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DEVELOPMENT OF THE HARDNESS MATHEMATICAL MODEL OF Ti-ALLOYED IRON FOR CAST PARTS USED IN CONDITIONS OF INTENSIVE ABRASIVE FRICTION

pages 6–9

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The object of research is wear-resistant cast iron, intended for cast parts that work under conditions of intense abrasive friction during operation. Examples of such parts can be mixer blades of various functional purposes, the operational properties of which include stability, which depends on the hardness, determined on the HRC scale. To give such cast parts wear-resistant properties, the cast iron from which they are made is alloyed with elements that contribute to the formation of carbides of different composition: W, V, Mo, Ti, etc. The main problem that prevents the purposeful selection of materials is incomplete knowledge about the effect of chemical composition on properties, in particular, wear resistance, which prevents a justified selection criterion.

Using regression analysis methods, a mathematical model was obtained, including a regression equation of the form $HRC=f(C; C_{eq}; Ti)$, which relates the content of carbon, titanium and carbon equivalent in cast iron and hardness. The resulting model allows for purposeful selection of the chemical composition, which ensures a given value of HRC, on which wear resistance depends. Optimization of the chemical composition, performed according to this model, made it possible to determine that the chemical composition, which provides the maximum hardness of $HRC=49$, is outside the planning area: $C=3.54$ %, $C_{eq}=3.95$ %, $Ti=3.56$ %. It was established that the same value of hardness can be obtained inside the considered planning area, which has an arbitrary appearance, provided with available conditions of a passive experiment. According to the available experimental data, the values of the input variables equal to $C=3.34$ %, $C_{eq}=3.727$ %, $Ti=0.73$ % ensure obtaining hardness at the level of $HRC=49$. Such alternative options regarding composition and properties may indicate that the $HRC=f(C; C_{eq}; Ti)$ response surface has a complex appearance that requires additional research.

Keywords: wear resistance of cast iron, HRC hardness, alloying of cast iron, chemical composition of cast iron.

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MECHANICS

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CONTRIBUTION TO MICROMECHANICAL MODELING OF THE SHEAR WAVE PROPAGATION IN A SAND DEPOSIT

pages 10–18

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The object of study is the vertical wave propagation in a sand deposit. This paper is aimed at analyzing the vertical wave propagation in a sand deposit through micromechanical modeling that inherently takes account of intergranular slips during deformation. Such a problem, which is part of the general framework of wave propagation in the soil, has long been analyzed using continuum models based on approximate behavior laws. For this purpose, a 2D Discrete Element Method (DEM) model is developed. The DEM model is based on molecular dynamics with the use of circular shaped elements. The intergranular normal forces at contacts are calculated through a linear viscoelastic law while the tangential forces are calculated through a perfectly plastic viscoelastic model. A model of rolling friction is incorporated in order to account for the damping of the grains rolling motion. Different boundary conditions of the profile have been implemented; a bedrock at the base, a free surface at the top and periodic boundaries in the horizontal direction. The sand deposit is subjected to a harmonic excitation at the base. Using this model, the fundamental and resonance frequencies of the deposit are first determined. The former is determined from the low-amplitude free vibration and the latter by performing a variable-frequency excitation test. It is noted that there is a significant gap between the two frequencies, this gap could be attributed to the degradation of the soil shear modulus in the vicinity of the resonance. Such degradation is well proven in classical soil dynamics. The effects of deposit height and confinement on resonance frequency and free-surface dynamic amplification factor are then investigated. The obtained results highlighted that the resonance frequency is inversely proportional to the deposit's thickness whereas the dynamic amplification factor R_d increases with the deposit's thickness. In the other hand, when the confinement increases the deposit becomes stiffer, which results in reducing the amplification. Such result is in accordance with theoretical knowledge which states that the most rigid profiles such as rocks do not amplify seismic movement.

Keywords: micromechanical model, sand deposit, discrete element method, shear wave propagation.

