ABSTRACT AND REFERENCES

APPLIED PHYSICS

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IMPROVEMENT OF THE METHOD FOR ANALYSIS OF NONLINEAR ELECTROTECHNICAL SYSTEMS BASED ON THE SMALL PARAMETER METHOD (p. 6-12)

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The small parameter method, implemented in frequency domain, was used for the analytical analysis of nonlinear electrical circuits of electrotechnical systems. To have the possibility of calculations in frequency domain, the automated method of forming orthogonal harmonic components of electrical magnitudes based on the algorithm of discrete convolution was used. The characteristic of a nonlinear element was represented by the polynomial function of third degree. It was shown that application of the small parameter method with its realization in frequency domain makes it possible to simplify the process of analyzing electrical circuits with nonlinear elements by automating calculations in the mathematical package. Analytical and numerical calculations of a circuit with actively inductive load demonstrated sufficient accuracy of the proposed method, the relative error for the main harmonic of current did not exceed 6 %. The conducted comparative analysis of the proposed small parameter method with the classic small parameter method on the example of calculation of an electrical circuit with RL load showed that the developed method provides better adequacy of results and high calculation accuracy in comparison with the existing one. Relative error by amplitude of first and third harmonics of current does not exceed 2.5 %, and by phase, it does not exceed $1.042 \cdot 10^{-3}$ %. The method of numerical structural modeling was used to determine the reference values of current of the researched circuit. The results of the research can be used in calculations of electrotechnical devices, containing semiconductor components and electrical devices with nonlinear characteristics. In addition, the obtained results will make it possible to improve the processes of active compensation of harmonics of current in electrical networks with nonlinear load and to develop the tools of passive compensation.

Keywords: nonlinear system, electrical circuit, analysis, small parameter method, frequency domain, automated algorithm.

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IMPROVEMENT OF THE MATHEMATICAL MODEL OF SINGLE-PHASE HALF-BRIDGE INVERTER IN STATE-VARIABLE FORM (p. 14-21)

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The mathematical model of the insulated-gate bipolar transistor in the IGBT module is improved due to the determination of analytical expressions for dynamic spurious capacitances of the device. The expressions are obtained by analytical differentiation of functions that approximate the dependence of the spurious capacitances of the transistor on the voltage between the collector and the emitter. The method of forming a mathematical model of the IGBT voltage inverter in the form of matrix differential equations of state in the Cauchy form and nonlinear equations is proposed. There are no restrictions on the number of transistors and the configuration of the circuit. The method is based on the matrix-topological method of electrical circuits analyzing. The application of this method is illustrated by the example of a single-phase half-bridge inverter with resistive load. The urgency of improving the mathematical model of the IGBT inverter is caused by the need to analyze the electrical safety of the state of the variable frequency circuit between the frequency converter and the motor. Existing models of frequency-controlled electric drives do not take into account a number of factors that significantly affect the accuracy of the simulation. Such factors include the dynamic nature of the IGBT spurious capacitances and the disconnection of one of the machine phases from the network during the dead time when switching adjacent power switches of the inverter. The obtained mathematical model differs from the well-known in advanced representation of separate elements by nonlinear differential equations and taking into account mutual influences. The proposed approach allows to investigate the high-frequency transient components of currents and voltages in electrical systems with semiconductor converters. This simplifies taking into account the recharging processes of the IGBT capacitances during a dead time when switching adjacent power switches in the model. The peculiarities of the IGBT inverter switching transients are revealed, in particular, the significant exceeding, more than twice, of the transistor current during opening the operating current at the end of the switching process.

Keywords: spurious capacitances, pulse-width modulation, matrix of the main sections, state variables, graph tree, topological equations.

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ENHANCING THE EFFECTIVENESS OF CALCULATION OF PARAMETERS FOR SHORT CIRCUIT OF THREE-PHASE TRANSFORMERS USING FIELD SIMULATION METHODS (p. 22-28)

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We conducted theoretical research into electromagnetic processes when testing power transformers under the mode of the test short circuit based on a three-dimensional model of the magnetic field in the frequency statement. Reliability and accuracy of determining the parameters for the test short circuit of the power transformer for frequency-domain statements were substantiated with the use of verification of the data of calculation of frequency-domain and time dependent models of the magnetic field for frequency statements. The main regularities of the magnetic field distribution in the volume of the active part of the transformer were determined. In the magnetic field localization zones, 3D intensity distribution is uniform and is determined by the 2D distribution in the horizontal cross section of the active part in the middle of the phase windings height. The values of the axial component of the magnetic field intensity approach 96–97 % of the intensity vector module. An effective approach to field modeling was implemented based on decomposition of the computational domain into spatial zones. Each calculation zone is put in compliance with an electrical circuit of the substitution scheme. Distribution of electric potentials in the horizontal cross-sections of the conductors between the coils or between the turns of windings was accepted as uniform. The superposition of magnetic fields in spatial zones was implemented by means of dynamic synthesis by the criteria of minimal current error for electric circuits of the substitution scheme. The decomposition of the 3D area of field simulation area into the central and end zones is implemented at a distance of 10–15 % of the height of the phase windings, which ensures high accuracy of the magnetic field calculation with the error not exceeding 1.62 %. Time consumption for field simulation of electromagnetic processes under the mode of the test short circuit decreased by 5 times and requirements for the capacity of computing hardware resources decreased by 4 times. High accuracy of identification of parameters of the test short circuit of three-phase transformers was proved by comparing the calculation data to the results of tests at the private company “Eltiz” (Zaporizhzhia, Ukraine). Calculation errors do not exceed 1.42 % for active losses and 1.39 % for short circuit voltage. The proposed approach with the use of the methods of decomposition and of dynamic synthesis makes it possible to significantly improve the effectiveness of the preliminary stage of design preparation of production and can be used for solving the problems of design solutions optimization.

