

## MATRIX REPLICATION IN NP-COMPLETE PROBLEMS OF COMBINATORIAL OPTIMIZATION

S.L. Podval'ny, E.M. Vasil'ev

**Abstract:** the task is to increase the probability of finding a global extremum in NP-complete high-dimensional combinatorial optimization problems. We show that the combinatorial nature of the formation of solutions leads to an isolated location of the global extremum in the domain of the goal function. This circumstance significantly reduces the efficiency of evolutionary search algorithms based on the reproduction of the properties of heredity and variability in biological evolution. In this regard, we propose to introduce a matrix replication mechanism into the mentioned algorithms. In accordance with the hypothesis of M. Eigen, this mechanism is characteristic of the prebiological stage of the emergence of life, and consists in the formation of macromolecules by building them up with elementary blocks according to the principle of signature - self-instruction. We analyzed the properties of matrix replication and disclosed the content of the algorithmic procedures necessary for its implementation: the construction of replication matrices, the implementation of independent evolution for each variant of the matrix; selection of the best options. We obtained quantitative estimates of the variety of options for possible matrices and solutions with them. We give recommendations on the choice of the length of the matrix and their number in solving practical problems. We note that the introduction of a replication matrix into the genetic search algorithm reduces the dimension of the original problem by the length of this matrix and, as a result, reduces the solution of the original problem to solving a finite number of subproblems of lower dimension. We presented an example of using the matrix replication mechanism for solving the NP-complete problem of finding the optimal route and confirmed the efficiency of using this mechanism in the search for a global extremum

**Key words:** NP-complete optimization problems, evolutionary algorithms, matrix replication

## SOFTWARE COMPLEX FOR CHECKING DYNAMIC RELATIONS OF TECHNOLOGICAL SCHEMES AND DATABASES

D.S. Sinyukov, A.D. Danilov, D.A. Denisov, M.E. Ushkov

**Abstract:** safety of operation of potentially hazardous industries is an urgent task in the industry. When managing such objects, one of the causes of violations is the erroneous actions of operational personnel. One of the tools for solving this problem is software verification of the results of human activity. To implement such a task, Novovoronezh NPP developed a software package designed to check the dynamic links between graphical objects of interactive process flow diagrams and the corresponding variable databases. As a methodology, the Kraftwerk Kennzeichen coding System (KKS) was used, which makes it possible to obtain identifiers for typical power unit objects. The result of the software operation is information about KKS codes that do not correspond to the databases. The organization of the proposed real-time database is similar to the organization of a relational database and allows for more than 10,000,000 single accesses per second. In this case, it is possible to obtain a file representation of tables in the form of dumps. When creating and editing video frames, database variables are used: each dynamic video frame object is associated with a variable value. The software for checking the dynamic links of technological schemes and the database was implemented in Python. As a result of the program, a list of video frame codes is formed, which is then compared with the list of database codes. If a video frame dynamic link code does not match the database code, an error message is displayed. Implementation of the developed software product at Novovoronezh NPP increased the reliability of data presentation to the operator from various power unit systems. New opportunities for information support of the operator were obtained, which facilitate the assessment of the state of the equipment and decision-making on the control of the unit. The proposed method for using KKS codes to check dynamic links between graphical objects of interactive flow diagrams and the corresponding database variables reduces the load on the operator of the nuclear unit and reduces the likelihood of his erroneous actions

**Key words:** software package, coding system, database, interactive diagram, dynamic links

## POSSIBILITY OF USING EXISTING ELECTRONIC DOCUMENT MANAGEMENT SYSTEMS IN THE PRODUCTION OF SOLID RELAYS

D.N. Trubitsyn

**Abstract:** the article discusses the functionality of various existing electronic document management systems and computer-aided design systems. The main functions of CAD and EDMS, when solving problems, in various departments of production are listed. As examples, EDMS Directum, Microsoft sharepoint and Delo are considered. From the range of existing computer-aided design systems, Compass-3D, Altium designer and AutoCAD are considered. I carried out the analysis of their functionality, advantages and disadvantages of systems, when using them in the design and production of solid relays. I also analyzed their compatibility with each other, and the difficulties that arise when exchanging information and translating documents from one system to another. The article provides a comparative table of the functionality of modern CAD and EDMS. The article also discusses options for solving the problem of data transfer between various CAD and EDMS, and concludes that it is expedient to expand the functionality of one of the existing EDMS or CAD systems to

ensure the relationship between various project documents, and possibly, in the future, the automatic release of individual documents, if available in previous documents all the necessary information to form a new document