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MECHANICAL ENGINEERING TECHNOLOGY

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EXPERIENCE AND EFFECTIVENESS OF THE NO-LOFT LINKING SHAPE AND DIMENSION METHOD USING LASER OPTICAL SYSTEMS IN AIRCRAFT PRODUCTION

pages 19–26

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The object of research is the application of the no-loft linking shapes and dimension method using laser measuring tools to reduce the labor intensity and cycle of mounting work. The study of the accuracy of the geometric parameters of cantilever wing and technological equipment at various stages of production was carried out. The problem is to create a method of using laser optical systems in aircraft production at the stage of mounting of technological equipment to minimize the impact on the accuracy of the dimensions of assembled parts of aggregates. The following results were obtained: the advantages of using the no-loft linking method in the modern production of aviation equipment were analyzed, which makes it possible to reduce the preparation cycle by 2–3 times. A study was conducted on the effective use of the Coordinate Measuring Machine (CMM) of laser tracker in the manufacture of the cantilever wing (CW) of the AN series airplane at all stages of mounting, as well as on the accuracy inspection of geometric parameters in comparison with the theoretical master geometry (MG).

The practical significance of the research is that the proposed method of using laser optical systems during the installation of equipment allows to reduce to a minimum the impact on the accuracy of low rigidity frames. And also, to reduce the equipment deformation due to the mass of the parts of the assembled aggregates and temperature deformations, which allows to ensure a reduction of the mounting error to ±0.1 mm. Also, the application of this technique allows to enter the plane's coordinate system without prior leveling, to mounting and inspection the installation of the wing, fin, stabilizer, engines and landing gear on the fuselage. In general, the application of the no-loft linking shape and dimension method with using laser optical systems in aircraft production allows to reduce the labor intensity and cycle of mounting work up to 10 times.

Keywords: accuracy of aircraft contours, laser means of inspection, aggregate digital mock-up, no-loft assembly method, laser tracker, aircraft leveling.

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ELECTRICAL ENGINEERING AND INDUSTRIAL ELECTRONICS

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NUMERICAL MODELING OF ELECTRICAL PARAMETERS OF $LiFePO_4$ BATTERIES

pages 27–34

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The object of research is the physical processes of electric energy storage in Li-ion batteries. The problem being solved in the work is related to the lack of reliable mathematical models of storage batteries, which leads to the appearance of undesirable effects or emergency situations when changing operating modes.

In the course of the work, Li-ion battery models based on electrochemical theory and electrical circuits were considered. The six most common equivalent battery replacement schemes are presented. The advantages and disadvantages of the considered substitution schemes are given. The dual-polarization mathematical model was found to most accurately describe the performance of the battery at the end of the discharge and charge cycles compared to the first-order Thevenin model, the RC model, and the active resistance battery model. The physical processes in the storage battery during pulse discharge, which is the main part of electrical energy storage systems based on electrochemical technology, were studied. Mathematical modeling was carried out in the Matlab software package using the Simulink application program package. The dependence of the parameters of the equivalent lithium-ion battery replacement scheme according to the second-order Thevenin model on the ambient temperature and state of charge is considered. It was established that the value of EMF E depends more on the change in SOC than on temperature. In turn, the active resistance R_{OM} shows a greater dependence on temperature than on the change in SOC. At high temperatures, the resistance value decreases. The parameters R_1 and C_1 characterizing the electrochemical polarization vary in the range from 10 to 75 % SOC. The parameters R_2 and C_2, which depend on the concentration polarization, vary in the intervals from 0 to 25 % SOC and 75 to 100 % SOC.

The recommendations for choosing a Li-ion battery model developed in the work can be used in practice. The established dependencies will help to better design electrical energy storage systems based on electrochemical technology.

Keywords: lithium-ion battery, electric model, parameters of the equivalent circuit of substitution, state of charge, temperature.

