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DETERMINATION OF ANALYTICAL DEPENDENCIES OF DISTRIBUTED FORCES IN A DEFORMABLE WHEEL – DEFORMABLE SURFACE CONTACT ZONE

pages 6–12

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The object of this study is the contact interaction of two deformable bodies of inconsistent geometric shape, in particular, change in the stress-strain state of the wheel and the supporting surface. The significance of this topic arises from growing demands for vehicle mobility in difficult terrains, the necessity of minimizing environmental impact, and the need to optimize the design of mobile machinery components. A major challenge lies in developing a suitable analytical solution to define the stress-strain state variations within the contact zone between the wheel and soil or other surfaces.

This study employs an approach grounded in the fundamental principles of mathematical physics applied to elasticity theory problems. This enabled the derivation of analytical equations that describe the absolute deformations of both the surface and the wheel (tire), along with the contact pressure distribution. The pressure distribution within the contact zone was determined using the properties of surface integrals of the second kind. Concentrated forces, when related to the contact area, were equated to the integral value of this surface integral. The values of these distributed forces were then incorporated into the transformed Boussinesq and Cerruti potential equations.

The resulting analytical relationships can be utilized to determine the relative deformations of the contacting bodies and the stress distribution within them. Crucially, these relationships also serve as a basis for deriving equations that define the contact zone boundaries and the rolling resistance coefficient for deformable bodies. These derived relationships are general and presented in a form applicable to loads on both driving and passive (driven) wheels.

This proposed model offers substantially improved analytical accuracy over existing empirical methods. Moreover, these analytical dependencies help circumvent the computationally intensive calculations typically required by FEM (Finite Element Method) or DEM (Discrete Element Method) simulations for every unique loading scenario and material property set.

Keywords: deformable wheel, deformable surface, soil compaction, contact surface, contact zone.

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DEVELOPMENT OF AN ANALYTICAL MODEL OF THE CONTROLLED MOVEMENT OF GRAIN MATERIAL ON THE BULK SHELVES OF A LOADING GRAVITY-CASCADE UNIT

pages 13–19

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The object of research is the gravitational movement of grain along the transfer shelves and a cascade loading unit with two acceleration and two braking sections. The study of such movement is carried out to confirm theoretical studies on the development and justification of an analytical model of controlled gravitational movement of grain along transfer shelves.

When loading grain, it can be injured when falling from a considerable height and hitting the bottom and walls of the container. This problem requires the development and study of a technical solution that would provide regulation of the velocity of grain movement when loading it into the container.

Theoretical studies were carried out using the developed analytical model of grain movement and the proposed equations to find the relationships between the angles of inclination of the acceleration and braking shelves of the gravity-cascade unit. Based on the analytical model, an experimental unit was made of two acceleration and two braking shelves. The shelves can freely rotate on the axes to the required angle in the range from 0° to 90° relative to the horizontal plane. For the shelves of the acceleration sections, the angle of inclination α was chosen from the variable series of 45°, 50°, 60°. Based on the angle α, according to the model, the shelf of the first braking section was set at an angle of 20.43°, 20.48°, 20.32°, and the shelf of the second braking section was set at 38.46°, 35.28°, 29.32°.

Experimental studies have shown that the velocity of grain movement is indeed regulated by a combination of the ratios of the angles of the acceleration and braking shelves. In this case, the velocity of grain in the last braking section is close to the initial flow velocity at the beginning of the first acceleration shelf. The values of the absolute and relative errors of the experiments of the experimentally determined velocities and the theoretical value of the velocity indicate quite acceptable limits of deviations for this multifactorial experiment. The relative deviation of the experimental from the theoretical velocity of movement of the grain mass does not exceed 12.76%.

The results obtained and their analysis indicate that the presented analytical model and the designed gravity-cascade unit due to the braking and acceleration sections allow solving the problem of controlled movement of the velocity of grain for its loading into containers without injury, in particular into silo structures.

Keywords: velocity of grain movement, acceleration and braking shelves, variable angles of inclination.

