ABSTRACT AND REFERENCES
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DEVELOPMENT OF THE TECHNIQUE FOR IMPROVING THE STRUCTURE OF A MAGNETIC FIELD IN THE APERTURE OF A QUADRUPOLE ELECTROMAGNET WITH A SUPERCONDUCTING WINDING (p. 6-12)

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It is of practical interest to construct models for a magnetic field of the quadrupole electromagnet that would make it possible to adjust the medium-integral coefficients of magnetic flux density by changing the geometrical parameters of magnet design. The aim of this work is to develop a method for the optimization of a quadrupole electromagnet's structure with a superconducting winding based on the criterion for a minimum of magnitudes of the non-quadrupole medium-integral coefficients of magnetic flux density in the aperture. Practical application of the technique makes it possible to optimize the design of a quadrupole electromagnet to minimize coefficients of magnetic flux density, medium-integral in length, based on the calculation of geometrical parameters for the yoke and winding. The derived analytical expressions to calculate the minimized magnetic flux density coefficients, medium-integral in length, generated inside the aperture of a quadrupole electromagnet, are based on their proportionality to the contributions from the current winding and the dependence on its position relative to the yoke. The relationships between the coefficients of magnetic flux density, medium-integral in length, and design parameters, established empirically, underlie the procedure for practical application of the technique for improving the uniformity of a gradient of magnetic flux density of a quadrupole electromagnet. The expressions obtained allow the calculation of the required correction of geometrical parameters in the already existing structure in order to optimize magnetic field inside the aperture of quadrupole electromagnets based on the assigned medium-integral coefficients.

The paper reports results of the optimization of design of a magnetoactive part of the triplet of quadrupole electromagnets at an accelerator complex for the project NICA. Optimization was carried out based on the proposed technique with the minimization to a level of 10^{-5} of the non-quadrupole medium-integral coefficients for the transverse components of magnetic flux density generated in the aperture of an electromagnet with a superconducting winding.

Keywords: beam of particles, quadrupole electromagnet, magnetic flux density coefficient, superconducting winding.

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DEVELOPMENT OF THE METHOD TO OPERATIVELY CONTROL QUALITY OF IRON ORE RAW MATERIALS AT OPEN AND UNDERGROUND EXTRACTION (p. 13-19)

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The main task of the mining industry is to improve the efficiency of extraction and processing of iron ore. One of the main factors

contributing to solving the task is determining the content of iron in the ore body at the initial stage of production chain. Traditional methods of chemical analysis that are widely used at present to achieve this goal do not possess a sufficient degree of responsiveness and require about two hours to obtain the results. That typically does not make it possible to properly adjust the parameters of the technological process of ore processing, but only provides for the opportunity to ascertain the status of the production process at the time of sampling.

Existing methods of accomplishing this task, which possess a sufficient degree of efficiency, are based on the use of direct methods. These include the nuclear-physical (interaction between gamma-radiation and mountain mass), magnetometric (changing the relative magnetic permeability when interacting with magnetic iron), ultrasound (a change in the ultrasonic wave propagation in the examined material) methods.

In order to improve the accuracy of determining the percentage of a mineral component in the examined mountain mass, in this work we have improved the nuclear-physical method for determining the content of total iron in iron ore lumps. The improvement of the method makes it possible to enhance the accuracy of control over a mineral component in the studied material by 1.5 % by registering not only the gamma quanta reflected from the surface, but the absorbed particles as well. We have experimentally established the sensitivity level (K=1.32–1.38), which characterizes a change in the intensity of the registered radiation due to a change in the content of iron in the irradiated material. We have also established the level of a statistical error (<0.65 %) in order to ensure the permissible measurement accuracy.

Based on a given method, we have proposed an information-measuring system for monitoring, analysis, and forecasting the qualitative characteristics of ore under conditions of an enrichment plant. The application of this system makes it possible for technological personnel to promptly intervene in the production process and to adjust the qualitative-quantitative parameters of ore.

Keywords: quality of mineral raw materials, logging of wells, gamma radiation, total iron, magnetic iron.