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TECHNOLOGY AND SYSTEM OF POWER SUPPLY

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DETERMINATION OF THE TYPE OF ARCHED CARBON FIBER REINFORCED FASTENING OF THE PREPARATORY OPENING FOR THE CONDITIONS OF THE «DNIPROVSKA» MINE IN WEAKLY METAMORPHIZED ROCKS

pages 35–40

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The object of study is an arched carbon fiber-reinforced support of constant cross-section in a layered massif of weakly metamorphosed rocks. The article presents an analysis of the possible use of arched fiber-reinforced support of constant cross-section in a layered massif of weakly metamorphosed rocks for the conditions of the «Dniprovska» mine (Ukraine) around the preparatory opening.

An analysis of the stability of mine openings in Western Donbas mines has shown that it is necessary to modernize the support system by introducing carbon fiber. The main reason for the low stability of the opening is the insufficient load-bearing capacity of the support, while its technical characteristics do not take into account the complex mining and geological conditions. The increase in stresses at mining depth is associated with impact safety, which is a serious problem during mining. Metal arch supports are deformable and have high rock loads and require a high level of energy absorption, i. e., to be very strong and flexible to withstand significant loads and avoid large displacements of the opening walls.

Carbon fiber-reinforced plastic is able to ensure the stability of the fastening system and eliminate the existing disadvantages of typical metal arch fasteners, namely, high labour intensity, low production speed and high weight of the structure. In this article, the stress-strain state for the specified conditions and the carbon fiber-reinforced plastic arch support of constant cross-section was analyzed using the SolidWorks software product, taking into account the physical and mechanical properties of carbon fiber-reinforced plastic and layered rocks. Taking into account the results of laboratory tests of an equivalent layered array on a press made of PLA and carbon fiber, the dependence of deformations of the equivalent array with increasing load was established.

The use of arched carbon fiber supports of various cross-sections can ensure the opening stability by reducing the intensity of stresses around its contour. On the basis of this study, a rational arched composite support of constant cross-section was proposed for the conditions of the «Dniprovska» mine. The obtained results indicate the need for further research, which will be considered in the author's future works.

Keywords: mine opening, opening stability, layered massif, carbon fiber, carbon fiber-reinforced plastic, rational parameters.

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SIMULATION OF THE WORK OF GLASS FURNACES WITH THE PURPOSE OF SEARCHING FOR RESERVES AND INCREASE THEIR EFFICIENCY

pages 40–46

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The object of research is the operation of a glass furnace. The work involved modeling the operation of a glass furnace by changing the technical and economic indicators of its operation in order to optimize the technological processes of manufacturing glass products, increase the energy efficiency of the process, and reduce the ecological burden on the environment. Glass furnaces are complex heat engineering units that require a large amount of energy to operate. Therefore, increasing their effectiveness is the main task of our research. In the work, computer modeling of thermal processes in the furnace was carried out, heat balances were calculated and analyzed, and the performance of the furnace was analyzed after changing and improving the technological regimes of combustion processes, glass boiling and furnace construction. Studies have shown that in order to increase the technical and economic performance of glass furnaces, it is advisable to conduct additional thermal insulation of the furnace enclosures. The thermal insulation of the vault increases the efficiency of the furnace by 2–3 %, and the thermal insulation of the remaining areas of the furnace in total allows to increase the efficiency of the heating unit up to 3 %. Such measures improve the sanitary and technical working conditions of the staff in the machine-bath shop. Studies have shown that additional heating of the air used for burning fuel significantly increases the efficiency of the furnace. Thus, an increase in air temperature by 100 °C increases the efficiency of the furnace by approximately 2.5 %. However, such a measure is possible with a corresponding increase in the volume of regenerator nozzles. A significant increase in the efficiency of the furnace was achieved when additional electric heating was installed. This allows to reduce the total energy costs, and at the same time, the introduction of every 10 % of additional electric heating increases the efficiency of the furnace by up to 3 % and improves the quality of the glass mass. Such additional heating can be recommended in the amount of 20–30 %

of the total heat consumption for the operation of the furnace. The analysis of the obtained results showed a fairly good convergence of the results, which indicates the acceptable adequacy of the models. The obtained process simulation results allow choosing the optimal design and operation parameters of the glass furnace. The results of the work can be used in practice for the design of efficient glass furnaces of various purposes and performance.

