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APPLICATION OF MODERN MATHEMATICAL APPARATUS FOR DETERMINING THE DYNAMIC PROPERTIES OF VEHICLES

Purpose. Study of hydraulic-mechanical transmissions in the process of braking a mining diesel locomotive and determining their efficiency.

Methodology. The paper uses the technique of matrix analysis of transmissions by Prof. V.B. Samorodov, based on the division of the kinematic scheme into structural elements. The method was chosen as the basic method due to its universality and the possibility of implementation with the help of computer technology. The developed mathematical models of the vehicle braking process take into account the possibility of a smooth change (decrease and increase) of the transmission ratio and the torque applied to the executive bodies.

Findings. The advantages and disadvantages of the use of hydromechanical stepless transmissions in the braking modes of the diesel locomotive are determined. It was mathematically proven that such transmissions are efficient, it is limited by methods of implementing braking. The results of the modelling allow to justify the braking control strategies of the locomotive equipped with a hydromechanical transmission.

Originality. The technique of matrix mathematical modelling of transmissions that work as part of mining and transport machines has got further development. The developed mathematical model of the braking process of a mine diesel locomotive with HMT allowed to study the change in the kinematic and power parameters of the transmission in different operating conditions of diesel locomotives – movement on traction and transport ranges, on descent and ascent, at different initial braking speeds for all possible ways of implementing the process braking. The obtained results made it possible to substantiate the braking control strategies depending on the initial speed and traction power of the mining diesel locomotive.

Practical value. The obtained results testify to the operational efficiency of the considered transmissions due to correctly selected strategies of braking control, which exclude the possibility of the occurrence of emergency modes of operation, failure, and reduction of the service life of the transmission elements. The practical value of the paper is confirmed by the social effect due to the improvement of labour safety in locomotive transport.

Keywords: *mine diesel locomotive, braking control, transmission, economy, speed regulation*

Introduction. The consequences of global climate change are more and more evident all over the world, and Ukraine is no exception. In June-July 2024, Ukraine was covered by anomalous heat (sometimes thermometers in cities showed 40–42 °C), which was complicated by stabilizing power outages caused by Russia military aggression against Ukraine. Experts state that the world is going through a climate crisis – the temperature is rising, and more and more extreme weather events are occurring. They attribute this to emissions of greenhouse gases, especially carbon dioxide (CO_2), from thermal power plants and internal combustion engines. An alternative is seen in the use of "cleaner" sources such as the sun and wind. The paradox is that in order to provide the world with low-emission energy, it is necessary to extract much more of some minerals (copper, aluminium, chromium, zinc, lithium, cobalt, nickel, platinoids), and this may turn out to be a "dirty" process. One of the methods of extraction of these minerals is underground development, in particular mining [1].

As it is known, Ukraine joined the international obligations, planning to stop using coal for energy purposes by 2030. However, the abandonment of fossil energy sources does not mean the complete closure of mines – the prospects of coal as a raw material are not limited by the use in energy. The presence of significant available coal potential of Ukraine makes it necessary to include the spread of non-energy use of coal in the state policy. It is known from open sources that currently there are 146 mines in Ukraine, of which 67 are in uncontrolled territory, 33 are state-owned, and 46 are privately owned. In modern conditions of intensive development of coal deposits using high-performance, high-cost mining equipment, issues of efficiency and reliability of production processes in mines are of particular importance. Significantly increased geometric dimensions of mining fields are accompanied by a wide variety of mining and geological conditions within mining pillars, in particular, a significant number of geological disturbances of various types. High-performance development of coal reserves, based on efficient and reliable technological processes, requires finding solutions for a significant increase in the characteristics of technological processes for coal mining. Modern models of an efficiently working coal industry provide for deep modernization of the sector based on private-state partnership. At the same time, modernization should be carried out not only due to the improvement of mining technology, but also due to the use of innovative means of mine transport [2].

Literature review. The use of diesel locomotives [3], which move on rail tracks [4, 5], is a proven promising way to increase the efficiency of mine locomotive rolling back [4, 5].

The use of diesel locomotives makes it possible to increase the productivity of intra-mine transport by increasing the load-carrying capacity of wagon trains. This significantly increases the load on the rail track, which can cause its structural changes. It is known that the rail track consists of an upper (rail) and a lower (ballast layer) structure. Article [6] is devoted to the analysis of time-frequency characteristics of track geometry irregularities using data recorded by a train for track inspection. Modelling of the dynamic deflection of the rail using the propagation of elastic waves is considered in [7]. The paper [8] is devoted to stability of the lower structure of the rail track due to the study of the influence of water content on the ballast layer of the track.