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DETERMINATION OF RATIONAL CONDITIONS FOR THE MOVEMENT OF TRANSPORT AND TECHNOLOGICAL UNITS WHEN USING TECHNOLOGICAL MACHINES WITH DRIVING WHEELS

pages 20–27

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The object of research is the operation process of a transport and technological unit with the driving wheels of a technological machine.

One of the most problematic areas of the effective operation of an energy-intensive tractor as part of a transport and technological unit is the incomplete use of the potential capabilities of the tractor engine. This is due to the fact that at the beginning and at the end of the technological operation the mass of the load of the technological machine will be different. A possible solution to this problem is the use of additional driving axles of the technological machine, which allows to increase the relative share of the coupling weight in the unit. This allows part of the engine power to be realized through the tractor's running system, and part to be transferred to the technological machine.

During the study, it was found that when transferring part of the power to the technological machine, three modes of movement are possible: $P_{kT} > P_{xm}$; $P_{kT} = P_{xm}$; $P_{kT} < P_{xm}$. For their analysis, taking into account the dynamic components of the movement, an equivalent dynamic model of the transport and technological unit was used. The oscillations of longitudinal forces acting on the unit characteristic of each mode of movement were obtained. It was found that the movement of the unit with the transmission of part of the power to the drive wheels of the technological machine must be implemented under the movement condition $P_{kT} > P_{xm}$, i. e. under partial underload. This is due to the fact that the proposed movement mode allows stabilizing the oscillations of longitudinal forces and increasing the part of the engine power that can be realized in the traction mode. In particular, for this movement condition, the potential traction force P_{ka} increases to 45.92 kN with a decrease in the mean square deviation $\sigma_{ka} = 1.74$ kN. Also, this movement mode is characterized by the absence of the technological machine running into the tractor, as a result, there are the smallest dynamic oscillations and a stabilizing effect for longitudinal forces.

Due to this, the possibility of activating the wheels of the technological machine with compensation for the negative factors inherent in the movement of all-wheel drive vehicles is ensured. Compared with similar known methods of using full engine power for transport and technological units with variable mass, ensuring a certain movement condition will increase the efficiency of their work.

Keywords: transport and technological unit, driving wheels, variable mass, dynamics, vibrations, engine load.

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IDENTIFICATION OF THE APPLICATION FEATURES OF FINISHING PROCESSING METHODS OF PARTS WITH FREE ABRASIVES AT RAILWAY ROLLING STOCK REPAIR ENTERPRISES

pages 28–35

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The object of research is the technological process of vibration finishing of the "Rotor Sheet" type flat parts, which are made of thin sheet metal at the enterprises of the railway industry of Ukraine in the process of repairing electric motors of rolling stock. Due to the peculiarities of operation, such parts often have residual defects after laser cutting – burrs, sharp edges, contamination – which negatively affect their further functioning. One of the most problematic areas is ensuring uniform, high-quality processing of a large number of thin parts simultaneously without their deformations and damages. During the study, methods of comparative analysis of technological solutions, experimental testing of vibration processing parameters and selection of the most effective operating modes of the machine were used. A selection of abrasive tools of various shapes and compositions was made and the influence of active alkaline solutions was studied, as well as the design of three structurally different special devices for placing parts in a container. The presented devices ensure positioning of the part with simultaneous access of the abrasive tool to all surfaces being processed. The research results can be used to design processing technologies for various types of flat parts made of thin sheet metal. A rational technological process has been obtained that allows for effective removal of surface defects, improving the quality of processing while maintaining high productivity. This is due to the fact that the proposed approach combines precise selection of processing modes and improved devices, in particular by controlling the movement of parts and optimal distribution of the working environment. This provides the possibility of obtaining high surface quality indicators with a significant reduction in processing time. Compared with similar known methods, this provides improved technological controllability, cost-effectiveness and adaptability to the conditions of mass production in mechanical engineering.

Keywords: finishing, vibration method, rolling stock, abrasive tool, thin sheet part.

