ABSTRACT AND REFERENCES

APPLIED PHYSICS. MATERIALS SCIENCE

**THE INTERRELATED MODELLING METHOD OF THE NONLINEAR DYNAMICS OF RIGID ROTORS IN PASSIVE AND ACTIVE MAGNETIC BEARINGS (p. 4-13)**

**Gennadii Martynenko**

A method is suggested for building mathematical models of dynamics of rotors in magnetic bearings of different types (passive and active). It is based on Lagrange-Maxwell differential equations in a form identical to that of Routh equations in mechanics. The expressions for magnetic energy and forces in active magnetic bearings with account for control laws for introducing them into the mathematical models have been found by adapting the analytical method of analysing magnetic circuits. This method is based on building equivalent circuits and using the loop flux method to account for dissipation fluxes and magnetic resistances of AMB magnetic circuit sections and ensure noncriticality of the mathematical model to emergence of "zero" gaps and currents. Besides, the mathematical models account for such nonlinearities as nonlinear dependence of magnetic forces on gaps in passive and active magnetic bearings and on currents in the coils of electromagnets, nonlinearities linked to coil inductance, a geometric link between electromagnets in one AMB and links between all AMB in one rotor, which results, among other factors, in connectedness of processes in orthogonal directions. The method's validity has been confirmed experimentally by a laboratory setup being a prototype of a complete combined magnetic-electromagnetic suspension in small-size rotor machinery. The suggested approach has helped detect in the system and investigate different nonlinear rotor dynamics phenomena such as super- and subharmonic vibrations with determination of resonance modes.

**Keywords**: rotor dynamics, passive magnetic bearings, active magnetic bearings, magnetic energy, mathematical model, nonlinear vibrations.

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## INVESTIGATION OF THE OXIDE PHASE HOMOGENIZATION IN THE CONVECTIVE CELL WHILE PRODUCING VACUUM-ARC REMELTING (p. 14-21)

**Liudmyla Bozbiei, Boris Borts, Ivan Neklyudov, Victor Tkachenko**

Discussion of the requirements for the placement of $ZrO_2$ powder in the cathode, which must be taken into account in the production of ODS steel by vacuum-arc remelting in order to provide the high level of homogenization of the oxide particle is presented. The description of the experimental setup and the cathode structure for vacuum arc remelting of steel, alloyed with oxide nano-powder is given. The role of convective processes in the homogenization of nano-particles in the production of ODS steel is highlighted. The convective flow of liquid metal captures $ZrO_2$ powder particles and carries them throughout its volume.

The use of the elementary convective cell with free boundary conditions is proposed for the description of homogenization of the oxide particles. The structure and spatial distribution of the convective mass transfer in the elementary convective cell with the non-planar bottom profile are provided.

Spatial distribution of convective flow in the cell is described by the Stokes lines, which are concentrically arranged smooth closed lines, which indicates the formation of convective flow in the form of a single vortex in the cell with free boundary conditions. Near the bottom, the Stokes lines reflect the curved cosine bottom profile. The scenario of vacuum arc melting and convective mixing of $ZrO_2$ nanoparticles is formulated.

Drops of the material of the cathode with $ZrO_2$ nano-particles fall to the central vertical flow of the ECC. Here, the particles are subjected to the action of the convective flow, which will result in the impact of multidirectional forces: Archimedes force (always directed upwards); gravity force (always directed downwards); friction force (Stokes force) (directed along the liquid velocity vector) on these particles.

The Archimedes force depends on the volume, i.e. size, of the particle. Thus, the less the nano-particle size, the lower the buoyancy force. The criterion of overcoming the Archimedes force allows determining the sizes of the particle at which their uniform distribution in the cell volume is possible.

It is necessary to provide such conditions:

– the deeper the drops get into the cell, the more evenly $ZrO_2$ particles are distributed in the cell volume;

– even distribution of $ZrO_2$ particles in the sample volume should be observed for sizes less than 80–100 nm.

