (42) 416–426
[22] Dasgupta K, Mukherjee A and Maiti R 1996 Theoretical and experimental studies of the steady state performance of an orbital rotor low-speed high-torque hydraulic motor Proceedings of the institution of mechanical engineers Part A - Journal of power and energy 6 (210) 423–429
[23] Furustig J, Almqvist A and Pelcastre, L 2016 A strategy for wear analysis using numerical and experimental tools, applied to orbital type hydraulic motors Proceedings of the institution of mechanical engineers part c-journal of mechanical engineering science 12 (230) 2086-2097
[24] Panchenko A, Voloshina A, Panchenko I, Titova O and Pastushenko A 2019 Reliability design
of rotors for orbital hydraulic motors. *IOP Conference Series: Materials Science and Engineering* **708** (1) 012017

[25] Xing K, Zhang Y and Jin X 2009 Performance analysis and experimental research of the orbital motor. *Proceedings of the seventh international conference on fluid power transmission and control* 131–135.

[26] Dasgupta K, Mukherjee A and Maiti R 1999 Estimation of critical system parameters that affect orbit motor performance-combining simulation and experiments. *Journal of manufacturing science and engineering-transactions of the ASME* **2** (121) 300–306

[27] Shah, Y. Vacca A and Dabiri S 2018 A fast lumped parameter approach for the prediction of both aeration and cavitation in Gerotor pumps. *Meccanica* **1-2** (53) 175–191

[28] Robison J and Vacca A 2017 Kinematic multi-objective optimization of circular-toothed gerotor pumps by genetic algorithm. *Proceedings of the asme/bath symposium on fluid power and motion control* UNSP V001701A016

[29] Velev E 2016 Study Cavitation Gerotor Motors *Renewable Energies and Innovative Technologies* 64–66

[30] Voronin S, Suranov A, Suranov A 2017 The effect of carbon nanoadditives on the tribological properties of industrial oils. *Journal of Friction and Wear* 38(5) 359–363

[31] Воронін С 2015 Розробка трібофізичних основ мастильної здатності рідкокристалічних присадок до базових олив *Східно-Європейський журнал передових технологій* 3 **7(75)** 53–57

[32] Voronin S, Onopreychuk D, Stefanov V, Bashkatov Ye and Panchenko V 2018 Reduction of construction duration by improving the anti-wear properties of power fluids in hydraulic drives of earth-moving machines. *International Journal of Engineering & Technology* **7**(4.3) 105–109

[33] Chernetskaya-Beletskaya N, Rogovyi A, Shvornikova A, Baranov I and others 2018 Study on the coal-water fuel pipeline transportation taking into account the granulometric composition parameters. *International Journal of Engineering & Technology* **7**(4.3) 240–245

[34] Rogovyi A, Khovanskyi S, Hrechka I and Gaydamaka A 2020 Studies of the Swirling Submerged Flow Through a Confuser. *Design, Simulation, Manufacturing: The Innovation Exchange* 85–94

[35] Rogovyi A 2018 Energy performances of the vortex chamber supercharger. *Energy* **163** 52–60

[36] Ding H, Lu J and Jiang B 2012 A CFD model for orbital gerotor motor. *IOP Conference Series: Earth and Environmental Science* **6**(15) 062006

[37] Yang D, Yan J and Tong S 2010 Flowrate Formulation of Deviation Function Based Gerotor Pumps. *Journal of Mechanical Design* **132** (6) 064503-5

[38] Panchenko A, Voloshina A, Boltyansky O and others 2018 Designing the flow-through parts of distribution systems for the PRG series planetary hydraulic motors. *Eastern-European Journal of Enterprise Technologies* **3** **1**(93) 67–77

[39] Voloshina A, Panchenko A, Panchenko I, Titova O and Zasiadko A 2019 Improving the output characteristics of planetary hydraulic machines. *IOP Conference Series: Materials Science and Engineering* **708** (1), 012038

[40] Voloshina A, Panchenko A, Panchenko I and Zasiadko A 2019 Geometrical Parameters for Distribution Systems of Hydraulic Machines. *Modern Development Paths of Agricultural Production. Springer* 323-336