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METALLURGICAL TECHNOLOGY

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OPTIMIZATION OF TECHNOLOGICAL MODES OF CUPOLA MELTING ACCORDING TO THE CRITERION OF MAXIMUM COMBUSTION TEMPERATURE

pages 36–40

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The object of research is the combustion temperature in the cupola furnace. The problem under study was the complexity of predicting the temperature as a function of the control parameters of the melting.

In the study, the control parameters were selected as the temperature of the air heating blown into the tuyeres and the completeness of fuel combustion. Using orthogonal experimental planning, a mathematical model was constructed in the form of a second-order polynomial, which allowed to identify the patterns of influence of each control factor on the resulting value – the combustion temperature.

The resulting mathematical model allowed to find out that both input variables are significant. However, if the nature of the influence of the air heating temperature on the combustion temperature is linear, then the completeness of combustion affects nonlinearly. The accuracy of the model turned out to be satisfactory, because all experimental data fell within the confidence intervals with a confidence probability of $P = 0.99$. This allows to state the possibility of using the constructed model to predict the combustion temperature within the planning area.

The ridge analysis of the response surface established that the theoretical maximum value of the combustion temperature at the boundary of the planning area is about 3000°C. This corresponds to the values of the input variables $T_{air} \approx 1120$°C and $\eta_0 \approx 82\%$. However, due to the fact that ensuring the air heating temperature at the level of 1120°C may encounter technical complexity of implementation, the following values of the input variables can be recommended: $T_{air} = 783–1060$°C, $\eta_0 = 71–80$. They provide combustion temperatures in the range of 2690–2980°C, i. e. values close to the suboptimal one determined by the ridge analysis.

These data allow making adjustments to the melting process, including being used for further searching for optimal melting control. The obtained solutions can be used in iron foundry shops of industrial enterprises equipped with cupola furnaces.

Keywords: cupola melting, cupola combustion temperature, air heating temperature, completeness of fuel combustion.

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INFLUENCE OF THE PROPERTIES OF SECONDARY α-TITANIUM CASTS, OBTAINED BY CHAMBERLESS ELECTROSLAG CASTING, FOR PROCESSING BY TURNING

pages 41–45

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The object of the study is the machinability by turning of secondary α-titanium casts produced via chamberless electroslag remelting (CESR) (hereinafter referred to as secondary α-titanium), using non-consumable electrodes fabricated from 100% VT1-0 titanium scrap. One of the most challenging issues is the difficulty of machining both primary and secondary titanium. Specifically, this includes chip adhesion to the cutting tool due to the high plasticity of titanium alloys and increased contact surface temperatures, which lead to oxidation.

The study employed modern metallographic methods to examine the macrostructure, chemical composition, and mechanical properties of α-titanium; experimental methods were used to determine optimal turning conditions; and the machinability coefficient was determined using graphical interpolation. Tool wear resistance was evaluated by comparative methods.

Optimal machining parameters were established for the removal of the alpha-case layer and achieving a surface roughness of classes 5–8: cutting speed

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V = 25–30 mm/min; feed rate S = 0.5–0.9 mm/rev; cutting depth T = 1.0–1.2 mm. The selected turning regimes enable the production of complex threaded profiles in accordance with ISO 724:1993 requirements. The study demonstrated that turning secondary α-titanium casts does not require additional technological measures or high-wear-resistant specialized tools. The machinability coefficient was determined to be 0.47–0.48. The improved machinability of the secondary α-titanium casts is attributed to the high quality of the metal, ensured by droplet-based metal transfer and consistent crystallization in a water-cooled copper mold, resulting in higher density and structural homogeneity. The application of chamberless electroslag casting technology enhanced the quality of α-titanium and expanded the potential for its use in the manufacturing of parts for mechanical engineering, chemical, and aerospace industries.

Producing secondary α-titanium using titanium scrap through this technology allows a reduction in production cost by approximately 25–30%.

Keywords: ingot, machinability, α-titanium, roughness, strength, macrostructure, microstructure, turning, wear resistance, hardness.