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Diesel trucks from the Czech company Ferrit, which underwent another fourth update in 2021, are considered classics on the world market of mining transport. The modernized diesel locomotive is powered by a John Deere 6068 TFM75 type 6068 TFM75 six-cylinder in-line turbocharged diesel engine with an electronic fuel pump equipped with a separate dry exhaust gas cooling system. The transmission is full-flow hydrostatic stepless, the power flow is transmitted using a hydraulic pump and two independent hydraulic motors from Bosch Rexroth. As it is known [9, 10], continuously variable transmissions are an effective method of increasing fuel economy and dynamic characteristics of vehicles. This is explained by the fact that mechanical transmissions are limited by specific power and smooth speed regulation; and electric ones may not withstand heavy loads in some operating modes. The German manufacturer Fendt was the first to develop a variator with hydrostatic power distribution called Vario [11], which was installed on the 191 kW Favorit 926 tractor. Due to the 45° variable axle tilt units, developed together with Sauer Sundstand, the Vario's full axle load efficiency could be maintained at 78–84 %. Compared to the full-flow version of hydrostatic transmission, the efficiency of power transmission can be increased due to power division [12]. Two-flow stepless transmissions are distinguished by increased indicators of the overall efficiency (efficiency) as a result of power transmission not only through a stepless converter with significantly variable efficiency, but also through a mechanical link with a relatively high efficiency [13]. In addition, such transmissions provide the necessary traction force and stepless regulation of the speed of the diesel truck when the diesel engine is operating with a constant crankshaft rotation frequency. This, in turn, guarantees minimal fuel consumption and, as a consequence, a reduction in gas emissions into the mine atmosphere [14, 15]. Many schemes of hydromechanical stepless transmissions (HMT) have been published in the scientific and technical literature. Different schemes are offered for different vehicles [16].

The advantages of the new continuously variable transmission with power distribution over traditional mechanical transmissions based on the analysis of fuel consumption are given in [17]. The MATLAB environment was used to model fuel consumption, and two different power flow control strategies with eight different scenarios were evaluated.

The dynamic characteristics of the vehicle and control of the transmission ratio are studied in [18] by means of modelling and experiment. Driving and braking characteristics of the off-road vehicle are checked and discussed. The results show that the acceleration and deceleration of the vehicle can be controlled by changing the gear ratio. The results are used to optimize the design and control strategy of the hydromechanical transmission.

In the study [19], a new design of hydromechanical transmission (CCHMT) is proposed, which realizes the reuse (regeneration) of energy on heavy-duty vehicles. CCHMT has an optimal design in combination with hydraulic and mechanical components, which ensures a smooth change of speed and maintenance of engine operation with high fuel economy. Simulation modelling and experiments were conducted to verify the effectiveness and operational efficiency of the transmission.

Optimization of the hydromechanical parameters of the power cycle of the continuously variable transmission of agricultural tractors was carried out in [20]. The authors analysed the influence of various structural parameters on system performance and proposed an indicator for evaluating the efficiency of the transmission. A comprehensive study of speed control characteristics, economic and dynamic indicators was conducted. A numerical model of multi-criteria optimization, which uses a genetic algorithm, has been created.

The design of a multi-range hydromechanical transmission by the modular method was carried out in [21]. A simulation model was built in AMESim (an integrated software platform for computer simulation of the operation of multidisciplinary mechatronic systems) to calculate HMT products. To check the characteristics of the transmission, the authors use a test bench. The proposed HMT has an average efficiency of about 83 % over a wide range of speeds. While full-flow hydraulic-volumetric-mechanical transmissions have efficiency rate at the level of 0.6–0.7 [22]. The authors of [23] also use the AMESim software platform to optimize the energy efficiency of the hydromechanical transmission component of heavy-duty vehicles. The results of the experiment show that the real efficiency rate of transmission is 80.6–86.0 %.

The study [24] is devoted to increasing the fuel economy of a continuously variable transmission of a tractor by analysing its power flows and fuel consumption. In this paper, the authors optimize the transmission by matching design and power, investigating the effect of changes in transmission control parameters and strategies on fuel economy. Their results show that fuel consumption can be reduced by 2–14 % due to optimization of parameters and up to 20 % due to appropriate matching of power.