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IMPROVEMENT OF SAFETY OF AUTONOMOUS ELECTRICAL INSTALLATIONS BY IMPLEMENTING A METHOD FOR CALCULATING THE ELECTROLYTIC GROUNDING ELECTRODES PARAMETERS (p. 20-28)

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We have solved the task of safety improvement in the grounding process of autonomous mobile electrical installations. Existing procedures for the calculation of normalized resistance of grounding electrodes in electric installations have been examined and studied. Their main drawbacks have been revealed: the difficulty and complexity of calculations; the probabilistic and approximate character; the use of source data taken to calculate the electrophysical parameters of stationary grounding electrodes; the calculations do not account for the structural-phase structure of soil and the volume of electrolyte. Based on the application of percolation theory and the apparatus of fractal-cluster geometry, we have modeled the process of electrolytic grounding in heterogeneous soils of different porous structure, which possess the percolation and fractal properties. A physical model of the process of electrolytic grounding has been developed, which takes into consideration the soil structure properties when changing the fractal dimensionality of a cluster over a certain range that forms the electrolytic grounding conductor with the normalized resistance. It has been shown that the model of conductivity of the electrolytic grounding electrode is defined by the soil electrical conductivity in a percolation channel of the porous structure of soil and can be considered as a function of the volumetric concentration of the electrolyte and the size of the volumetric structure of the electrolytic percolation cluster. We have derived analytical expressions to relate the normalized resistance of electrolytic grounding conductors and the specific resistivity of soil to the fractal dimensionality, volume of the electrolyte, the number of pores to the electrolyte, density of a geometrical volumetric body. We have improved a method for calculating the electrophysical parameters of electrolytic grounding conductors, based on accounting for the main linear size of the cluster of an electrolytic volumetric body, which coincides with the electrolyte penetration depth for various soil structures. We have established conditions for conductivity of the electrolytic grounding conductor in order to ensure safety during operation of the autonomous mobile electrical installation.

Keywords: grounding process, electrolytic grounding conductors, percolation and fractal properties, normalized impedance.

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DETERMINATION OF OPTIMAL PARAMETERS OF THE PULSE WIDTH MODULATION OF THE 4qs TRANSDUCER FOR ELECTRIC ROLLING STOCK (p. 29-38)

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Operating modes of the single-phase 4qs transducer with pulse-width modulation as part of the AC electric rolling stock are investigated. The method is developed for determining the PWM parameters, at which the optimum transducer mode in terms of minimizing the reactive power in the "locomotive-traction network" system is implemented.

The features of the developed method are the division of the process of determining the optimum PWM parameters into 2 steps. This allows removing unnecessary blocks from the simulation model and reducing the total simulation time. At the first step, the values of the power factor and current of the DC link in the whole range of coefficients of modulation and shift between the network current and the reference sine-wave signal are determined. Further, from the received data array, pairs of values of the PWM parameters, which ensure the highest power factor of the "electric locomotive-traction network" system are allocated and entered into the table system for setting the PWM parameters. At the second step, the dependences of power loss, and, consequently, both the efficiency and total harmonic distortion of the network current on the transducer clock frequency are determined. The determination of power loss is based on the calculation of the energy dissipated for 1 s on the IGBT transistor and snubber resistor depending on instant values of current through them.

Keywords: 4qs transducer, electric rolling stock, power factor, PWM, simulation, power loss.

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STUDYING THE COMPUTATIONAL RESOURCE DEMANDS OF MATHEMATICAL MODELS FOR MOVING SURFACE EDDY CURRENT PROBES FOR SYNTHESIS PROBLEMS (p. 39-46)

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Distribution of eddy current density for three types of coils of excitation of moving surface eddy current probes, in particular circular, rectangular, orthogonal-rectangular shapes was calculated according to the formulas of "exact" electrodynamic mathematical models with allowance for the speed effect.