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MATERIALS SCIENCE

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JUSTIFICATION OF THE PARAMETERS OF THE ACTIVE CONICAL WOOD DEFORMER

pages 46–51

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The object of research is the parameters of mechanisms for the destruction of anisotropic materials by a conical mechanical deformer. One of the known renewable energy sources is a material of plant origin (wood). Based on this, the search for optimal operating parameters and design features of working bodies for mechanized splitting of logs is relevant. Therefore, a new solution to the scientific problem is proposed, which consists in substantiating the main geometric parameters of an active conical deformer for splitting logs from wood at the lowest energy costs for its drive.

The analysis conducted during the study showed a general positive feature of the principle of operation, in which the penetration of an active deformer of a conical shape perpendicular to wood fibers facilitates the destruction of their ties and has a more promising and productive design. A mathematical model for determining the force required to destroy a log of wood has been developed.

The specified dependence takes into account the elastic characteristics of the material, the forces that exist between the fibers of anisotropic substance, the friction forces between the deformer material and wood, and its geometric parameters. It was determined that the necessary value that characterizes the physical and mechanical properties of wood is the force required to destroy the bonds between the fibers (coefficient of longitudinal destruction). Therefore, the values of the coefficient of longitudinal destruction were experimentally obtained, which were for pine – 2533 ± 66 N/m, oak – 5583 ± 145 N/m and aspen – 5000 ± 279 N/m.

According to the research results, analytical recommendations for the geometric parameters of the active deformer were obtained. For pine material with a diameter of 0.15 m, the optimal cone length is in the range of 0.02–0.20 m at a cone angle of 20–90°. At the same time, the theoretical force for its destruction is 568–864 N. Similar results were also obtained for aspen and oak materials. This provides the opportunity to design the design of a conical wood deformer according to the specified ranges, which are optimal for each material or their groups.

Keywords: technology, biomass, wood, active deformer, anisotropic material, splitting, destruction force.

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ELECTRICAL ENGINEERING AND INDUSTRIAL ELECTRONICS

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DETERMINATION OF THE INDUCTIVENESS OF A PHYSICAL MODEL OF TRACK COILS FOR HIGH-SPEED TRANSPORT

pages 52–57

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The object of research is the parameters and characteristics of track coils with different design parameters for a physical model of high-speed maglev transport. The problem that arises in such a system is the untimely switching on of the track coils, which leads to a malfunction due to a short-term disappearance of the traction force. Solving this problem will allow the vehicle to improve the conditions of movement of the high-speed maglev transport. This will make it possible to make a reasonable choice of the parameters of the track coil of a physical model of high-speed transport, which would have the required inductance value at different switching modes.

The required switching frequency will depend on the desired speed of movement of the vehicle and the parameters of the track coils. An important task within the framework of research on maglev transport is the development and creation of a fundamentally new control system. Such a system would have a track structure with traction coils of a rational shape and parameters that would implement certain control processes of the experimental unit. The task of the research is to create a physical model of track coils of high-speed transport and to conduct an experimental determination of the dependence of electrical parameters (inductance) on the frequency of a sinusoidal signal for different winding parameters of track coils. To implement the technical solution, a physical model of the track coil was created, which takes into account the necessary requirements for the study. The search for more favorable technological solutions requires conducting research on electrical processes in the track structure circuit of the physical model of the track coil. This will allow to substantiate the prerequisites for the creation, accumulation and transfer of the necessary energy to the track coils in physical models that will simulate the principles of movement and control of magnetic levitation transport.

During the research, the results were obtained by applying mathematical statistics methods and the development of a track coil with optimal parameters for a physical model of a high-speed transport experimental unit was carried out.

The results obtained with the correct selection of the track coil parameters can create prerequisites for the further development of an experimental switching system for physical model of high-speed transport. In this case, the operating reserve can be determined by the required reserve of effective operation of the track coils to implement the necessary laws of rolling stock control.

Keywords: magnetic levitation transport, track coils, physical model, experiment, inductance, transient processes, control system.