Strategies for controlling a vehicle equipped with a two-stage hydromechanical transmission, using the example of a city bus, are presented in [25]. The authors of [25] developed a methodology that allows extending the strategy of controlling the minimum fuel consumption for the engine to the "engine-transmission" system. The papers [24, 25], which make it possible to evaluate the influence of the control strategy on the efficiency and performance of the transmission, are a modern development of the theory of transmission modelling. Their importance is explained by the fact that the traditional fuel economy management strategy required the control system to keep the engine on the fuel economy line (the so-called universal performance core). However, this strategy is not the best since the performance of the power plant depends on both the efficiency of the engine and the efficiency of the transmission. The conducted analysis proves the rationale and expediency of using stepless transmissions on mining diesel trucks. Two-flow transmissions have a higher efficiency in comparison with full-flow ones, but they are characterized by circulation modes, which leads to emergency modes of operation of units, especially in braking modes. The analysis of the efficiency and productivity of two-flow transmissions of wheeled tractors, taking into account the circulation modes of the transmission, was carried out in the work of the followers of the scientific school of Professor V. B. Samorodov [26].

It is known that only locomotives are equipped with braking means in mining trains. The limiting braking capabilities of a diesel locomotive is a rather important parameter that often determines and limits the range of application of mine locomotive transport.

Purpose. The purpose of the paper is a study of hydraulic-volumetric-mechanical transmissions in the process of braking a mine diesel locomotive and determination of their efficiency.

Methods. The central block of hydraulic-mechanical transmissions is the hydrovolume transmission (HVT), which provides stepless speed regulation. Planetary (differential) reducers are used to sum or separate power flows. Modern hydrovolumetric-mechanical transmissions can be built either according to the input differential scheme (Fig. 1) [13] or according to the output differential scheme (Fig. 2) [27]. We will remind that due to the lack of power circulation in HMT, in which the planetary mechanism is located at the input, such transmissions are more promising and can be aggregated by irreversible variators [22].

This study used the method developed by Professor V. B. Samorodov method of matrix analysis of transmissions. The methodology is based on the division of the kinematic scheme into structural units [9]. This methodology was chosen as the main one due to its multifunctionality and ease of use when using computer technologies. The developed generalized mathematical models of the braking process of a mining diesel locomotive with HMT, which differ from the existing ones by taking into account the laws of changing the parame-

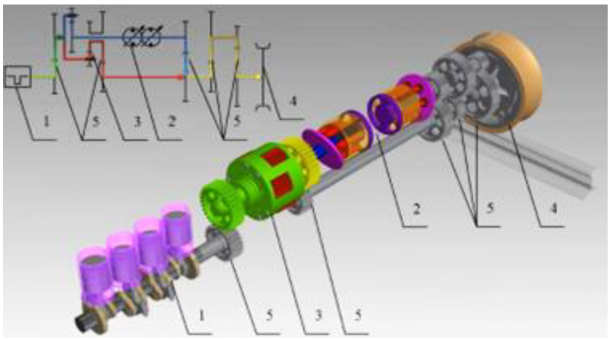

Fig. 1. Model HMT No. 1 with differential input:

1 – internal-combustion engine; 2 – hydrovolume transmission; 3 – planetary reducing gear; 4 – wheel; 5 – reducing gears

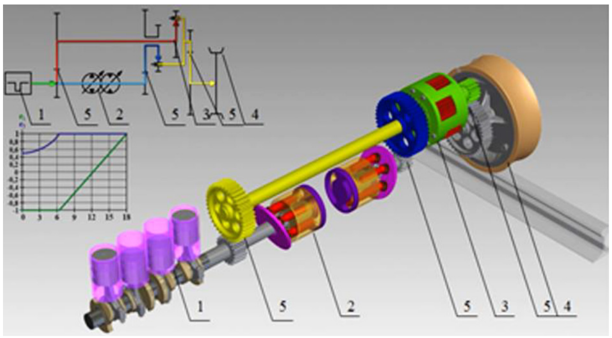

Fig. 2. Model of HMT No. 2 with differential output:

1 – internal-combustion engine; 2 – hydrovolume transmission; 3 – planetary reducing gear; 4 – wheel; 5 – reducing gears

ters of the HVT regulation and methods of implementing braking, are described in detail in the previous works of the authors [13, 27], but most of the results will be presented for the first time. These models make it possible to study the change of kinematic, power and energy parameters of HMT in different operating conditions of diesel locomotives and to justify rational ways of implementing the braking process.