**Keywords**: steel reactor, oxide powder, vacuum-arc remelting cathode, homogenization, convective mass transfer, convective cell.

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## MECHANISM OF CAPACITIVE CHARGE OF ELECTRODES ON THE BASIS OF ACTIVATED CARBON MATERIALS IN $ZnI_2$ SOLUTION (p. 22-29)

**Ivan Dupliak, Bohdan Bakhmatyuk, Andrij Kurepa, Ivan Grygorchak**

The electrochemical and thermodynamic features of the iodine electrosorption process on the surface of microporous activated carbon materials (ACM) ($S_T$ BET=1600–1900 $m^2 \times g^{-1}$) in 25 % $ZnI_2$ aqueous solution are investigated. The kinetic reversibility of the process, electrode polarization, fractional surface coverage by iodine atoms ($\theta_I$) are found. The thermodynamic analysis of the surface adsorption compound of ACM with iodine allows using the known Frumkin adsorption ratios to describe the iodine adsorption process. Comparison of theoretical adsorption isotherms (TAI) and the relationship between the specific pseudocapacity ($C_p$) and $\theta_I$ ($C_p$–$\theta_I$) with practical galvanostatic discharge curves built from experimental data is made, and the parameter of the interatomic interaction (g) in the adsorption monolayer is determined. Correlation of the data of electrochemical impedance spectroscopy (EIS) with the data of galvanostatic cycles (GC) is found. Good agreement of the EIS experimental data with transmission electrical equivalent circuit for the porous electrode is obtained. The study provides insights into the process mechanism, the EEC of the interface between electrode and electrolyte, and efficiency of the material as a positive electrode in molecular energy storage (MES) systems. Sufficiently high efficiency of GC of electrodes based on ACM1 ($S_T$ BET=1600 $m^2 \times g^{-1}$), and ACM2 ($S_T$ BET=1900 $m^2 \times g^{-1}$) in the MES system is obtained. The specific discharge of ACM1 $C_d$=1200 $C \times g^{-1}$ ($\theta_I$=0.99) with the Coulomb efficiency $\eta$=95 % almost reaches its maximum theoretical value 1.216 $C \times g^{-1}$ ($\theta_I$=1). The similarity of the experimental desorption isotherm and $C_p$-$\theta_I$- relationship of ACM1 gives an indication of the process mechanism by the Frumkin model with g=–0.88. The maximum value of ACM1 $C_p$=F×8.8 $m^2$ obtained according to the EIS is close to 9.4 $F \times m^{-2}$ obtained according to the GC. At the same time, 70 % of the total pseudocapacity of ACM1 has a low time constant $\tau$=RC=82 s.

**Keywords**: Frumkin adsorption, activated carbon materials, specific pseudocapacity, molecular energy storage.

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## A DESIGN OF RADIATION-PROOF MATERIAL FOR PROTECTING THE MEDICAL STAFF (p. 30-37)

**Vladimir Semenets, Tetiana Stytsenko**

The use of sophisticated medical equipment that operates at microwave frequencies draws attention to the methods and means of protecting the medical staff from exposure to occupational hazards, such as electromagnetic super-high frequency (SHF) radiation. The article considers improving the properties of expanded polystyrene (EPS)-based absorbent materials with graphite additives and emphasizes the ratio “an effective protection – a cheaper production.”

The test material was of two types: with a matching layer and without it. The absorbent material with a matching layer has a lower reflectance than the one without it. In addition, the reflectance of material with a matching layer is almost insensitive of the angle of incidence of electromagnetic waves. The test frequency band corresponds to reflectance higher than 30 dB and the frequency of 75 GHz – to reflectance of 40 dB.

The study of a graphite-using absorbent material that provides damping of electromagnetic waves in the direction of their propagation has focused on the effect of the size of graphite particles in an aquadag on its absorptive properties. An aquadag with the graphite particles’ size of 30–70 microns has the best characteristics of the selected frequency band.