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IMPROVEMENT OF A MICROFILTER PROTOTYPE AND ITS REALIZATION: CHEMICAL APPLICATIONS

pages 58–63

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The object of this research is microfilters. This study aims to develop a microfilter that can be used, for example, for air or water filtration as traditional applications. The closed indoor environments demand the control of the air quality for the health of humans who work there. The implementation of different technologies as MicroElectroMechanical Systems (MEMS), NanoElectroMechanical Systems (NEMS) and MicroEquipment Technology (MET) for microcomponents production is analyzed. The advantages and disadvantages of these technologies are described. MET was used to produce and develop microfilter structure.

The structffure and model of the microfilter is presented. The problem to be solved is connected with microfilter structure simplification and preparation it for the use of new technologies for their production. For its realization the 3D printer was used. 3D printers are the equipment that realizes an additive technology that has been actively developed in recent years. From computer 3D model it is possible to build the 3D prototype. The essence of the results is the possibility of mass production of microfilters. Different possible applications, not only filtration of air and liquid are described, but applications in chemistry for microreactions module and microseparation units.

It was compared new microfilter design with our previous prototype of microfilter developed and produced using the MET. The MET has advantage that it works with various materials and not just those used in microelectronics. Their tests and investigations demonstrated that the microfilters can be used in practice. New prototype was made by 3D printer. Comparative assessment of the first microfilter prototype and new prototype shows that the new prototype has a simplified structure and is easier to manufacture. One of the most interesting areas of their applications is for chemical microreactors. It is one of the new, interesting and promising areas of application.

Keywords: MEMS, NEMS, MET, 3D printer, microfilter, microfabrication, chemical microreactor, microseparation unit, air and liquid filtration, human health.

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TECHNOLOGY AND SYSTEM OF POWER SUPPLY

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MATHEMATICAL AND GRAPHICAL APPROACHES TO IMPROVE THE PROCESS OF SATURATION OF FLUSHING FLUID WITH AIR IN THE CIRCULATION SYSTEM OF A DRILLING RIG UNIT

pages 64–71

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The object of research is the process of air saturation of the flushing fluid using a multi-nozzle foam generator in the circulation systems of drilling rigs.

One of the most problematic areas in the known designs of foam generators is the insufficient efficiency of air saturation of the fluid, which is solved by the design proposed in the work. The design of a multi-nozzle foam generator is proposed by improving the mixing chamber. This design allowed to provide improved foam formation, more efficient air saturation of the flushing fluid, reduce the time of well development and increase the productivity of the device without changing the pressure and supply of fluid and air.

During the study, computer mathematical modeling was used (in the Maple 9.5 software environment), a study of the dependence of air flow on pressure and fluid flow at nozzle diameters of 4 mm and 6 mm was performed. The studies considered graphical analysis to determine the optimal operating modes of the foam generator.

An improved multi-nozzle foam generator with improved foaming efficiency, uniform saturation of the flushing fluid with air, reduced energy consumption and reduced well development time was obtained. This is due to the improvement of the design of the mixing chamber, which has a number of features. The proposed design provides intense turbulence, uniform mixing of the fluid with air, optimization of the geometric parameters of the nozzles and feed channels, as well as reduction of hydraulic losses in the foaming process.

Thanks to this research, it is possible to obtain indicators that characterize the pattern of increasing air flow in proportion to increasing pressure. Compared with known analogues, the proposed foam generator, thanks to the variable geometric parameters of the mixing chamber and nozzles, allows to obtain foam mixtures with a wider range of properties. Such geometric changes provide better saturation of the fluid with air, create more intense turbulence, reduce hydraulic losses, and also increase the productivity and efficiency of well development.

Keywords: circulation system, cleaning unit, design, foam generator, mathematical modeling, software environment, graphical research.