Results. The distribution of kinematic, power and energy parameters of HMT in the braking process depends significantly on the type of transmission, the initial braking speed, the traction force, the lifting angle, and the method of implementing the braking process.

The process of braking a mining diesel locomotive can be carried out in the following ways:

1. When kinematically disconnecting the engine from the wheels (implementation method No. 1).

2. When maintaining the kinematic connection of the engine with the wheels:

- speed reduction due to the HVT and the braking system while maintaining the kinematic connection between the engine and the wheels (implementation method No. 2);
- speed reduction due to HVT while maintaining the kinematic connection of the engine with the wheels (implementation method No. 3);
- speed reduction due to the braking system while maintaining the kinematic connection between the engine and the wheels (implementation method No. 4).

The determination and theoretical justification, from the point of view of the dynamics of the braking process, of the prospective HMT is due to the use of the software implementation developed in MatLab/Simulink.

In the process of braking simulation, the following transmission parameters are studied:

- the maximum value of the working pressure drop in the HVT $|dP|_{max}$, which should not exceed 40.0 MPa for hydraulic machines with a working volume of 90 cm^3 of the "PSM-HYDRAYLIKS" company;
- the maximum value of the angular velocity of the hydraulic pump shaft ($|w_2|_{max}$ – HMT No 1, $|w_0|_{max}$ – HMT No. 2) should not exceed 460.0 rad/s;
- the maximum value of the angular velocity of the hydraulic motor shaft ($|w_3|_{max}$ – HMT No 1, $|w_1|_{max}$ – HMT No. 2) should not exceed 460.0 rad/s;
- the maximum value of the angular velocity of the drive shaft of the clutch HMT No. 1– $|w_{20}|_{max}$;
- the maximum value of the angular velocity of the driven clutch shaft HMT No. 2 – $|w_2|_{max}$;
- the maximum value of the power output from the hydraulic branch of the closed HMT circuit – $|N_{gk}|_{max}$;
- the maximum value of the power output from the mechanical branch of the closed loop HMT – $|N_{mk}|_{max}$;
- braking distance – *S*;
- braking time – *t*.

The simulation of the braking process of a mining diesel locomotive was carried out for HMT No. 1 and HMT No. 2 when moving on traction and transport ranges on descent and ascent at different initial braking speeds with four ways of implementing the braking process.

The results of modelling the braking of a diesel locomotive with HMT No. 1 and HMT No. 2 when moving on the downhill transport range by all methods of implementing the braking process in the form of graphic dependencies are shown, in Figs. 3 and 4 respectively.

As a result of a comprehensive study of the braking process of a mining diesel locomotive, it was established:

1. Due to the kinematic break of the mechanical branch of the closed circuit of the HMT, the traction force of the mining diesel locomotive during the braking process does not significantly affect the distribution of the kinematic, power and energy parameters of the HMT.

When braking method No. 1 is used in the closed loop of both HMT No. 1 and HMT No. 2 due to the clutch, a kinematic break of the mechanical branch occurs, neither the initial braking speed, nor the angle of ascent/descent, nor the traction force on the hook of the mining diesel locomotive do significantly affect the distribution of kinematic, force and energy parameters of HMT.

The mechanical branches of the closed circuits HMT No. 1 and HMT No. 2 are always unloaded during braking, since the moments are equal to 0. Through the hydraulic branch HMT No. 1, power is transmitted only to the HVT and does not exceed 1.55 kW, the hydraulic branch HMT No. 2 is completely unloaded.

Based on a comprehensive study of the braking process of a diesel locomotive with HMT No. 1 and HMT No. 2 when the engine is kinematically disconnected from the wheels, in both cases, the implementation of the braking process to preserve the operability of the transmission must take place before the diesel locomotive comes to a complete stop.

2. In the course of a theoretical study of the braking process of a diesel locomotive at the expense of the HVT and the braking system while preserving the kinematic connection of the engine with the wheels, it was established that the mechanical branch of the closed loop HMT is more loaded during the braking process. Through the mechanical branch of the closed circuit, the power is transferred more than through the hydraulic one: up to 6.3 times in HMT No. 1 and up to 21.5 times in HMT No. 2.

