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SUMMARY. KEYWORDS

MECHANICAL AND THEORETICAL ENGINEERING

P. D. Balakin, V. N. Belkov, O. S. Dyundik, I. P. Zgonnik
Functional compensators in machine drives

Omsk State Technical University, Omsk, Russia

Real mechanical systems are characterized by real parameters, which include primary manufacturing and assembly errors, force and temperature deformations, and abnormal operating modes, the full knowledge of which is unknown when designing systems. Incomplete knowledge about the object is compensated by using coefficients entered into calculation formulas. The coefficients form the basis of reference literature and are obtained on the basis of generalization of experience in creating objects that are similar in design and purpose. This statistical technique is used to increase the margin of safety, but it does not allow us to obtain optimal performance criteria for the design of mechanical drives in particular.

It is proposed to use the principle of designing mechanical systems by giving them the property of adaptation to real parameters at the design stage. The means of adaptation is an additional motion of links to the main one, implemented in particular by functional compensators. An algorithm for the synthesis of a compensator is given on the example of the basic scheme of a friction planetary gearbox.

Keywords: real system parameters, adaptive motion, functional compensators, geometric-kinematic model, redundancy.

K. A. Vansovich, V. I. Yadrov
Biaxial testing of metal samples on testing machines with one load axis

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The necessity of experimental studies to assess the growth rate of fatigue cracks under biaxial loading is substantiated. An overview of testing machines for biaxial testing of metal samples, devices and fixtures used to ensure biaxial loading is made. An original device for distributing the vertical force of the testing machine along two axes of a cruciform sample is described.

Keywords: fatigue tests, cruciform specimen, surface crack, biaxial loading, biaxial loading coefficient, testing machine.

E. S. Gebel
Analysis of singularity planar multi-linkage mechanism of fourth order

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The planar multi-linkage mechanism of the fourth order, the output rocker of which implements an approximate stopping in one critical position is described in the article. The mechanism consists of three dyads passing through their limit positions in a single duty cycle. That is why the singularity problem is relevant for such mechanisms and should be studied to avoid jamming of links or the appearance of uncontrolled movements. The mathematical model is based on the theory of screws and contains the closed-loop equilibrium equations obtained for the investigated mechanism. Based on the obtained results of the geometry and singularity analyses, it is shown that there are eight different positions in which some joints stop momentarily and then their angular velocity direction changes.

Keywords: planar multi-linkage mechanism, singularity positions, screw theory, geometric analysis, approximate stopping, closed loop.

**Yu. P. Makushev¹, T. A. Polyakova¹,
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The features of kinematic calculation for Wankel's rotary piston engine

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It is presented the design features and the principle of operation for Wankel's rotary piston engine (RPD). It is given the analysis of scientific research aimed at improving the design of RPD. It is proposed the design study technique that allows in a graphical way to realize the construction of an RPD cylinder with a circular shape, the surface of which is made according to the epitrochoid. The derivation of equations is justified that allows to determine the coordinates of the position of the points of the epitrochoid depending on the eccentricity, the values of the radii of the initial generatrix of the epitrochoid, gear and fixed gear. It is given the calculation definition of the required value of the compression ratio. Using the Mathcad system as an example, it is shown the possibility of application mathematical software packages for calculations related to the study of the features of the Wankel's RPD epitrochoid, its calculation, its research and its construction.

Keywords: rotary piston engine, epitrochoid, gear wheel, rolled gear, eccentric, Mathcad.

**K. N. Pantyukhova¹, O. Yu. Bourgonova¹,
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Improvement of the technology of flame arrester manufacturing

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When mining hard coal the underground method is prevailed. This method provides a higher quality of the mineral. Methane emissions occur in coal mines during the development of gas-bearing seams. These emissions are the reason for the formation of an explosive mixture when mixed with mine air, and also contribute to the spontaneous combustion of coal. Methane alarms are used to monitor the mine atmosphere. Thermocatalytic sensor is the main element of such a gas analyzer. The sensor is placed in a breathable housing. This body is called a flame arrester. This article discusses the possibility of replacing the material used for the manufacture of a flame arrester. The basis of the existing material is nickel powder. It is proposed to replace it with a cermet bond. The composition of the ceramic material of the part is developed by the author and presented in the article. Replacement of material will lead to a significant reduction in the cost of the part and simplification of the manufacturing technology.