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IMPROVEMENT OF PREDICTION OF OIL DISPLACEMENT EFFICIENCY DURING WATERFLOODING DUE TO DETAILING OF LITHOLOGICAL DISTRIBUTION

pages 72–77

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The object of research is the process of oil displacement during waterflooding. The research aims to develop and substantiate a methodology that improves the reliability of predicting oil displacement efficiency during waterflooding. For this purpose, the classical Buckley-Leverett method and the State Standard of Ukraine method for calculating the oil displacement efficiency during waterflooding were extended by integrating lithological data, which allows considering the influence of geological characteristics on the process of oil displacement by water.

The developed methodology for improving the reliability of oil displacement efficiency prediction encompasses the identification of lithofacies and the determination of core and fluid sample properties. Subsequently, the representative elementary volume (REV) is ascertained for each facies. Based on this, the irreducible water saturation and irreducible oil saturation are calculated. Relative permeability curves are then constructed for each facies. The Buckley-Leverett equation is applied, and fractional flow curves are generated. The data is integrated into a three-dimensional reservoir model, with facies volumes determined using the kriging method. Finally, the averaged oil displacement efficiency is calculated.

A comparative analysis of the reliability of methods, with and without lithological subdivision, was conducted by constructing an experimental histogram and a normal distribution plot, considering or disregarding lithological distribution, respectively. For the comparative analysis, this research generates one hundred reservoir realizations, both with and without lithological subdivision, using the Sequential Indicator Simulation tool.

It was established that the use of lithological data in the calculations of the Buckley-Leverett method, with consideration of the lithological factor, allows a reduction in the scatter of predicted values by 11% in comparison with a similar method without consideration of the lithological factor.

The originality of the research lies in integrating lithological distribution into the Buckley-Leverett method and the State Standard of Ukraine method of calculating the oil displacement efficiency during waterflooding, which significantly improves the predictive results. The proposed approach allows considering the lithological factor at the level of analytical formulas when calculating the two methods.

Keywords: oil displacement efficiency, waterflooding, Buckley-Leverett method, lithological distribution, relative permeabilities.

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EXPERIMENTAL SPECIFICATION OF THE NATURE OF ROCK MASS FRAGMENTATION BY BLASTING OF BOREHOLE CHARGES OF VARIABLE LENGTH

pages 78–85

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The object of this study is the process of rock mass destruction in open-pit mines during large-scale blasting operations using borehole charges of variable length. The deficiencies identified during the experimental audit include the discrepancy between the particle size distribution of the blasted rock mass and the design parameters. This mismatch is particularly evident under conditions of geogenic and anthropogenic disturbances, zones with variable bench heights, and contacts between different types of rock. One of the most problematic areas includes sections with developed fracture systems, which influence the propagation of blast waves and lead to zones of anomalous destruction and increased proportions of oversized rock fragments.

The inconsistency between the actual and calculated particle size distribution of the blasted rock mass in disturbed rock bodies complicates the design of blasting operations and the execution of technological processes in open-pit mining. This challenge becomes even more significant when mining activities are conducted in close proximity to urban development.

The research utilized experimental blasting methods, stepwise excavation with photographic documentation, and visual analysis of fragmentation zones, taking into account the length of charges and detonation delays. A qualitative outcome was achieved: the hypothesis regarding the regularities in the formation of volumetric zones in the rock mass was confirmed. Within these zones, the rock mass fragmented by the blast exhibits a relatively uniform particle size distribution. It was established that the key factors influencing the efficiency of explosive fragmentation in heterogeneous rock masses are the degree of natural fracturing and the detonation velocity (brisance) of the explosives. Observations from the layer-by-layer excavation of the fragmented rock partially confirmed the predicted effects of intentional variation in delay times between charges within groups of blast boreholes.

As a result, the blasting process becomes more technologically controllable, leading to improved granulometric composition of the rock mass and a reduction in the proportion of oversized material. Compared to traditional blasting schemes, the use of variable-length borehole charges allows for more effective adaptation to the complex structure of the rock mass and to conditions involving proximity to urban infrastructure, thereby providing technical and economic advantages in open-pit mining operations.

Keywords: open-pit mine, anthropogenically disturbed rock mass, explosive fragmentation, adaptive large-scale blast design, fracture wave-guiding effect, particle size distribution.

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