With a decrease in the traction power of the diesel locomotive from 8 wagons to 2 during downhill braking for all HMTs, there is a decrease in the power coming from the hydraulic branch of the closed loop to 55.4 %, the power coming from the mechanical branch of the closed loop HMT to 28.2 %, braking distance up to 44.2 %; when braking on a ascend, an increase is observed: the working pressure drop in the HVT up to 41.2 times, the power coming from the hydraulic branch of the closed loop up to 12.3 times, the power coming from the mechanical branch of the closed loop HMT up to 8.5 times, braking distance up to 3.9 times.

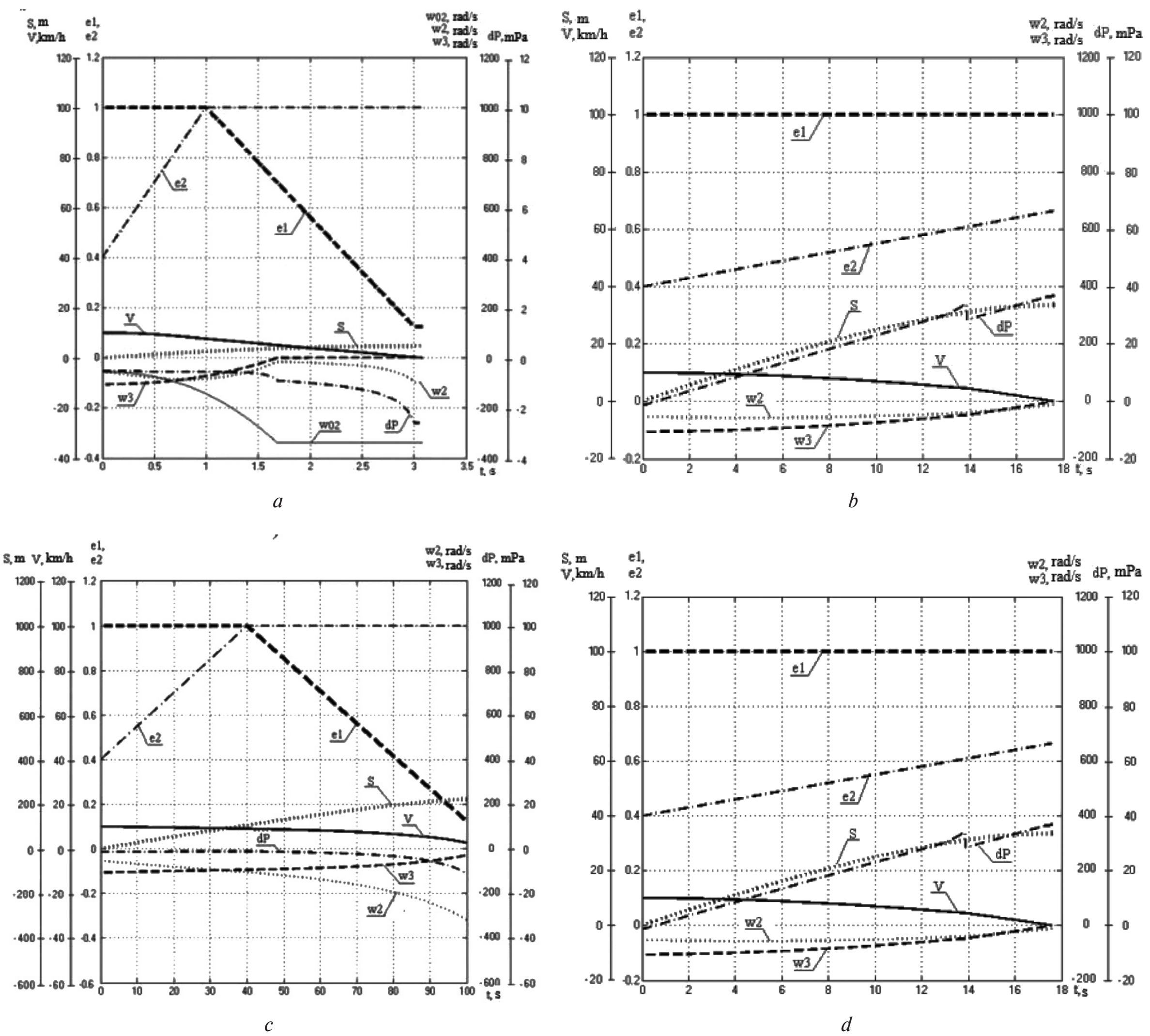

Fig. 3. Results of simulation of braking of a diesel locomotive with HMT No. 1 at the initial speed $0.5 \cdot V_{max}$:

a — when the engine is kinematically disconnected from the wheels; b — due to the HVT and braking system while maintaining the kinematic connection of the engine with the wheels; c — at the expense of HVT while maintaining the kinematic connection of the engine with the wheels; d — due to the braking system while maintaining the kinematic connection between the engine and the wheels

There is a clear increase in the power output from the mechanical branch of the closed loop HMT up to 15.9 times and the angular velocity of the hydraulic motor shaft up to 22.6 times when braking starts from speed V_{max} instead of speed $0.5 \cdot V_{max}$.