Keywords: gas analyzer, methane, flame arrester, nickel powder, ceramic bond.

Yu. O. Filippov, E. N. Eremin, D. A. Sedykh, O. V. Kropotkin
Features of nickel alloy structure, conditions for crystallization and isolation of main and redundant phases during modification

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The influence of modification of heat-resistant nickel-based alloys on the crystallization kinetics of alloys was established

by the methods of thermal analysis. This effect is expressed in the increase in solidus temperature and, as a consequence, narrowing the crystallization range of the alloy, the increase in the growth rate of a solid solution, and change in the temperature of precipitation of eutectic and strengthening phases. As a result, the use of modification with refractory particles makes it possible to exert an additional effect on the structure and properties of nickel-based alloys without additional heat treatment.

Keywords: heat-resistant alloys, modification with refractory particles, solid solution, eutectic, crystallization.

A. E. Korneev
Device for studying uneven rotation of crankshaft

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The main topic of the article is the choice of the direction and implementation of the use of electronic measuring instruments and monitoring of the working process occurring in the diesel internal combustion engine. For this purpose, an analysis is performed and a device is created that allows controlling the uneven rotation of the engine crankshaft containing photoelectron sensors, one of which allows reading the moment of passing the upper dead point, the other is designed to control the angular speed of the flywheel. The device converts the signals of these sensors into the form necessary for visualization of the working periodic process on the oscilloscope screen. The article presents a block diagram of the device and its amplitude-frequency characteristic. This device can be used for research and development work to improve fuel supply systems in internal combustion engines.

Keywords: air-fuel mixture, fuel combustion efficiency, technical system, uneven rotation of the crankshaft, infrared sensors, electronic frequency meter, oscilloscope, universal device.

ELECTRICAL ENGINEERING

V. V. Kharlamov, D. I. Popov,
P. S. Sokolov, L. E. Serkova
Experimental studies of the method of mutual load of induction motors

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The article presents the results of comparison of experimental studies and mathematical modeling of the stand for testing induction motors by the method of mutual load. A detailed description of the composition of the experimental equipment, which is based on a pair of frequency converters and connected to them a pair of engines of the АИС71В4 type with a nominal power of 0,75 kW, the shafts of which are rigidly connected by a coupling. The mathematical model of the electromechanical system used in the calculations is presented, and its main assumptions are listed. A table of parameter values and graphs obtained from calculated and experimental data are presented. The analysis of the obtained data shows the possibility of using the considered mathematical model with the existing assumptions in the design of electrical complexes intended for testing induction motors by the method of mutual load.

Keywords: experimental research, traction motor, test bench, frequency converter, mathematical model, comparison of results.

D. V. Antonenkov¹, V. Z. Manusov¹,
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Adaptive optimal control of prosumer energy storage system with renewable energy sources

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The prosumer can use energy storage to enhance the benefits of electricity trading by transferring buy and sell points. Improving energy efficiency is not considered from the standpoint of the entire system, but from an individual prosumer and in conditions of difficult-to-predict wind power generation. This work aims to optimize the prosumer's electrical complex by developing a method for adapting the base of heuristic rules of the prosumer control to its parameters and climatic conditions. A method for adaptation control rules using swarm intelligence algorithms is

proposed. The computer simulation has shown that the use of swarm algorithms makes it possible to increase the economic efficiency of managing the prosumer's energy storage system by 2–4 times compared to the control rules manually constructed by an expert. It is shown that the proposed method makes it possible to automate the construction of the base of control rules.

Keywords: prosumer, distributed generation, optimal control, smart grid, energy storage system, swarm intelligence.

B. I. Kosimov
Application of ANSYS software package for electromagnetic and thermal analysis of the electric motor of the pilger mill drive seamless pipe manufacturing technology