**Key words:** electronic document management system, computer-aided design

## **REINFORCEMENT LEARNING ALGORITHM FOR DECENTRALIZED MULTI-AGENT SYSTEMS BASED ON EXCHANGE OF EXPERIENCE AND TRAINING OF AGENTS IN RANDOM INTERACTION**

**Yu.V. Dubenko, N.A. Rudeshko**

**Abstract:** here we present the developed new reinforcement learning algorithm for decentralized multi-agent systems based on the exchange of experience and training agents for random interaction. We listed the main problems of multi-agent reinforcement learning. We described a class of decentralized multi-agent systems based on random interaction of agents, which leads to the emergence of intelligent global behavior not controlled by individual agents. We defined an urgent task for decentralized systems implemented on the basis of the reinforcement learning paradigm. We indicated that the ultimate goal of learning to interact with each other is to maximize the average reinforcement. We proposed algorithms, the application of which leads to the achievement of this goal, such as the algorithm for training agents in random interaction, as well as the algorithm for forming subgroups of subordinate agents based on the "visibility area" of the leader agent. To test the effectiveness of the proposed reinforcement learning algorithm for decentralized multi-agent systems, based on the exchange of experience and training agents for random interaction, we chose the task of finding agents to exit the maze. We presented the results of the algorithm execution on a model developed in the Microsoft Unity environment. The algorithm differs from the existing analogs by using the method of forming subgroups of subordinate agents based on the "visibility area" of the leader agent in order to reduce the dimension of "information messages" and taking into account the agent's hardware component when implementing the exchange of experience

**Key words:** reinforcement learning, multi-agent systems, random interaction, agents-leaders, agents-subordinates, labyrinths

## **CALCULATION OF THE RESIDUAL FUNCTION IN THE BASIS SPACE TO SEARCH FOR AREAS OF UNCERTAINTY OF THE RATE CONSTANTS OF THE POLYMERIZATION PROCESS**

**E.R. Gizzatova, A.R. Shagiakhmetov, G.K. Khisametdinova, S.L. Podvalny**

**Abstract:** the paper proposes a mathematical model of the polymerization process on Ziegler-Natt catalysts, assuming the existence of only three elementary stages: the growth of the polymer chain, the transfer of the chain to the monomer and the transfer of the chain to the organoaluminium compound, provided there is no stage of initiation of active centers. We give the statements of direct and inverse kinetic problems, the latter of which consists in finding the regions of the chain growth stages and gears that are indeterminate for the rate constants. We show that for the process under consideration, the values of the constants can be determined in the basis space constructed on the vectors of the constants. Unlike the original three-dimensional space, the basis space allows calculating and visualizing grid surfaces by the residual function for the average calculated molecular weight. If the discrepancy is calculated as the maximum of deviations or the sum of the squares of deviations, different surfaces are obtained. We show the way the superposition of surfaces on each other localizes the minimum regions, which can subsequently be characterized as the solution of inverse kinetic problems. At the same time, this approach allows us to evaluate the shape and appearance of "gully" minima and, in general, to determine the optimal set of constants identifying the minimum points

**Key words:** polymerization, kinetical modeling, mathematical model, kinetic constants, method of moments

## **DESIGNING THE TRAJECTORY OF THE ROBOT IN A CONFINED SPACE**

**A.V. Kalyashina, T.S. Evdokimova, V.Yu. Erkhov**

**Abstract:** this study is devoted to designing the trajectory of a robot in a confined space using modern robotics and sensor devices. The aim of the study is to provide autonomous movement of a mobile robot along the route with obstacles, using motion algorithms based on graphs. Previously, we carried out an analysis of existing algorithms for the movement of mobile robots and reflected their advantages and disadvantages. To achieve this goal, we developed a block diagram of a mobile robot, which demonstrates the connection of the controller with external devices for collecting information and controlling movement. We carried out reception of signals and their preliminary processing by on-board sensor devices. The preprocessed signal is transmitted from the hardware logic level to the upper level of the controller. To do this, we implemented an information system that includes receiving signals from sensors and transmitting them to the controller level. We developed an algorithm for constructing a motion trajectory. Thanks to the implementation of the shortest path search algorithm based on a well-known terrain map, the exact following of the mobile robot to a given endpoint in a warehouse environment is ensured. We solved the issue of navigation with the help of a map of black lines, which forms a network of possible routes. We tested the results in the conditions of an engineering landfill

