**Informatics, computer engineering and control**

## RECEIVING THE JAVA APPLICATION METRICS IN DOCKER CONTAINERS

**V.F. Barabanov, A.K. Donskikh, N.I. Grebennikova, S.L. Kenin**

Abstract: the objects of research are java-application with support of JMX technology, daemon for collecting metrics collectD; Graphite time series storage software, Grafana data analytics and visualization system. The relevance of developing the solution is determined by the fact that web applications currently need to process huge streams of data. To solve this problem, Docker is used. Working with Docker is somewhat different from working with traditional applications, although in the corporate segment, there is a large layer of classic developments. As a result, the development of a solution that will work with classic solutions in Docker containers is currently relevant. The article describes and features java-applications in Docker containers. A solution is proposed for collecting, storing, processing, analyzing and visualizing web application metrics using JMX, Collectd, Grafana and Graphite. It is shown how these components interact with each other. An example of configuring a java application to work with JMX, adding the FastJMX plugin to collectD, as well as settings for Grafana and Graphite are given. The result of the work described in the article is a system that meets all the requirements for systems for storing and analyzing large amounts of data, and has all the advantages of using Docker. The resulting solution will reduce labor costs, and the use of open source software in the development will further reduce the costs of development and subsequent use

Key words: web application, metric collection, data processing, analytics and visualization software

## MATHEMATICAL MODELING OF THERMOMECHANICAL DESTRUCTION OF IRRADIATED RUBBERS

**S.L. Podvalny, A.A. Khvostov, A.V. Karmanov, G.S. Tikhomirov, A.P. Popov**

**Abstract:** the paper presents the results of a study of the rubber thermomechanical destruction previously exposed to ionizing radiation in electron accelerator at doses of 100, 150 and 200 kGy. Thermomechanical treatment of irradiated rubbers based on butyl rubber was carried out in a rotary viscometer chamber for 40 minutes at temperatures of 373, 393, 413 K. The proposed process of thermomechanical destruction of irradiated rubbers provides a more efficient processing of polymers and allows one to obtain a polymer material with specified viscoelastic properties. We found that an increase in the dose of butyl rubber treatment with ionizing radiation leads to a decrease in the Mooney viscosity by about 2.6-3.9 times. During the process study, we evaluated the influence of temperature and duration of thermomechanical treatment on the change in Mooney viscosity of irradiated rubbers. We proposed a mathematical model of the dynamics of the process of changing the Mooney viscosity during the thermomechanical treatment of irradiated rubber. Using the experimental data for measuring the Mooney viscosity of the samples, we calculated the kinetic characteristics of the process. We found that the rates of individual stages of the process are determined by the irradiation conditions of the initial samples and weakly depend on the processing temperature. Analysis of the simulation results confirmed the adequacy of the model; the calculation error did not exceed 8%

Key words: mathematical model, destruction, butyl rubber, viscosity, kinetics

Acknowledgments: the work was carried out in the framework of the grant of the program “U.M.N.I.K.-2018”, no. 14279GU/2019 dated 10.07.2019

## MULTI-DIMENSIONAL SIMULATION MODEL ON THE BASIS OF NEURAL NETWORK

**I.Yu. Galkin, A.M. Litvinenko, M.A. Chursin**

Abstract: the article considers the mathematical model of reproducing the movement of the original object in the concept of unification and progressive development of the model itself as a result of multi-dimensional growth. The harmonic features of the object of study are analyzed. The problem that needs to be solved is the creation of a model that allows you to recreate and predict the stochasticity of data obtained empirically in the framework of field experiments using identification algorithms defined by the category of description objects. A methodology for modeling trajectories was developed, including an algorithm for training and checking the adequacy, taking into account the piecewise-harmonic components of the study based on numerical and identification methods. An algorithm for the numerical optimization of the parameters of the activation functions was developed, which differs in the use of piecewise-linear harmonic functions and allows one to realize the possibility of forming the trajectory of the object. An algorithm is proposed for checking the adequacy of the mathematical model, based on the implementation of the procedure for processing the results of a full-scale experiment, characterized by the use of the cubic spline interpolation method and allowing one to determine the best parameters at the input of the ANN and reflect the specific features of a harmonic nature. A feature of this model, which can be considered, is the possibility of a multidimensional increase in the number of neurons, which in turn allows us to formalize the processes of a deeper description