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Currently, the metallurgical production contains a large number of morally and physically outdated electrical equipment that requires modernization. Large capital expenditures are required to replace it. For this reason, it is slow to implement, long-term use for the purpose of payback, and slowly decommissioned. In this regard, the new equipment should be innovative and in many ways ahead of the existing level of development of the industry. The article offers such a solution for the company PJSC «Chelyabinsk pipe rolling plant». To replace the existing collector motor of the pilger mill drive for the manufacture of seamless pipes, which has been operating since 1928 and is in critical condition, a large-size low-speed valve motor with a large built-in inertial mass, having a permanent magnet magnetic system and claw-poles, is proposed to replace the existing collector motor of the pilger mill drive for the manufacturing of seamless pipes, which has been operating since 1928 and is in critical condition. Such a technical solution for drives of this class has not been used in the world. The motor eliminates the existing 120-ton flywheel, improves reliability due to contactless current supply, and reduces operating costs by eliminating excitation losses. The design of the engine allows its assembly without additional technological equipment, which is very important for large engines with permanent magnets. To develop a unique motor, a design system consisting of a synthesis subsystem and an analysis subsystem was created. The synthesis subsystem implements multi-level single-criteria optimization. As a result of its work, the optimal geometry is determined according to the selected criterion. The analysis system confirms the accuracy of the calculation using simplified optimization methods and finally removes technical risks before manufacturing an industrial design. It is based on the Ansys Electronics Desktop and Ansys Icepak systems that are well-developed for CAE electric machines. The analysis has several stages and includes electromagnetic and thermal analysis. The proposed design system is tested on a real project and implemented as a calculation of the magnetic and thermal state with dynamic load in JSC «Russian electric motors».

Keywords: pilger mill, CAE systems, synthesis, analysis, thermal analysis, brushless DC electric motor, claw-poles, magnetic system, tangential magnets, two-dimensional model, three-dimensional model.

INSTRUMENT ENGINEERING, METROLOGY AND INFORMATION MEASURING EQUIPMENT AND SYSTEMS

S. V. Biryukov
Three-axis electrical induction sensor of electric field strength in form of three mutually perpendicular disks

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Measuring the parameters of electric fields affecting technical and biological objects is impossible without the use of electric field strength sensors. Accurate measurement and control of electric field strength levels is challenging. This is due to the fact that the intensity is a vector quantity, characterized not only by the modulus, but also by the direction. The existing wide variety of strain gauges of various shapes (cubic, cylindrical, spherical), the principle of action (directional and non-directional reception) and design features (case, bodyless) do not provide the desired metrological characteristics. Therefore, the work related to the development of electric field strength sensors does not stand still and is relevant. The aim of the study is to create a frameless three-axis sensor of electric field strength, the calculation of which would be simple as for the case, and the simplicity of design and

low weight as for the frameless sensors. The sensor created as a result of research is structurally represented by three mutually perpendicular dielectric disks, the bases of which are conducting sensitive elements. The sensor depending on the desired error has a different spatial measurement range and the larger the error, the wider the range. For a measurement error not exceeding 10 %, the maximum possible spatial measurement range will be $a = 0,4$. Therefore, the minimum possible distance to the field source, at which the sensor error does not go beyond 10 %, will be $d = 2,5R$, where R is the radius of the sensor disk.

Keywords: three-axis electric field strength sensor, frameless electric field strength sensor, disk electric field strength sensor, electric field strength, error from field nonuniformity, electrometric measurements.

**V. V. Bolotov,
V. E. Kan, E. V. Knyazev**
Changes in crystal structure of MWCNTs under impact of high-powered pulsed ion C:H beam

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The structure of multi-walled carbon nanotubes exposed to a pulsed high-power ion beam is investigated using the methods of Raman spectroscopy and transmission electron microscopy. It has been shown that irradiation with an ion beam generates significant defects in the structure of nanotubes. With an increase in the number of pulses, processes associated with the annealing of defects in the internal structure of the samples are observed. Electron microscopy data make it possible to distinguish two types of defects leading to a decrease in the interlayer distance of the carbon nanotube wall.

Keywords: transmission electron microscopy, Raman spectroscopy, pulsed and ion irradiation, high-power ion beams, multi-walled carbon nanotubes.

**V. V. Bolotov,
I. V. Ponomareva, K. E. Ivlev**
Morphology of macropores in n-Si formed in NH_4F -containing solutions during photoanodization

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The features of pore formation during photoanodization in electrolytes based on ammonium fluoride are studied depending on illumination, pH, current density. When comparing electrolytes with different pH (acidic and alkaline), a decrease in the pore diameter is observed at the same illumination and current densities in alkaline HF: NH_4OH solutions at a relatively equal etching rate in depth. In dilute HF: NH_4OH : H_2O under low illumination, there is a direct dissolution of silicon with the formation of a «star-like» pore morphology and a branching tendency. In the case of a concentrated solution of HF: NH_4OH 1: 4 branching is observed with increasing current density.