Keywords: glass furnace, regenerators, combustion, electric heating, computer simulation of technological processes.

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INCREASING THE ACCURACY OF OIL RECOVERY FACTOR PREDICTIONS BY INTEGRATING LITHOLOGY DATA

pages 47–52

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The object of research in the paper is the process of oil extraction during flooding. The Buckley-Leverett method, which is widely used to estimate oil production in flooding, has certain limitations that lead to uncertainty in the results. This paper proposes to extend the Buckley-Leverett algorithm by integrating lithological data. This approach allows to take into account the influence of geological characteristics of the formation on the process of displacement of oil by water, which leads to a significant increase in the accuracy of forecasting the oil production coefficient. The effectiveness of the proposed method is confirmed on the basis of data analysis of a real oil field.

The methodology for calculating the oil recovery coefficient during flooding using lithological dissection is presented. In this work, the steps of determining the oil recovery coefficient were analytically determined, which achieves a certain degree of accuracy due to the inclusion of the lithological characteristics of the permeable zone of the formation. The basic calculation of the lithological distribution over the layer was performed using the Kriging method. To confirm the accuracy of the Buckley-Leverett method, taking into account lithological dissection, the use of data analysis, including an experimental histogram and a theoretical normal distribution plot, is proposed. For data analysis, one hundred cases of lithological distribution were generated using the Sequential Indicator Simulation method.

The comparative analysis of the data of the experimental histogram and the theoretical graph of the normal distribution of the determination of oil recovery coefficients by the Buckley-Leverett method for cases with and without lithological dismemberment allows to quantitatively assess the accuracy of both studied options. On the basis of a real oil field, it is shown that the accuracy of oil recovery coefficients by the Buckley-Leverett method, taking into account lithological fragmentation, exceeds the similar method without taking into account lithological fragmentation by 11 %.

Keywords: oil recovery coefficient, Buckley-Leverett method, waterflooding, fractional flow curves, oil production, lithofacies data.

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DETERMINATION OF THE CHARACTERISTICS OF DRILL STRING VIBRATIONS DURING THE DRILLING PROCESS

pages 53–60

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The object of research is vibration processes of a certain origin in the drill string with typical design deviations depending on the mode parameters of drilling. A drill string is an oscillating system with an infinite number of degrees of freedom of a multifactor system. An exhaustive study of oscillatory processes in the drill string is impossible neither analytically nor experimentally, due to the specifics of the hole deepening in various rocks, the design of the well, its shape, etc. Therefore, in practice, they try to solve the problems of the dynamics of the drill string for an idealized system and, while preserving the main oscillatory properties, solve some problems of the rod system. The work carried out was aimed at experimental studies of vibrations of the drill string during the drilling process.

It is shown that the effectiveness of the use of hydrodynamic cavitation requires the development of methods and devices for intensifying the well drilling process. It is proven that the design of the cavitation generator organically fits into the existing well drilling equipment and allows for the intensification of technological processes with lower specific energy consumption. It is found that all oscillatory processes that occur in the drill string are random in nature and must be considered using the mathematical apparatus of the theory of random oscillations.

The study of vibrations during well drilling shows that vibrations can be considered as random stationary processes, since transient modes have a sufficiently short duration for homogeneous rocks with fixed drilling modes. The analysis of the vibrations of the drill string elements based on random oscillations in a number of cases allows to increase the reliability of determining the vibration reliability of the drill string elements. It has been proven that the response of drill string elements to broadband random vibration can be defined as the combined effect of several narrowband random vibrations.

Keywords: well drilling, drill string, vibration reliability, hydrodynamic cavitation, cavitation generator design.

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