Key words: multidimensionality, analytical model, neural network, multidimensional growth, hidden processes

## BILINEAR NEIGHBORHOOD SYSTEMS WITH FUZZY LINKS

**A.G. Yartsev**

Abstract: in this article, we study bilinear neighborhood systems with fuzzy relationships by state, by control, and by bilinear terms of state and control. The formation of the adjacency matrix of a bilinear neighborhood model is shown. An example is a bilinear model with four nodes. The problem of determining the compensating increments of the control parameter to stabilize the system near the nominal mode is considered. For the existence of compensating increments, the condition must be fulfilled: the number of desired values of the increments must be greater than or equal to the number of equations. The stabilization of the nominal mode can be enhanced by the introduction of a neighborhood fuzziness coefficient. This coefficient can be interpreted as a coefficient of the intensity of connections between the nodes of the system. Fuzzy coefficients are considered dynamic, that is, they can change their value during the operation of the system and are considered as additional control variables. Based on this, the linear part of the original (clear) system becomes bilinear, and the bilinear part becomes trilinear. The problem of stabilization of the system near the nominal mode is discussed using only dynamic fuzziness coefficients and when using these coefficients together with other control variables

Key words: neighborhood systems, fuzzy links, neighborhood fuzziness, dynamic fuzziness, nominal modes, stabilization

Acknowledgments: the study was carried out under the financial support of the Russian Foundation for Basic Research and the Lipetsk Region as part of scientific project 19-48-480007 p_a

## STRUCTURE OF A MULTIAAGENT SYSTEM FOR OPTIMIZATION OF MINE TRANSPORT MOTION

**E.Yu. Bozyukova, S.A. Oleynikova**

Abstract: the object of the research in this work is the mine transport and its movement along one of the many routes. The subject of the study is a set of models and algorithms that optimize the schedule of vehicles. At this stage of solving the problem, it is assumed that the schedule drawn up for transport, in general, is effective. However, since the time taken to extract a given amount of minerals is a random variable, slight deviations from the schedule are possible. In this regard, optimization means effective control of the movement of vehicles in order to prevent their collision and ensure traffic safety. In part, these tasks have already been solved, but most of the similar software tools do not fully cover the entire functionality of dispatch control and control. In this regard, there is a need to develop our own software, as well as methods of control and management. In addition, it is necessary to solve the problems of positioning and preventing the possible occurrence of emergency situations. An analysis of possible approaches to solving this problem made it possible to choose an approach based on the interaction of intelligent agents as the most promising at the present time. The result is the structure of a multi-agent system that monitors and controls the movement of mine transport, as well as visualizing the movement of each of the units of equipment

Key words: multi-agent system, automated control system, mine transport, logistics

## AUTOMATION OF TEST CONTROL PROCESSES OF FINITE STATE MACHINES

**G.V. Petrukhnova, S.A. Prutkova**

Abstract: the object of research is the automation features of test control processes of finite state machines. A finite state machine is used as a model of a digital device or a software module. Test control operation is testing information operation [1], in which a set of in-circuit control input signals is being fed into inputs of finite state machines while output responses to these signals are being taken from other contacts. The control test is presented in the form of a binary matrix and is generated by a pseudo-random number generator. In this case, technology of weighted pseudo-random testing is used. Input weight is the frequency of supplying a single logical signal to the input of the finite state machines. Test control of the finite state machine is carried out on the basis of a given weight vector. The developed software product allows one to determine the input weight input by solving the problem of optimizing the probability distribution of input signals based on a generalized entropy criterion. The software product allows one to manage test objects, to set the weight for each input of the state machine, to select optimization criteria for the vector of weights from the specified set, to set parameters for the optimization process, to conduct test control of the finite state machines, to save information about the test object based on the set vector of weights, to save information about the testing management and the optimization process; to view test results and optimization process. The software product interface is presented. The software product can be used to research the processes of test optimization and test control of various automaton models