**Key words:** robotics, automated devices, mobile robot, warehouse logistics, onboard sensors, microcontroller, kinematics, search algorithm

**N.M. Zhevandrov, A.D. Danilov**

**Abstract:** the article presents the results of the development of a configuration extension for the specialized software that implements interaction modules with different types of ARINST product line devices. Many aspects of the software functionality can be customized to suit user's tasks and needs: such as graphical representations and data processing modes. For convenience of a user it is necessary to provide a feature of automatic saving and restoring configuration of the software set by the user from one working session to another and from one connection of ARINST device to another, as well as at any moment of a work session using a user-defined path. At that the following requirements were set for the software under development: to provide automatic saving and restoring of software configuration data from one working session to another and from one connection of ARINST device to another, as well as at any moment of a work session using a user-defined path; to split configuration data according to interaction modules; to store configuration data on the user's system in the form of files; to place configuration files in directories of a file system that do not require elevated privileges for read and write access regardless of the operating system. The format of configuration data, configuration system and the mechanism behind configuration manager in both previous and current implementations are described. The directions of development of the developed configuration module are defined

**Key words:** ARINST, specialized software, interaction modules, software extension, software configuration

## **DEVELOPMENT OF SOFTWARE TOOLS BASED ON EXPANDABLE OPEN SOURCE PLATFORMS**

**O.V. Minakova, N.V. Akamsina, O.V. Kuripta**

**Abstract:** the article presents an analysis of well-known architectural approaches and architecture analysis models for the purpose of rapid development of applications on a ready-made technological platform. We used the selected methods to design a management system for the fund of appraisal funds, as an example of a software tool for professional activities. We analyzed in detail the sequence of stages in the development of a software system based on the architectural approach. For the implementation, we justified the choice of the microkernel architecture of the widespread technological platform Visual Studio Code with open source code and a set of standard extensions. We designed the architecture for the core functionality - text editing and interoperability with LMS and perspectives - prevalence, usability and modifiability. We present a description of the implementation of the necessary extensions, in particular, navigation through the bank of test items. The conducted research allowed us to propose a methodology for the rapid development of software tools based on extensible platforms based on an architectural approach. We present the description of the technology in the paper for discussion. Since the rapid development of new software tools is necessary in modern conditions, research on the possibilities of using extensible platforms, standardizing approaches to using open source code, and designing patterns is vital. We proposed possible solutions to these key tasks in the work on the example of special software tools

**Key words:** software development, gift-file, microkernel architecture, implementation of extensions, open source

## **MAIN STAGES OF THE EVOLUTION OF NUMERICAL METHOD FOR DETERMINING THE PARAMETERS OF A MULTI-STAGE STOCHASTIC SYSTEM**

**S.A. Oleynikova, I.A. Selishchev, D.A. Tyunikov**

**Abstract:** the object of research is a multi-stage system, the distinctive feature of which is the random duration of series-parallel work, which depends not only on random factors but also on the choice of the performer. Thus, it is necessary to solve two problems simultaneously: the assignment problem, which consists in determining the relationship between jobs and specialists, and the planning problem, which allows you to assign the optimal start time for each job. Each class of these tasks has its own methods, however, they are not applicable to the case when these tasks must be solved simultaneously. In this regard, we developed our own methods, a distinctive feature of which is the possibility of obtaining a comprehensive solution of two problems. An analysis of possible approaches to solving the problem under study made it possible to dwell on evolutionary algorithms for solving it. In particular, experimental studies have shown that genetic algorithms are quite efficient for cases where classical methods are not applicable. However, in order to obtain solutions, close to optimal, it is necessary to develop such stages as crossing and mutation, taking into account all the features of the problem being solved. It is these questions that this work will be devoted to. The scientific novelty lies in the development of an approach to crossing based on a single-point crossing over and providing the possibility of redefining the start and end times in the offspring chromosome, taking into account the employment schedule of specialists, as well as a mutation that allows you to randomly change the genes of the performer, starting from a randomly selected job and redefine the start genes and completion of work. The practical significance lies in the possibility of using the developed algorithms for any multi-stage systems that require the definition of a work schedule and the assignment of specialists to them