The use of this method of implementing the braking process is unacceptable, as it is accompanied by exceeding the permissible value of the working pressure drop in the HVT by up to 2.8 times.

3. In the course of a theoretical study of the process of braking of a diesel locomotive due to HVT while maintaining the kinematic connection of the engine with the wheels, it was established that the mechanical branch of the closed circuit of the HMT during the braking process is more heavily loaded. More power is transmitted through the mechanical branch of the closed loop than through the hydraulic one: up to 90.0 times in HMT No. 2 (it is impractical to provide data on HMT No. 1, since the HVT is not able to completely stop the diesel locomotive).

With a decrease in the traction force of a diesel locomotive with HMT No. 2 from 8 wagons to 2 when braking on a descent, a decrease is observed: the difference in working pressure in the HMT to 81.5 %, the angular velocity of the hydraulic pump shaft to 43.0 %, the angular velocity of the shaft of the hydraulic motor up to 42.9 %, the power coming from the hydraulic branch of the closed circuit up to 94.1 %, the power coming from the mechanical branch of the closed circuit HMT up to 93.6 %, the braking distance up to 5.1 %; when braking on a ascend, a decrease is observed: the working pressure drop in the HMT up to 39.1 %, the angular velocity of the hydraulic motor shaft up to 75.8 %, the power coming from the mechanical branch of the closed circuit of the HMT up to 90.0 %, the braking distance up to 3.9 times, the angular velocity of the hydraulic pump shaft and the power output from the hydraulic branch of the closed loop remain unchanged.

There is a clear increase in the values of the angular velocity of the hydraulic pump shaft up to 97.0 %, the hydraulic motor shaft up to 85.5 times, the power output from the hydraulic branch of the closed circuit HMT up to 84.0 times, the power output from the mechanical branch of the closed circuit HMT up to 12.9 times when starting braking from speed V_{max} instead of speed $0.5 \cdot V_{max}$.

The use of this method of implementation of the braking process allows you to slow down the movement of the diesel locomotive with HMT No. 2 without a mandatory stop, however, it is necessary for each HMT scheme at the stage of development of the control system to limit the intensity of changes in parameters e_1 and e_2 at a certain level so that the driver does not have the opportunity this method can be used for emergency braking.

4. In the course of a theoretical study of the braking process of a diesel locomotive at the expense of the braking system