Calculation time from 8 to 20 hours was established for a circular excitation coil with dimensions of testing zone 50×50 mm at speed υ_x=40 m/s. The calculation time was from 8 to 9 hours for a rectangular excitation coil at a speed of movement in direction of two components υ_x, υ_y=20 m/s with the testing zone dimensions of 80×48 mm. The calculation time was more than 7 hours for an excitation coil of orthogonal rectangular shape with dimensions of the testing zone of 15×35 mm at a speed of movement in direction of components υ_x, υ_y=40 m/s; and for the testing zone dimensions of 12×24 mm for υ_x, υ_y=40 m/s it was longer than 9 hours. It was found that the computational complexity of calculation of distribution of the eddy current density with the use of "exact" mathematical models was rather large when changing even two spatial coordinates in the testing zone. That is, the direct use of "exact" mathematical models when calculating the values of distribution of the eddy currents density in the points of the controlled zone is inappropriate taking into account the considerable resource intensity of the computational process.

The necessity for using a mathematical apparatus of surrogate optimization was substantiated for designing eddy current

probes with a uniform distribution of eddy current density in the testing zone.

This study is useful for non-destructive testing specialists in the field of mechanical engineering. The study results can be used in designing eddy current probes with improved metrological characteristics, in particular homogeneous sensitivity, localization of the probing excitation field, improved noise immunity, possibility of eliminating the edge effect manifestations in testing.

Keywords: optimal synthesis, eddy current probe, distribution of eddy current density, computational resource consumption.

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CONSTRUCTION OF THE INTEGRATED METHOD TO MODEL A SYSTEM FOR MEASURING THE DENSITY OF INFRARED RADIATION FLOWS (p. 47-52)

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We have constructed an integrated method to model the system of measuring the density of flows of infrared radiation based on solving the inverse problems of dynamics using the Volterra equation of the first kind and focusing on solving the problem on dynamic correction. Solving a problem on the structural correction of the dynamic characteristics of the system for measuring the density of flows implies the construction and application in a transforming channel or a circuit in the system of a certain unit. This unit, owing to its specially formed dynamic properties, ensures the best dynamic characteristics of the entire system.

We have experimentally verified the technique for the compensation for a dynamic error. To this end, the experiments were conducted to measure the density of a non-stationary flow of infra-red radiation with the assigned law of change, which is characteristic of the practical working conditions for receivers. A change in the

density of the incident flow of infrared radiation was achieved at the expense of the receiver's rotation around the axis that passes through the middle of its receiving surface, in the flow of the stationary emitter. The result of the experiment is the derived nonlinear approximation of the experimentally obtained transitional characteristic in the form of the receiver's response to the sinusoidal flow of infrared radiation.

It should be specifically noted that the results of numerical simulation and the experiment show a satisfactory convergence, which allows us to argue about the correct choice of the model. The developed algorithms are capable to provide a numerical implementation of integrated models and serve as the basis for constructing high-performance specialized microprocessor systems to work in real time. That has made it possible to successfully implement the dynamic correction of the system for measuring flows of infrared radiation and to significantly increase its accuracy. A combined application of the devised method for solving mathematical problems and computer tools would provide an opportunity to improve the efficiency of processes to synthesize and design computational devices for correcting means of measurement.

Keywords: Volterra integral equation, infrared radiation, measurement system, dynamic correction.

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WELDED JOINTS GEOMETRY TESTING BY MEANS OF AUTOMATED STRUCTURED LIGHT SCANNING (p. 53-60)

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Nuclear industry in Russia plays an important role in total power generation. At the same time, it is considered to be dangerous in terms of high potential risk in a case of any failure occurrence. Therefore, constant monitoring and quality control is essential on every stage of energy production process, as well as maintenance of the technical quality of the exploited components. For that reason, specified regulatory documents are developed. They provide quality requirements for each component type and regulate inspection procedures. In this paper, welded joints were considered as the controlled object. It is represented that standard quality control methods based on the manual visual inspection are not accurate enough. Therefore, this paper suggests an advanced method of automated optical scanning for misalignment evaluation of welded parts based on structural light technique. Precision improvement was achieved by implementation of a robotic manipulator, which led to the development of the specific calibration technique. Considering that there are no established methodologies for such method the validation experiments were performed. The ability to detect the minimum displacement in accordance with nuclear industry regulatory documents was studied. The results demonstrated that misalignment of 0.47 mm can be measured, and it proves that proposed method can be further implemented for a practical application in nuclear industry.