**Key words:** genetic algorithm, crossover, mutation, network planning, assignment problem

## DEVELOPMENT OF AN AUTOMATIC CONTROL SYSTEM FOR THE DRYING PROCESS OF SUGAR BEET PULP IN A DRUM-TYPE DRYER

I.A. Boldyrev, A.V. Lyubimov

**Abstract:** the history of the development of industrial regulators is inextricably linked with the development of technology. Initially, regulators were created as exclusively mechanical systems. The implementation of mechanical regulators was limited by the possibilities of mechanics of that time. The Vyshnegradsky equations describing the operation of the Watt regulator are rightfully considered the foundation of such a science as the theory of automatic control. The invention of electronic lamps made it possible to create the first regulators on an electronic platform. This was followed by transistor regulators, and then regulators on operational amplifiers. All the above platforms for the hardware implementation of regulators imply that the logic of their decisions is embedded in them at the stage of their design and in the future only adjustment is possible. Modern regulators are implemented on a digital platform, which gives an unlimited opportunity to implement control algorithms without changing the circuit solutions of the hardware platform, since the implementation of algorithms is laid at the level of the program code. Such a democratic approach to the implementation of control algorithms has undoubted advantages, but also disadvantages, because previously created exclusively hardware regulators were designed by the corresponding research institutes and design bureaus, which included specialists of various profiles. To date, the implementation of software control algorithms very often falls into the hands of specialists who can be attributed more to programmers than to specialists in control theory. In this regard, the implementation of software algorithms is limited to combinations of P.I.D. links, taking into account the weight coefficients that play the role of tuning parameters. Thus, the limitless possibilities of implementing control algorithms on a modern hardware and software platform are limited only by the qualifications of specialists implementing regulators at control facilities. This paper presents the synthesis of a regulator for controlling moisture content in the technological process of drying sugar beet pulp based on the Q-parametrization method. The code for implementing this controller in the controller is presented in the ST language in the CoDeSys 2.3 development environment. This work can be considered an example of using the latest achievements of TAU in the implementation of control algorithms for industrial control facilities based on modern software and hardware complexes

**Key words:** ACS-automatic control system of the dryer beet pulp, Q-parameterization, Smith founder

### Radio engineering and communication

## SINGLE-MODE APPROXIMATION IN THE PROBLEM OF THE DIELECTRIC LEAKY WAVE ANTENNA SYNTHESIS

A.V. Ostankov, S.A. Ostankov, G.V. Litvinov, S.Yu. Dachian, N.N. Shchetinin

**Abstract:** electrodynamic modeling of a dielectric leaky wave antenna with a diffraction grating containing a large number of periods with inhomogeneities takes a significant amount of time even in modern commercial electromagnetic analysis packages. It is customary to evaluate and optimize the directivity indicators of these antennas on the basis of numerical projection models. Here we consider our projection model obtained by the partial area method and using the description of the field in the grooves of a comb grating in the form of an ensemble of waveguide modes, the number of which determines the accuracy of modeling and the dimension of the final system of linear algebraic equations. There are relations that allow analyzing the main parameters of a dielectric antenna containing a planar dielectric waveguide and a conducting comb grating in the mode of radiation of a vertically polarized radio wave, including the case of a single-mode approximation, in which one waveguide mode is taken into account in the grooves. Using specific examples for different radiation modes, we show the expediency of a single-mode approximation for express analysis and parametric synthesis of a dielectric antenna. We established that the loss of accuracy in assessing the main energy indicators and directivity indicators of the antenna in the oblique radiation mode is acceptable. We found out that in the transition to the single-mode approximation, the optimized index of the dielectric antenna, as a rule, is the most stable in magnitude. WE shown that accounting in one mode grating grooves with a number of grating elements of 30 or more guarantees a gain in time by an order or more. We pointed out that the single-mode approximation for the analysis and synthesis of an antenna in a regime close to Bragg diffraction should be avoided due to the loss of accuracy

**Key words:** dielectric antenna, comb grating, groove, single-mode approximation, directivity pattern, directivity indicators

## INFLUENCE OF THE SPATIAL ORIENTATION OF THE CONDUCTING ELEMENTS OF THE COMPOSITE METASURFACE ON THEIR FREQUENCY CHARACTERISTICS AND SCATTERING DIAGRAMS IN THE RF RANGE

A.S. Mazinov, I.Sh. Fitaev, N.A. Boldyrev

**Abstract:** in this work, we considered the diffraction characteristics of checkerboard-like metasurfaces consisting of cells with different orientations of conducting resonators formed from rectangular strip lines symmetrically placed on a dielectric substrate of 18x18 mm size. The linear sizes of the conducting metaparticles were 4.2 mm, the distance between them was 1.7 mm, and the distance between adjacent vertical rows was 5.15 mm. For the diagonal symmetry, the dimensions of the copper resonators remained unchanged, while the distance between parallel rows in it was 4.29 mm. The choice of such geometry is due to the average frequency of the studied range - 20.5 GHz. To obtain experimental data, we used the method of bistatic measurement of the dependence of the level of reflected radiation on the angle of the receiving antenna.