The improved methods of asymptotic solution of the problem of synthesizing the non-reflective layer at the normal incidence of a plane wave have extended to the general case – an arbitrary structure of the field in the direction of the fall. It is proved that the properties of the coating are determined ultimately by the spatial inhomogeneity of the electrical and physical properties of the material in the direction of propagation of electromagnetic waves.

The findings are important for further research on absorbent materials with improved properties of absorption and reflectance in a broad range of angles of incidence from the lower portion of the frequency spectrum. This study and the findings thereof allow improving the properties of the materials to ensure collective and individual protection of medical personnel from exposure to high levels of radiation.

**Keywords**: medicine, equipment, protection, materials, absorption, electromagnetic radiation, expanded polystyrene, staff/personnel, graphite.

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## STUDY OF HEAT DEFORMATION INFLUENCE IN SURFACE STRAIN HARDENING OF STEEL BY THERMOFRICTION PROCESSING (p. 38-44)

**Oleg Volkov**

The paper deals with studying the heat deformation influence in the surface strain hardening of steels by thermofriction processing. The main objective of the work was to determine the relationship between the surface heating temperature during TFP, cooling rate, deformation, structure formation and properties of steels, hardened by TFP. The study solved the thermal conductivity problem, which allowed determining the surface heating temperature of samples of steels 15Kh11MF, 65G, U8A, Kh12M in TFP. The photographs of microstructures, which show changes over the cross section of the samples are presented. The presence of surface-hardened “white layer” with increased hardness is obvious, as evidenced by the prints of microhardness measurements. The data showed that the deformation mechanism of hardening in a short-term heating of the hardenable surface is predominant in TFP. It is also noted that the “deformed grained martensite” structure is formed, the hardness of which is more than twice the hardness of the martensite structure obtained in hardening of the proposed steels and can be considered as a type of nanostructure.

**Keywords**: thermofriction processing, friction, hardening disc, “white layer”, strain hardening, ε-carbide, nanostructure.

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## MODELING OF THE CASE DEPTH AND SURFACE HARDNESS OF STEEL DURING ION NITRIDING (p. 45-49)

**Mohanad Muzahem Khalaf, Viktoriia Kostyk, Dmitriy Demin, Kateryna Kostyk**

Modeling of the ion nitriding process allows solving many problems of operations management, forecasting of results and development of new treatment regimes, which is an urgent issue today. The goal of the paper was modeling of the case depth and surface hardness of 38Cr2MoAl A steel during ion nitriding. The experimental data showed that the case depth varies from 20 to 620 μm in the ion nitriding temperature range of 500–560 °C and duration of 1–12 hours, with the surface hardness varying from 8 to 12 GPa. The mathematical models in the form of quadratic polynomials, describing the dependence of the nitrided case depth and surface hardness on the temperature and duration of thermochemical treatment were obtained. The graph-analytical description of variations in the nitrided case depth and surface hardness depending on variations in temperature and duration of treatment, which allows determining the specific conditions of ion nitriding 38Cr2MoAl steel is constructed.

**Keywords**: thermochemical treatment, ion nitriding, case depth, surface hardness.

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## OPTIMIZATION OF PROCESS PARAMETERS OF CHROME PLATING FOR PROVIDING QUALITY INDICATORS OF RECIPROCATING PUMPS PARTS (p. 50-62)

**Liubomyr Ropyak, Vasyl Ostapovych**

The analysis of methods of surface hardening to improve wear resistance and corrosion resistance of replacement parts of double-acting reciprocating pump hydraulics is performed. Application of electrochemical chrome plating of parts in the spilling solution, which provides wear-resistant coatings with high surface quality is justified. The influence of process parameters of chrome plating of steel parts: mass ratio of the solution component concentrations (C), current density (i), solution flow rate (v) and solution temperature

(T) on the microhardness ($Y_h$), wear ($Y_w$), roughness ($Y_r$) and taper ($Y_t$) using mathematical experimental design is investigated. The optimum values of process parameters which provide maximum microhardness, minimum wear, minimum roughness and taper of the chromium coating are determined.