Keywords: macroporous silicon, photoanodization, electron microscopy.

K. P. Latyshenko, T. N. Nurmagomedov
Algorithm of development for system operation monitoring of water-soluble bases in hydraulic structures
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The article discusses algorithm of development of the monitoring system operation for water-soluble bases of a hydraulic structures based on the conductometric control method using special technical measuring instruments. The structure of the information system for monitoring water-soluble bases of hydraulic structures is presented. A mathematical description of the monitoring method based on the conductometric control method is carried out. A general algorithm for the information system operation and an algorithm for polling conductometric sensors have been developed. An adaptive algorithm for polling sensors is proposed, which allows changing the polling period depending on the level of threat of an emergency.

Keywords: water-soluble base, information system, algorithm, hydraulic structure, conductometer, emergency.

**N. A. Davletkildiev,
E. Yu. Mosur, I. A. Lobov**
Gas-sensitive properties of individual carbon nanotubes modified by ion and electron irradiation

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The time characteristics of resistance change of individual nitrogen-doped multi-walled carbon nanotubes (N-MWCNTs), initial and irradiated with electrons, protons and argon ions has been measured upon exposure to ammonia and nitrogen dioxide. It is found that the initial N-MWCNTs have n-type conductivity, N-MWCNTs irradiated with protons and argon ions have p-type conductivity, and those irradiated with electrons have n-type conductivity. The relative gas sensitivity of individual N-MWCNTs, initial and irradiated with ions and electrons, has been determined.

Keywords: individual carbon nanotubes, electron and ion irradiation, gas sensitivity.

**N. A. Davletkildiev, E. Yu. Mosur,
D. V. Sokolov, I. A. Lobov**
Study of the charge transfer process in the polyaniline/graphite heterojunction by conductive atomic force microscopy

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Thin layers of polyaniline on the surface of highly oriented pyrolytic graphite are obtained by in-situ chemical oxidative polymerization of aniline. The current-voltage characteristics of the tip/polyaniline/graphite contact, which have a form characteristic of tunnel contacts, have been measured by the method of conducting atomic force microscopy. By modeling the current-voltage characteristics using the Simmons model, the width of the potential barrier is determined, which for the investigated heterojunction is 0,5 nm.

Keywords: polyaniline, graphite, heterojunction, conductive atomic force microscopy, potential barrier width.

A. G. Zavadovsky
Determination of dry residue of drinking water by quartz crystal microbalance method

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The dry residue of water characterizes its quality with great completeness, since it contains all impurities, including non-volatile organic substances. Therefore, the mass of dry residue can characterize the depth of drinking water treatment and is an important indicator of its quality. Currently, this parameter is determined by the gravimetric method. The determination of the dry residue mass by this method requires considerable time for the analysis and the use of a large mass of the substance. Quartz microweights, the sensitive element of which is a quartz piezoresonator, do not have these disadvantages. The purpose of this work is to evaluate the possibility of using the piezoquartz microweighing method for rapid analysis of drinking water quality. The use of this highly mass-sensitive method (10^{-8} – 10^{-9} g) can significantly reduce the mass of water used for the experiment, and, accordingly, the analysis time, which is determined by the evaporation time of the substance. An experimental module based on a quartz piezoresonator is created to perform experimental studies. The mass-sensitive coefficient of microweights is determined using calibration measurements. For the given experimental conditions (temperature 20°C , pressure 10^5 Pa), it is equal to $C_f = (9,5 \pm 0,5) 10^{-9}$ g/Hz.

To assess the possibility of practical use of the piezoquartz microweighing method, various samples of drinking water are studied and the results analyzed. Based on the experimental data, the parameter X is calculated, which characterizes the mass of dry residue in a liter of water. In the course of experimental studies, it is found that the tap water used in the experiment is optimally mineralized by the value of the parameter X , and its purification using a household filter slightly reduces the amount of dry residue. When boiling water, some of the substances dissolved in

it precipitates, but its mineralization remains satisfactory. During the distillation process, the amount of dry residue is significantly reduced, and the water becomes slightly mineralized. The results obtained in this work are consistent with the known experimental data. Thus, the piezoquartz microweighing method can be used to determine the dry residue of drinking water when evaluating its quality in various technological processes.