We obtained frequency characteristics for elementary symmetries, and showed the dynamics of changes in scattering diagrams for different orientations of multidirectional elements. At the selected characteristic points, in which the transmittance had a maximum, average and minimum value, we found the characteristic dependences of the magnitude of attenuation of the main lobe of the reflected wave on the frequency of the incident radiation and the orientation of the conducting structures of the metasurface. By comparing the frequency characteristics, we established the influence of the metasurface structure on its output diagram and determined the symmetry that provides the maximum scattering of the incident electromagnetic wave, the relative power attenuation coefficient of which was  $K = 0.23$ . The results of the work can find application in the development of stealth coatings and passive phased antenna arrays

**Key words:** metasurface, microwave, radio transparency, frequency dependence, transmittance factor

## FORMING A PATCH ANTENNA FROM A SOLAR CELL

**E.A. Ishchenko, S.M. Fyedorov, I.A. Chernoiivanenko, A.V. Bunina, L.V. Sopina,  
E.D. Men'shikova**

**Abstract:** the article considers a patch antenna with a solar panel integrated in its design, which is used as an emitter instead of a completely metal one. To determine the characteristics of the resulting antenna, we modelled it to compare the main characteristics of the developed antenna with a basic all-metal radiator. The results obtained show that the use of the proposed design makes it possible to maintain high quality indicators of the antenna, while ensuring the generation of electricity due to the photocell installed in the design. In addition to comparing the design with a metal patch emitter, we studied the possibility of increasing the relative fraction of the photocell in the antenna area by removing dielectric sections. The results obtained show that in this case it is also possible to maintain the quality indicators of the emitter, while the solar cell no longer occupies 20% of the area of the antenna element, but 42%. Thanks to this design, it is possible to expand the possibilities of using antenna elements not only as signal transmission devices, but also as a source of energy, which is obtained by converting a renewable energy source - sunlight. Thanks to the deep integration of antenna elements and solar panels, it becomes possible to expand the functionality of antenna systems

**Key words:** patch antenna, solar cell, green energy

## SIMULATION OF PROCESSES OF ELECTROMAGNETIC INTERACTION OF DISTRIBUTED OBJECTS OF A CELLULAR COMMUNICATION SYSTEM

**I.S. Kireev, I.V. Zubarev, V.L. Burkovskiy, E.V. Koshcheev**

**Abstract:** are consider the problems of ensuring electromagnetic security in the conditions of active interaction of distributed cellular communication objects on the basis of mathematical models of pre-project analysis of the relevant processes, and give analytical expressions for estimating the magnitude of electromagnetic radiation generated by systems of various standards. We carried out a brief analysis of the literature on the subject under consideration. To analyze the structure of cellular communication systems in conditions of dense urban development, we propose a method for studying electromagnetic interaction based on the implementation of models of the theory of long lines and telegraph equations. As a method for increasing the efficiency of using cellular communication systems in densely populated areas, we offer to use antenna systems with a special type of radiation pattern, which can improve the quality of communication in certain angular sectors of the antenna operation by providing a constant power level on the receiving side, for which it is proposed to implement the pattern synthesis method directivity based on the expansion of the function in a Kotelnikov series. We considered a linear equidistant antenna system consisting of isotropic radiators as an antenna array. Here we give the results of the synthesis of the radiation pattern for 12 and 24 emitters

**Key words:** mathematical modeling, electromagnetic interaction, electromagnetic safety, theory of long lines, telegraph equations, Kotelnikov series, radiation pattern

## ABSORBING PROPERTIES OF FUNCTIONAL STRUCTURES BASED ON $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_x(\text{SiO}_2)_{100-x}$ NANOCOMPOSITE FILMS