Key words: finite state machine, entropy, binary matrix, digital device, software module, test control, automation of processes

## ANALYTICAL MODELING OF CLOSED EXPONENTIAL QUEUING NETWORKS WITH TRANSITION PROBABILITY MATRIX DEPENDING ON THE NETWORK CONDITION

**I.V. Zubarev, A.A. Chumichkin, V.L. Burkovskiy**

Abstract: the models used in the theory of queuing networks simply and clearly demonstrate the behavior of real objects. This, in turn, allows one to minimize the costs of designing and developing real objects, avoiding a lot of network design errors, and optimizing existing networks. The article deals with the analytical apparatus for analyzing the structure of a closed queuing network with an exponential distribution of the service duration depending on the transaction flows in the system, which ensures the reproduction of non-stationary states. The description of the process of changing the structure of interaction of its elements is presented in the framework of the mathematical model using the components of the transition probability matrix, which depends on the state of the queuing network. The main characteristic of a closed queuing network is the stationary probability distribution of the transition state of the application after service, i.e. any application, in a finite number of steps, performs a transition from some network node to any other network node. To describe the stationary probability distribution of the state of a closed homogeneous queuing network, we used the method of compiling local balance equations. The final simulation result was a formula for calculating the flow of applications in a node and the average cycle time between visits to a given node. The use of performance calculation algorithms for closed queuing systems allows one to form effective models of distributed information processing systems

Key words: mathematical modeling, closed queuing networks, analytical modeling, transition probability matrix, exponential distribution, service intensity, stationary state probability distribution, average cycle time

## SYNTHESIS OF ROBUST LINEAR-QUADRATIC REGULATORS FOR LINEAR INTERVAL DYNAMIC SYSTEMS

**I.A. Boldyrev, A.S. Kozhin**

Abstract: in the study of control objects, we encounter various inaccuracies in determining their parameters. One of the methods for dealing with uncertainties is the use of various estimates of the parameters of the control object. Modern science has developed various methods for assessing the uncertain parameters of the control object. Parameter uncertainty occurs when the set of parameters of the control object is more than one point. If this set is specified using probabilistic characteristics, then this is the so-called probabilistic uncertainty of the parameters of the object. If the boundaries of the intervals in which they are enclosed are known for the parameters of the object, then such uncertainty is called interval. If the parameters of the object are specified using the membership function, then in this case the theory of fuzzy logic is used. The interval determination of the parameters of the control object is used when working with quantities for which are known, only the boundaries of the intervals within which their values are enclosed. The interval approach in the description of object parameters is used to take into account rounding and errors that occur during calculations on a computer and is a powerful method in representing objects with undefined parameters. The reason for using interval systems is that the information about the control object is incomplete, the errors in measuring the parameters of the object, linearization errors, and so on. Various tasks of the classical theory of automatic control make it possible to replace lumped parameters with their interval counterparts. Many interval tasks are adequate for practical applications. LQR synthesis refers to the classical methods, which allows one to obtain regulators that minimize the integral quality criterion with respect to the resource of regulated and regulatory quantities. In this paper, we study the possibility of synthesizing LQR for objects given at intervals. This application of two well-known methods makes it possible to work with nonlinear objects using the classical linear control theory

Key words: LQR −linear quadratic regulator, LIDS − linear interval dynamic system

## STRUCTURAL ANALYSIS AND MODIFICATIONS OF SYSTEM WITH BOUC-WEN HYSTERESIS

**N.N. Karabutov**

Abstract: we propose the method of structural identification of a dynamic system with hysteresis described by the Bouk-Wen equation under conditions of uncertainty according to the input-output data. The method is based on the introduction of a special class of geometric structures that reflect the state of hysteresis. Based on the analysis of structures, we considered a method for assessing the structural identifiability of the system is proposed and the conditions for its use. It is based on the fragmentation of the geometric structure and further analysis of its properties. To evaluate them, we used the secant method, which allows one to obtain indicators on the class of linear models that make it possible to decide on the structural properties and identifiability of the system. The solution to the structural identification problem is based on the application of the hierarchical immersion method, which allows one to establish significant relationships at each iteration of structural synthesis that affect the hysteresis yield. At the same time, at each iteration, the condition of structural identifiability should be fulfilled. The solution to the problem is given for the classical Bouk -Wen model. We determined the conditions under which the hierarchical immersion method is possible. We propose modifications of the Bouk -Wen model and show their performance. Modifications can simplify the process of identifying system parameters and guarantee system stability. The results of applying the proposed approach confirmed the structural properties of the considered nonlinear system