Keywords: assessment of water quality, the degree of purification, the dry residue of water, piezoquartz microweight.

E. V. Leun

Features of circuitry of acousto-optic laser measuring systems for controlling three-coordinate (3D) movements of products and equipment elements

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The article is devoted to the construction of acousto-optic (AO) laser measuring systems (LMS) for measuring product displacements in three coordinates (3D): with one longitudinal Δl_z and two transverse Δl_x , Δl_y with high resolution and an increased measurement range for the latter two. The paper discusses the circuitry of the measuring circuit based on the phase-locked loop (PLL) system, which makes it possible to achieve the maximum resolution when the AO LMS operates in the start-stop mode, i.e. starting and ending with a stationary state at $v=0$.

The paper considers the possibilities of using a prismatic optical scheme, which makes it possible to use a one-axis (1D) AO modulator to control two-coordinate (2D) displacements Δl_x , Δl_y of a laser beam, a multi-aperture AO modulator, a fiber photodetector and other units.

Keywords: acousto-optic modulator, laser interferometer, phase shift, phase interpolator, phase meter, signal noise, microlens, multimode optical fiber, intermode dispersion, raster.

V. A. Sachkov

The influence of atoms of second coordination sphere on phonon dispersion of diamond.

Omsk Scientific Center of Siberian Branch of Russian Academy of Sciences, Omsk, Russia

Within the framework of the phenomenological model of two-particle interaction, the effect of the interaction energy of atoms from the second coordination sphere on the phonon dispersion is considered. This approach makes it possible to vary the growth of the phonon frequency relative to the optical phonon in the center of the Brillouin zone. The effects of the contribution to the Raman spectra from longitudinal optical phonons with frequencies higher than their frequency at the center of the Brillouin zone are discussed. The contribution to the frequency of interaction of atoms from the second coordination sphere for some phonons is obtained in an explicit form. The formulas obtained will be useful for calculating the spectra of Raman scattering of light by optical phonons localized in diamond nanocrystals.

Keywords: phonon, diamond, nanocrystal, Keating model.

V. A. Sachkov

Object of defects of vacancy type in graphene plane into clusters and the influence of vacancy clusters on morphology and electronic properties of structure

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This work is devoted to the study of the effect on the morphology and on the electronic properties of the graphene plane of defects of the vacancy type in the form of a vacancy cluster, depending on the size of the cluster. The optimal configurations of the arrangement of carbon atoms for the graphene plane from vacancy clusters are found. The electronic band structure is calculated for them. The calculations are performed by the ab initio method. The analysis of the dependence of the morphology of the structure and some parameters of the electronic structure on the size of the vacancy cluster is carried out. The results obtained are applicable to the analysis of the band structure of single-walled carbon tubes containing vacancy-type defects.

Keywords: nanosensoric, carbon nanotubes, graphene, band structure, point defects, «ab initio».

Yu. A. Stenkin, D. V. Sokolov, K. E. Ivlev

Gas sensing response of metal oxide layers based on Co_xO_y with lithium ions

Omsk Scientific Center of Siberian Branch of Russian Academy of Sciences, Omsk, Russia

The gas response of layers based on lithium-doped cobalt oxides with different $\text{Li}_2\text{O}/\text{Co}_x\text{O}_y$ ratios is investigated. The synthesis conditions of oxide composites and the structural analysis of the obtained layers by scanning electron microscopy are presented. It is found that composites with the ratio of the initial components 1:1 have selectivity to formaldehyde, and with the ratio 3:2 — to nitrogen dioxide.

Keywords: cobalt oxide, lithium oxide, gas response.

A. S. Bryukhova, N. V. Volkova,

A. Yu. Kuzmenko, A. A. Kuznetsov

Determination of chemical composition on internal surfaces of hollow reinforced concrete structures under the influence of corrosion

Omsk State Transport University, Omsk, Russia

The paper presents the results of experimental studies on the determination of corrosion products on the surface of reinforced concrete structures. Methods for creating samples with artificial electrocorrosion under conditions close to real operation are discussed. The results of testing samples with different degrees of corrosion using laser-spark emission spectrometry (LIBS) devices are presented. The test is carried out on two different devices, a LIBS setup and a portable American-made laser analyzer LIBZ-300pe.

Keywords: reinforced concrete structures, corrosion defects, surface, laser spectrometry, concrete sample, laser analyzer, instrument sensitivity.