**O.S. Tarasova, A.V. Sitnikov, Yu.G. Pasternak, D.S. Pogrebnoy, O.I. Remizova, A.R. Shakurov**

**Abstract:** we studied absorbing properties of fiberglass samples coated with a functional coating of nanocomposite  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}$  and multilayer structures  $[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}]/[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5} + \text{O}_2]_n$  as well as quasi-fractal structures with a functional coating based on  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_x(\text{SiO}_2)_{100-x}$  composites on a lavsan surface in the radio frequency range from 1 to 10 GHz. We show that in the specified radio frequency range, the resistive absorption spectrum of glass fiber with a functional coating of nanocomposite  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}$  and multilayer structures  $\{[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}]/[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5} + \text{O}_2]\}_n$  has a broad Gaussian peak at 5 GHz. Quasifractal structures with a functional coating based on  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_x(\text{SiO}_2)_{100-x}$  composites on a lavsan surface are characterized by a superposition of two Gaussian curves with a resonant frequency of 4 GHz and 7 GHz, which is associated with the structural features of the spatial distribution and fragmentation of the functional coating, and the absorption value with electrical resistivity of heterogeneous films. We found that the adsorption of electromagnetic radiation by samples, measured in the geometry of the Salisbury screen, in the frequency range of 1–10 GHz for fiberglass

with a functional coating of the nanocomposite  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}$  and multilayer films  $\{[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}]/[(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_{58.5}(\text{SiO}_2)_{41.5}+\text{O}_2]\}_n$  are well described in terms of intrinsic resistive absorption

**Key words:** absorption of electromagnetic radiation, nanocomposite, functional radio-absorbing coatings, multilayer structures, quasi-fractal structures,  $(\text{Co}_{40}\text{Fe}_{40}\text{B}_{20})_x(\text{SiO}_2)_{100-x}$ , frequency-selective surfaces, thin films

## Mechanical engineering and science of machines

### ON THE EFFECT OF DILUTION IN THE CONTACT GAP ON THE KINETICS OF AUTOVACUUMING DURING DIFFUSION WELDING OF TITANIUM

A.B. Bulkov, V.V. Peshkov, I.B. Korchagin, G.V. Selivanov

**Abstract:** the purpose of this work is to study the effect of air vacuum in the welding chamber on the development of the process of auto-vacuuming the gap between the contact surfaces during diffusion welding. The studies were carried out on cylindrical samples with a diameter of 16 mm made of titanium alloy OT4 and armco-iron, assembled with a gap of 0.1 mm. Oxide films with a thickness of 70 microns were previously formed on the surface of armco-iron samples by annealing. Annealing of the samples was carried out in a vacuum from  $10^{-2}$  to 2.6 Pa in the temperature range from 525 to 600 °C. According to the results of changes in the interference coloration of armco-iron samples and ellipsometric measurements after vacuum annealing, we determined a decrease in the thickness of the oxide film. We established that the process of dissolution of the oxide layer on the surface of armco-iron is preceded by a certain period of time, called incubation, during which the pressure in the contact gap drops to the pressure of the elasticity of the dissociation of iron oxides. The duration of the incubation period increases with increasing pressure in the vacuum chamber and decreases significantly with increasing temperature. The processing of experimental data shows that the process of autovacuuming of the contact gap was controlled by the diffusion of oxygen in titanium. According to the results of the conducted studies, we obtained dependences that allow estimating the time of autovacuuming of the contact gap depending on the degree of air dilution and heating temperature

**Key words:** titanium, annealing, gas-saturated layers, strength, topography

### METHOD FOR DETERMINING THE POSITION OF THE TEETH OF A MILLING CUTTER WITH A CONSTRUCTIVE RADIAL FEED FOR PROCESSING EC-PROFILE HOLES

V.V. Kuts, M.V. Mitrofanov, Yu.A. Mal'neva, O.N. Kirillov

**Abstract:** this article discusses a new method of processing EC-profile holes using a milling cutter with a constructive radial feed and shows the processing scheme. In view of the fact that the main indicator of processing is the error of shaping, the article provides a calculation of the deviation of the profile from the nominal values in the radial direction when processing the hole. Based on the calculations performed, we established the dependence of the deviation of the profile of the processed EC-profile hole on the angular location of the cutting teeth of the milling cutter in question. We presented the results of calculations performed at different average milling cutter radii and the number of cutting teeth in the form of graphs of the profile deviation values, which made it possible to establish the non-uniformity of the error along the profile of the hole being processed. To equalize the deviation of the processed hole profile, we proposed to install the teeth of the milling cutter with an uneven angular pitch, for which we developed an algorithm for calculating the angular positions of the teeth on the tool based on a given value of the largest deviation of the profile of the processed hole and the average radius of the cutter. The article shows the results of calculating the number of teeth of the milling cutter, performed using the developed algorithm, for various accuracy standards of the processed hole. In conclusion, we identified further ways of research to assess the health conditions of the design of this milling cutter

**Key words:** EC-profile, mathematical model, milling cutter, shaping, eccentricity, profile deviations, angular parameter