Key words: nonlinear system, hysteresis, Bouc-Wen model, geometrical framework, structural identifiability, hierarchical immersion

## METHODOLOGY OF ORGANIZATION AND ASSESSMENT OF QUALITY OF RESEARCH WORKS OF THE CADETS OF THE MILITARY SCIENTIFIC SOCIETY BASED ON THE RASCH MATHEMATICAL MODEL

**Yu.V. Korypaeva, N.E. Krasova, V.V. Peshkov, S.V. Ryabov**

Abstract: the paper deals with the problem of formation of working groups of cadets of a military University to perform certain stages of research in the framework of the military scientific society. When studying this question, building a model, choosing a method and means of its solution, different levels of mathematical training of cadets and their interests in various fields of science are taken into account. To identify the degree of mathematical training of cadets, to diagnose the complexity of each stage of the study, as well as to build a mathematical model of the formation of research groups to perform different stages of scientific work, a modified Rasch method is used. To assess the probability of successful completion of scientific research as a whole by the whole group under certain assumptions, a mathematical model is constructed that relates to integer programming problems and can be implemented using computer application packages. The paper provides an example, in which, with specific data, as a result of calculations, groups of cadets are formed for the successful implementation of research work. This model of organization of working groups, consisting of the desired number of participants, to perform any activities can be successfully applied not only in universities in solving scientific problems, but also in public production, in private business, etc.

Key words: Rasch method, logistic function, expert estimates, integer programming, least squares method

**Radio engineering and communication**

## DISAMBIGUATION OF PHASE MEASUREMENTS IN THE MULTIPOSITION FINDER BASED ON THE SIMILARITY OF AZIMUTH AND ELEVATION TRAJECTORIES

**B.V. Matveev, V.A. Ivanov, A.A. Golikov, A.A. Makarov**

Abstract: the article considers the problem of ambiguity resolution phase measurements when determining angular coordinates of radio-emitting spacecraft using multiple phase direction finders. To solve it, we propose an improved methodology compared to the known ones, based on the identification of the similarity of the trajectories obtained by the results of phase and amplitude measurements with a multi-position direction finder of two coordinates of a radiating spacecraft: azimuth and elevation. The implementation of the proposed approach is illustrated by the example of a correlation-phase direction finder having an additional mode of correlation-amplitude direction finding. The characteristics of the approximating line of the combination of discrepancies of the elevation and azimuthal trajectories are used as a criterion for the reliability of disambiguation. In the presence of systematic errors in the amplitude measurements, the residual lines will shift. In this case, the nature of the residual lines will not change, but if the ambiguity is corrected, the corresponding residual line will not be zero. In the process of eliminating the ambiguity of phase measurements by the method of similarity of two trajectories, arrays of measuring information are used. We can conclude about the effectiveness of the combined use of amplitude and azimuthal elevation phase direction finding for high-precision restoration of the trajectory of a bearing object. We can conclude about the effectiveness of the combined use of amplitude and azimuthal elevation phase direction finding for high-precision restoration of the trajectory of a bearing object

Key words: phase measurements, multi-position direction finder, disambiguation elimination

Acknowledgments: the work was carried out under the financial support of the Council for Grants of the President of the Russian Federation (project no. SP-834.2019.3)