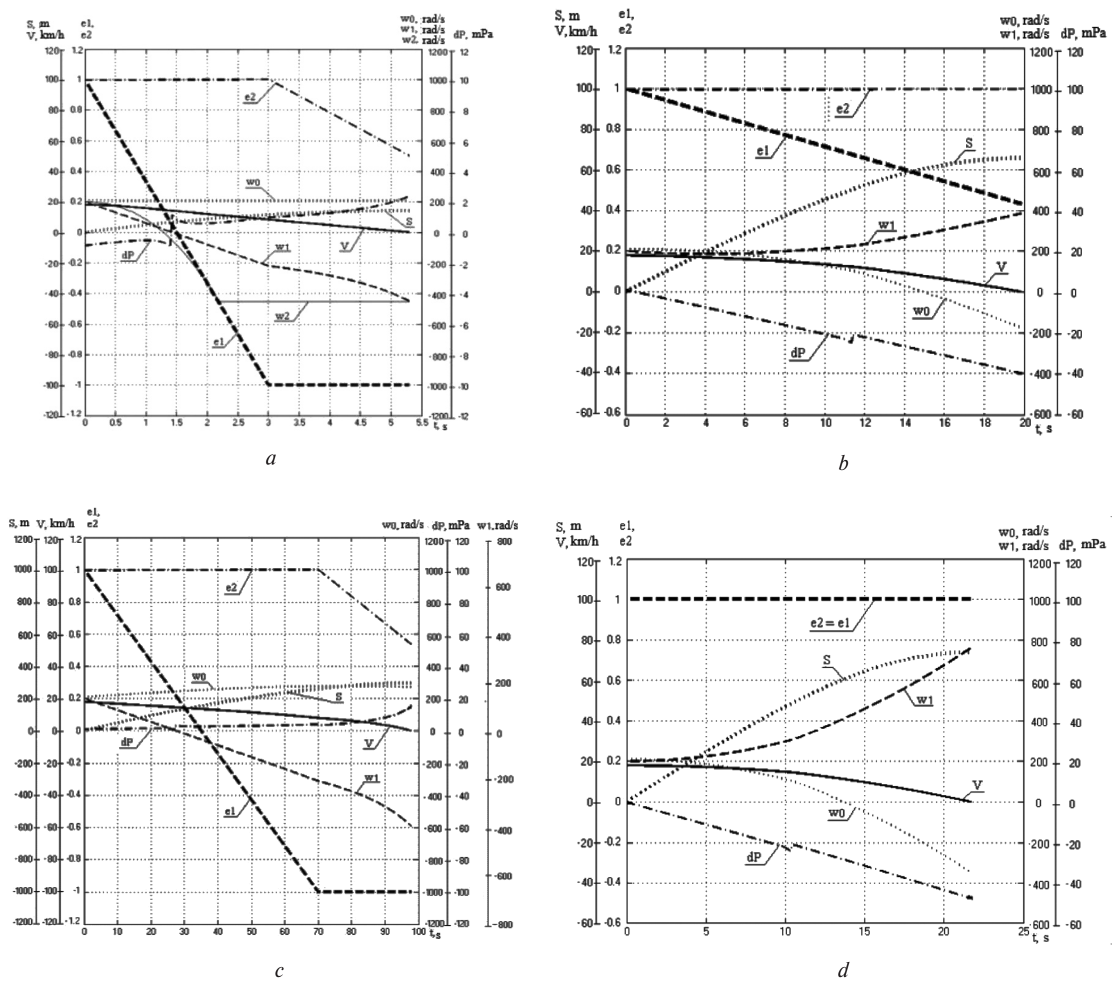

Fig. 4. Results of simulation of braking of a diesel locomotive with HMT No. 2:

a — when the engine is kinematically disconnected from the wheels; b — at the expense of the HVT and the braking system while maintaining the kinematic connection of the engine with the wheels; c — at the expense of HVT while maintaining the kinematic connection of the engine with the wheels; d — due to the braking system while maintaining the kinematic connection of the engine with the wheels

while preserving the kinematic connection of the engine with the wheels, it was established that the mechanical branch of the closed circuit of the HMT during the braking process is more heavily loaded. Through the mechanical branch of the closed circuit, the power is transferred more than through the hydraulic one: up to 8.1 times in HMT No. 1 and up to 95.0 times in HMT No. 2.

With a decrease in the traction power of a diesel locomotive from 8 wagons to 2 during downhill braking for all HMTs, there is a decrease in the power coming from the hydraulic branch of the closed loop to 92.7 %, the power coming from the mechanical branch of the closed loop HMT to 47.7 %, braking distance up to 46.1 %; when braking on a ascend, an increase is observed: the working pressure drop in the HVT up to 4.05 times, the angular velocity of the hydraulic pump shaft up to 3.03 times, the angular velocity of the hydraulic motor shaft up to 4.4 times, the power output from the hydraulic branch of the closed circuit up to 15.04 times, the power coming from the mechanical branch of the closed loop HMT up to 15.04 times, the braking distance up to 3.9 times.

There is a clear increase in the angular velocity of the hydraulic motor shaft up to 465.5 times, the power coming from the mechanical branch of the closed loop HMT up to 15.9 times when braking starts from speed V_{max} instead of speed $0.5 \cdot V_{max}$.

The use of this method of implementing the braking process is unacceptable, as it is accompanied by exceeding the permissible value of the working pressure drop in the HVT by up to 2.74 times.

Conclusions. The study of the dynamic characteristics of the vehicle and the control of the transmission ratio are carried out by means of simulation and experiment. The braking process was simulated for diesel locomotives with HMT No. 1 and HMT No. 2 running on traction and transport ranges on descent and ascent with different initial braking speeds. We consider the following ways of implementing the braking process: kinematic disconnection of the engine from the wheels; the use of HVT and the braking system while maintaining the kinematic connection of the engine with the wheels; the use of HVT while maintaining the kinematic connection of the engine with the wheels; use of the braking system while maintaining the kinematic connection between the engine and the wheels.