It is found that the maximum microhardness of the chromium coating provides minimum wear. Optimum process parameters are within the factor space. To achieve minimum roughness and taper, process parameters are outside the space factor. Based on the results of studies, it is recommended to take the optimum process parameters of electrochemical chrome plating in the spilling solution as those that provide minimum wear of the coating: $Y_w$=0.095 g: C=79.5; i=133.5 A/dm$^2$; v=114.7 cm/s; T=59.3 $^o$C, and the necessary surface roughness and taper of the part is advisable to obtain in further machining operations.

**Keywords**: process parameters, electrochemical chrome plating, spilling solution, microhardness, wear, roughness, taper, machining.

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## STUDY OF THE EFFECT OF ION NITRIDING REGIMES ON THE STRUCTURE AND HARDNESS OF STEEL (p. 63-68)

**Oleg Sobol, Anatoly Andreev, Vyacheslav Stolbovoy, Sergey Knyazev, Alexander Barmin, Natalya Krivobok**

Application of low-temperature plasma nitriding of non-self-sustained arc low-pressure discharge allows solving a critical problem of increasing the stainless steel hardness and getting a wide range of structural states, including metastable at low temperatures, such as the S-phase (nitrided austenite).

Using ion nitriding at a pressure of $P_N$=(4...40)·10$^{-4}$ Torr and constant negative potentials –600, –900 and –1300 V, the possibilities of structural engineering in the ion-induced surface modification and its influence on hardness are examined.

When using ion nitriding regimes, the S-phase formation at the lowest pressure is revealed, the grating spacing of 0.381 nm is determined, which corresponds to the formula $FeN_{0,4}$, and a large width of the diffraction reflections of the S-phase evidences fragmentation and high microstrain of the

initial austenite in the S-phase formation. It is shown that the highest hardness can be obtained when the composition of CrN, S and the original austenitic phase is formed in the nitriding process, which is achieved under the following nitriding regimes: the pressure of $4 \cdot 10^{-3}$ Torr and relatively low negative bias potential of 600 V.

**Keywords**: ion nitriding, austenitic, S phase, chromium nitride, diffraction spectra, hardness.

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## THE STUDY OF THE INFLUENCE OF LASER HARDENING CONDITIONS ON THE CHANGE IN PROPERTIES OF STEELS (p. 69-73)

**Alaa Fadhil I Idan, Oleg Akimov, Leonid Golovko, Olexiy Goncharuk, Kateryna Kostyk**

Development of new technologies to improve the durability of high-wear parts is urgent. The goal of the study is to investigate the influence of laser processing conditions on the properties of 40, 40Cr and 38Cr2MoAl steels for surface hardening. Comparative analysis of hardness parameters after the through hardening, hardening and tempering, and laser hardening of steels showed that laser

hardening improves the hardness by 1.3–1.35 times compared to the through hardening and by 1.7–2.32 compared to the steel hardness after hardening and tempering. The mathematical patterns of the influence of laser beam travel speed on the case depth depending on the steel grade in the form of quadratic and cubic polynomials are found. These patterns allow predicting the case depth values. Microhardness distribution over the cross section in the zone of local laser hardening showed that the highest hardness values for steels correspond to the zone of the most dispersed martensite, further increase in grain dispersion reduces the hardness parameters. Due to the local surface hardening of 40, 40Cr and 38Cr2MoAl steel parts by laser hardening, operational properties of parts in further operation can be improved. This method is suitable for hardening difficult-to-access areas of parts, local contact areas. The hard case is formed through laser hardening, the matrix of the part remains viscous and softer. This combination of properties improves the durability of parts.

**Keywords**: steel, laser hardening, case depth, hardening, hardness, hardening, hardening and tempering.

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