Keywords: electromagnetic field, three-phase transformer, test short circuit, decomposition, dynamic synthesis.

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RESULTS OF STUDYING THE Cu/ITO TRANSPARENT BACK CONTACTS FOR SOLAR CELLS SnO_2:F/CdS/CdTe/Cu/ITO (p. 29-34)

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We have studied transparent rear contacts Cu/ITO for the CdTe-based solar cells intended to be used in tandem and two-side sensitive instrumental structures. Creating an ohmic contact to the base layers of p-CdTe under industrial production is not practical as only platinum has the work function of electrons required for forming the ohmic transition. That is why the tunnel contacts are typically formed, using the thin films containing copper or copper chalcogenides. However, the diffusion of copper into the base layer leads to the degradation of initial parameters of film solar cells based on CdS/CdTe. Therefore, conditions for creating the transparent rear contacts when using a layer of copper require examination. It was established that the preliminary application of a nanodimensional layer of copper on the CdTe surface in order to form a rear electrode allows the formation of a quality tunneling contact. It is shown that the obtained instrumental structures demonstrate high degradation resistance. After 8 years of operation, the magnitude of efficiency for the examined PEC is nearly identical to the initial value. Studying the light volt-ampere characteristics of the SnO_2:F/CdS/CdTe/Cu/

ITO solar cells when illuminated from both sides allowed us to establish significant differences between the initial parameters and the light diode characteristics at illumination from a glass substrate and from the rear transparent electrode.

The established differences are due to the influence of a rear diode on the efficiency of photovoltaic processes in the base layer. The examined structure implements an inverse diode regime when a rear contact represents a diode, connected in series relative to the principal diode, which leads to the lower values of efficiency at illumination from the rear electrode. The results obtained demonstrate the need to reduce the thickness of the base layer in order to create effective two-side sensitive elements.

Keywords: cadmium telluride, transparent rear contact, tandem structure, two-side sensitive photoconverter.

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MODELING THE PROCESS OF POLYMERS PROCESSING IN TWINSCREW EXTRUDERS (p. 35-44)

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We developed a mathematical model of the process of polymer processing in co- and counter-rotating twin-screw extruders. The model takes into account a heat transfer of a polymer with screws and a barrel, as well as real boundary conditions (screws rotate, a barrel is stationary).

We used the model of the allocated C-shaped volume, which is limited by one turn of cutting of each of screws and in which contains a volume of the processed polymer is located, for the analysis of the process. The model gives possibility to describe the process of processing both in the case of complete and partial filling of an operation channel with processed material. This is especially important in the

case of dosed feeding of an extruder with a polymer, which is typical for modern extrusion equipment.

We studied a temperature field of a polymer in operation channels of co- and counter-rotating twin-screw extruders and compared the results of the calculation with experimental data. We substantiated theoretically and confirmed experimentally, that, unlike in a single-screw extruder, it is necessary to heat operation elements firstly and to cool them then (in the direction from a loading funnel to an extrusion head) in a twin-screw extruder.

We used the developed technique successfully at the development of modes of processing of various polymeric materials on co- and counter-rotating twin-screw extruders with screws of a diameter of 125 and 83 mm, respectively.

The discrepancy between the calculated values and the experimental values of temperature at the outlet of a twin-screw extruder with co-rotation screws Ø83×30D does not exceed 10 %. The experimental value of the temperature somewhat exceeded the given value. We explain this by the fact that the system of thermal stabilization of working elements for the studied processing modes could not remove released heat of dissipation effectively.

Application of the developed mathematical model will give possibility to forecast effective modes of operation of twin-screw extruders better, especially at processing of materials with low thermal stability.

Keywords: twin-screw extruder, co- and counter-rotating screws, boundary conditions, temperature field.

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THE CONCEPT OF CREATING A PULSE WATER GUN WITH A LARGE ACTION RANGE (p. 45-52)

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We presented the concept of creation of a pneumatic pulse water gun. Its original feature is a use of a developed turbulent flow at the attenuation stage for formation of a jet. We suppose to create the required structure of small-scale turbulence according to a known procedure by means of a lattice in a barrel channel. The maximum intensity of this turbulence will be at a certain distance from a lattice, where a nozzle must be installed to take a turbulent structure into a jet. Well-known theoretical concepts and experimental facts give possibility to state that small-scale turbulence has the property of flow stability to excitations. We assumed that this property would act in a jet and provide its stability before expenditure of turbulence energy and prevent appearance of large-scale turbulence. Thus, it will delay the disintegration of a jet and increase a range of its flight.