Keywords: 3D-reconstruction, visual testing, structured light, industrial robot calibration, welding misalignment.

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DEVELOPING AND PROGRAMMING THE ALGORITHM OF REFINEMENT OF THE CRYSTAL STRUCTURE OF MATERIALS WITH POSSIBLE ISOMORPHOUS SUBSTITUTION (p. 61-67)

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In general, the software for analyzing data using the X-ray diffraction method does not include the possibility for using stoichiometric principles between chemical elements and the relations between the occupation of crystallographic positions by atoms. In the article, the algorithm and its program realization for defining the distribution of atoms according to the crystallographic positions using stoichiometric principles in materials with isomorphous substitution are developed. A combination of using the developed algorithm and the FullProf program is proposed for taking into account different conditions that should be satisfied by the distribution of atoms according to the crystallographic positions. It is proposed to estimate the unambiguity of the initially defined distribution of atoms by finding local minima in certain physically substantiated limits of changes in the parameters of the structure. The complex method for minimization of a function of the deviation of the theoretically calculated diffractograms from the experimental ones is given to avoid falling of the objective function to a local minimum. Two ways for minimization of the difference between theoretically calculated and experimental diffractograms are proposed. By the first of them, with the help of the developed algorithm, the occupation of crystallographic positions can be established, and the minimization method built-in in FullProf calculates all other parameters. By the other way, the developed algorithm is used only and the rest of parameters approximately calculated by FullProf before are fixed. The efficiency of the developed algorithm is illustrated by finding the distribution of atoms in sublattices in ferrite-spinels. The developed algorithm can be used for any materials in which isomorphous substitution is possible, such as spinels, garnets, perovskites, and others.

Keywords: algorithm for analysis of diffractograms, structure refinement, FullProf, structural analysis, solid solution.

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IMPROVEMENT OF A DISCHARGE NOZZLE DAMPING ATTACHMENT TO SUPPRESS FIRES OF CLASS D (p. 68-76)

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The software package COSMOSFloWorks has been used to study a discharge nozzle damping attachment. A procedure has been proposed to estimate the covering of surface with dimensions of 0.4×0.4 m by a fire-extinguishing powder. It was established that existing discharge nozzle damping attachments are not efficient because at extinguishing light metals they do not effectively reduce the speed of powder supply onto a flammable surface and fan the fire, not being able to cover the burning surface by a fire-extinguishing powder. After putting out the fire the surface that was covered with powder reveals the burnouts. We have modeled the optimal structural parameters for a discharge nozzle damping attachment in order to extinguish fires of class D in the form of a discharge nozzle damping attachment with an elliptical top and a parabolic reflector. It has been proven that a damping attachment with two working surfaces outperforms the previous damping attachment with a single working surface by 30 %. Given this, the fire-extinguishing powder covers the burning surface by a larger layer, preventing the fanning of chips from the surface of a burning metal, thereby shortening the duration of burning and improving the efficiency of a fire-extinguishing powder supply. Experimental study has confirmed that the use of a damping attachment that supplies a fire-extinguishing powder with two working surfaces in order to extinguish fires of class D increases the powder feed to a fire site, reaching above 90 %.

The diameter and the shape of the attachment have been determined. The attachment must acquire the form of a diffuser with a diameter of 16 mm.

Our development could be used when designing the stationary and portable fire extinguishing systems for light metals and alloys, including incendiary grenades under condition of proper selection of the powder. We have achieved positive results during field tests of the discharge nozzle damping attachment using a make-up fire to burn the shavings of magnesium alloys.

Keywords: discharge nozzle damping attachment, fire of light metals, extinguishing the fire of magnesium, optimal pressure, optimal distance.

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