A generalized mathematical model of the braking process of a mining diesel locomotive with HMT was developed, which differs from existing models in that it takes into account the laws of changing the parameters of the HVT regulation and methods of implementing braking. This model makes it possible to study the changes in the kinematic and power parameters of the HMT in different operating conditions of diesel locomotives and to justify rational methods of braking control. The adequacy of the developed mathematical model is confirmed by the repeatedly proven reliability of all its components.

The use of HMT No. 1 on diesel locomotives from the point of view of braking with 8 loaded carriages and on a slope of 50 ‰ is not recommended, since it is not possible to achieve deceleration of the diesel locomotive without a complete stop while maintaining the operability of the transmission. It will not be possible to reduce the speed due to HVT while maintaining the kinematic connection of the engine with the wheels in the entire range of operating conditions of the diesel locomotive, the use of the brake system and HVT or only the brake system while maintaining the kinematic connection of the engine with the wheels will lead to the failure of the HMT, because the working pressure drop in the HVT exceeds the permissible value by up to 2.8 times. Only the braking of the diesel locomotive remains when the engine is kinematically disconnected from the wheels, but this method of implementation is not recommended for decelerating the diesel locomotive with continued further movement due to the inconsistency of the angular velocities of the driving and driven clutch shafts. The difference between the angular velocities of the driving and driven clutch shafts can reach 335.0 rad/s.

The use of HMT No. 2 on diesel locomotives is allowed under the condition of using braking due to the braking system when the engine is kinematically disconnected from the driving wheels (for emergency braking with a complete stop of the diesel locomotive) or due to HVT while maintaining the kinematic connection of the engine with the wheels (for decrease in movement speed). Using the brake system and HVT or only the brake system while maintaining the kinematic connection of the engine to the wheels will cause the failure of the HMT, since the operating pressure drop in the HVT exceeds the permissible value by up to 2.74 times.

The simulation results can be used to optimize the design and control strategy of the hydromechanical transmission.

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Застосування сучасного математичного апарату для визначення динамічних властивостей транспортних засобів

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Мета. Визначення працездатності гідрооб'ємно-механічних трансмісій у процесі гальмування шахтного дизелевозу.

Методика. У роботі використовується методика матричного аналізу трансмісій проф. В. Б. Самородова, що базується на розділенні кінематичної схеми на структурні елементи. Методика обрана за базову завдяки її універсальності й можливості реалізації за допомогою обчислювальної техніки. Розроблені математичні моделі процесу гальмування транспортного засобу враховують можливість плавної зміни (зниження та збільшення) передаточного відношення трансмісії та прикладеного до виконавчих органів крутного моменту.

Результати. Визначені переваги й недоліки застосування гідромеханічних безступінчастих трансмісій у гальмівних режимах руху дизелевозу. Математично доведена працездатність таких трансмісій, що обмежується способами реалізації гальмування. Результати моделювання дозволяють обґрунтувати стратегії управління гальмуванням локомотива, обладнаного гідромеханічною трансмісією.

Наукова новизна. Отримала подальший розвиток методика матричного математичного моделювання трансмісій, що працюють у складі гірничо-транспортних машин. Розроблена математична модель процесу гальмування шахтного дизелевозу з гідромеханічною безступінчастою трансмісією дозволила дослідити зміну кінематичних і силових параметрів трансмісії в різних умовах експлуатації дизелевозів – руху на тяговому та транспортному діапазонах, на спуску й підйомі, при різних початкових швидкостях гальмування для усіх можливих способів реалізації процесу гальмування. Отримані результати дозволили обґрунтувати стратегії управління гальмуванням залежно від початкової швидкості й сили тяги шахтного дизелевозу.

Практична значимість. Отримані результати свідчать про працездатність розглянутих трансмісій завдяки правильно обраним стратегіям управління гальмуванням, що виключають можливості виникнення аварійних режимів роботи, виходу з ладу та зниження терміну експлуатації елементів трансмісії. Практична цінність роботи підтверджується соціальним ефектом за рахунок підвищення безпеки праці на локомотивному транспорті.

Ключові слова: *шахтний дизелевоз, управління гальмуванням, трансмісія, економічність, регулювання швидкості*

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