The analysis of a flow in known fountains with a transparent jet showed that representation of a laminar mode in them is incorrect. We presented a substantiation that special properties of jets are a consequence of a turbulent flow in fountains. This conclusion speaks in favor of the proposed use of turbulence as a tool against vortex formation. However, it is not possibly to apply the technique of creation of a jet in fountains for a high-power pulse water gun.

We proposed a schematic diagram of the pulse water gun with a pneumatic ejection of a water projectile. An obvious problem of combination of a pulse flow with creation of small-scale turbulence is instability of a flow at the initial moment of a pulse. We showed the way of the solution to this problem by the experimental determination of real flow characteristics in a particular water gun design. We offered solutions to the most important technical issues of water gun creation.

Keywords: pulse water gun, stability of a jet, developed turbulence, small-scale turbulence.

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DETERMINING THE ELECTROMAGNETIC FIELD PARAMETERS TO KILL FLIES AT LIVESTOCK FACILITIES (p. 53-61)

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We have considered the electromagnetic method to kill the larvae of flies – agricultural pests. To address the task, a problem on the distribution of electromagnetic fields in their body was solved. The solution is based on the Maxwell's equations in the integral form, which automatically take into consideration the boundary conditions at the surface of the larvae. Since we propose the electromagnetic radiation whose wavelength is much larger than the linear sizes of insects, the derived integral equations were solved in the approximation of quasi-statics. That made it possible to convert them into a system of inhomogeneous linear algebraic equations whose solution is the components of electric field inside the larvae of flies. The study was conducted for the single-layer and two-layer insects of an ellipsoidal shape. The obtained fields provide a possibility to determine the magnitudes of potentials that occur at the larva cover, as well as to find out which of these values lead to breaking this cover with the ensuing death of the fly larva.

To construct a dependence that would relate the number of imago from the larvae of flies to the parameters of electromagnetic radiation in the presence of an additive disturbance of a random character, we employed a full-factorial second-order planning. Electromagnetic radiation was applied to the fly larvae at the end of the second age. The exposure of fly larvae to the electromagnetic radiation was carried out in a frequency range of 10.2–9.8 GHz, a power flux density of 0.62–038 mW/cm^2 and an exposure of 2–12 s. The development of larvae was observed until the formation and release of an adult insect.

Based on a multifactor experiment, we derived the optimal values for the frequencies of radiation, power flux density, and exposure. To suppress insects at livestock facilities, starting from the larval stage and up until the release of imago, the electromagnetic radiation is needed with the following parameters: frequency is 10.2 GHz; power flux density is 0.37 mW/cm^2; relative instability of the generator frequency is 10^{-8}, exposure is 6 s. The release of imago from the pupae of fly larvae at livestock premises, irradiated with electromagnetic radiation, was less than 5 %.

The experiment with piglets showed that when the chemical method for treating the premises was applied, a gain in the live weight amounted to 7.2 %; when the electromagnetic method was used, it was 9.2 %. A smaller increase in the live weight upon chemical treatment is due to the fact that a chemical solution exerts a negative impact not only on flies and their larvae, but also on animals. The study that we conducted could be used to create industrial installations to kill the larvae of flies at livestock facilities.

Keywords: destruction of the larvae of flies, Maxwell integral equations, parameters of electromagnetic field.

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DEVELOPMENT OF A METHOD FOR EXPERIMENTAL INVESTIGATION OF COMBUSTION PROCESS IN LEAN BURN GAS ENGINES (p. 61-79)

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The problems of engine experiments in the conditions of unstable combustion were considered. A practical problem was the experimental study of the influence of spark discharge parameters of the ignition system on the operation of the gas engine at the lean limit. The possibility of expanding the lean limits by applying a high-energy capacitor discharge spark ignition system under the condition of limited erosion rate of the spark plug electrode surface was investigated. Particular attention was paid to the instability of the spark discharge as a process of transferring a portion of energy to the mixture in order to develop a flame kernel.

After analyzing the results of the experiment, its significant shortcomings associated with the lack of consideration of the phenomenon of cyclic instability of pocesses before ignition of mixture – for example, the spark discharge at the spark plug electrodes were revealed. This fact led to a thorough revision of the experimental research method and formulation of technical requirements to the measuring equipment.

A new method of bench tests by applying the latest automated system for the cycle-by-cycle measurement of spark discharge parameters with simultaneous processing of recorded indicator diagrams and statistical analysis of results for the last 1,000 engine cycles was proposed. The main advantage of the method is an increased reliability of the results of the experiment on the lean burn gas engine and reduction of the time for finding experimental errors.

Given that this method can be implemented only in a specialized measurement system, functional requirements as part of technical specifications for developing a new measuring system were formed.

The results obtained can be used in the experimental studies of combustion in lean burn gas engines at the stage of experiment planning and selection of measuring equipment.

Keywords: gas engine, cyclic variations, flame kernel, ignition energy, spark discharge, statistical analysis.

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