## VARIANTS OF THE SMALL-DRONE BASED DIRECTION FINDING ANTENNA ARRAYS

**P.V. Pershin**

Abstract: the paper presents the analysis results of the direction-finding antenna arrays variants intended as part variants for a small-size wide-scale radio monitoring station placed on a drone. The weight and size parameters of antenna array are strictly limited by the specified requirements. The influence of the antenna system carrier platform on the complex vector patterns of antenna elements of the array is investigated. It was shown that the carrier metal platform substantially distorts the radiation patterns of asymmetric and symmetric vibrator antenna elements and significantly reduces the cross-polarization isolation, and gives rough misses in evaluating the bearing of signals with elliptical polarization when using the correlation-interferometric direction-finding method. A method for reducing the influence of the carrier metal platform using absorbing surfaces of various types is proposed. In the limiting case of the platform absence, the systematic error of direction finding using an antenna array of symmetrical conical elements does not exceed 2 degrees. It was determined that the optimum characteristics among the options considered when placed above a metal platform have an antenna array of symmetrical cones. The use of a Salisbury double-screen absorber reduces the direction-finding error caused by wave scattering on the carrier platform at frequencies above 200 MHz

Key words: antenna array, direction finding, correlation interferometer, complex vector radiation pattern, small drone

## COMPARATIVE ANALYSIS OF THE PARAMETERS OF BIO-POTENTIAL AMPLIFIERS

**D.V. Zhuravlev, V.A. Meshcheryakov, M.V. Shubin, M.A. Sivash, V.S. Volkov, D.S. Potapov**

Abstract: in the modern world there are more and more different systems for assessing the parameters of the human body using non-contact reading of biomedical indicators. We examined the features of the development of a system designed for non-contact reading of biomedical indicators (ECG signals) by analyzing the parameters of biopotential amplifiers when used in a three-electrode circuit and in a circuit with electrode shielding intended for use in a device that has small dimensions, analog processing of medical-biological characteristics that meet the trends of the modern development of medical electronic systems. For comparison, operational amplifiers such as OP193, LMP7701, LT6010 are used, which are compared by the following calculated indicators: input range value, relative voltage measurement error, nonlinearity, sensitivity error, frequency response unevenness and common mode rejection ratio. The choice of these operational amplifiers is due to the optimal combination of both financial and operational-technical characteristics in them. This study aims to gain an understanding of how these operational amplifiers are suitable for use in non-contact reading systems for biomedical indicators, and how they correspond to the set of requirements for these operational amplifiers

Key words: non-contact reading system for biomedical indicators, ECG, biopotential amplifier, switching circuit with three electrodes, switching circuit with shielding electrodes

## ALGORITHMS OF FORMATION AND PROCESSING OF RADIO SIGNALS OF COMMAND AND TELEMETRY RADIO LINES AND TECHNICAL PROPOSALS FOR THEIR IMPLEMENTATION

**D.G. Pantenkov, V.P. Litvinenko**

Abstract: stochastic parallel-serial broadband signals (SPSBS) can be used in command and telemetry channels of unmanned mobile objects of aviation, land or sea basing due to the fact that they have a low probability of detection by radio monitoring compared to the broadband signals of deterministic structure, high structural stealth and high resistance to intentional interference. The notion of secrecy in the transmission of the useful information includes the energy, informational and structural aspects that mean the resistance to access to information contained in the radio signal, to the opening of the "fine structure" and the subsequent analysis, and to detect the signal from its power spectral density (the ratio of the energy of the radio signal for occupied bandwidth). This article presents the results of development of a hardware-software complex (radio systems) based on stochastic M-ary parallel-serial wideband signals, and discusses the analysis of crest factor, autocorrelation functions, spectral correlation, the error probability for the transmitted information bit SPSBS, the developed structural diagram of a transmission device of a multifunctional algorithm for demodulation and synchronization SPSBS. The principal possibility of realization of stochastic parallel-serial broadband signals on modern hardware platforms taking into account the requirements for computational resources, information transfer rates is shown

Key words: stochastic parallel-serial broadband radio signals, spectral correlation function, oscillogram, error probability, demodulation and synchronization algorithm, practical implementation, FPGA, digital signal processor, computing resources

## OPTIMIZATION OF THE TEMPLATE TO INCREASE AN EFFECTIVENESS OF SYNTHESIS OF THE ANTENNA ARRAY WITH A COSECANT PATTERN

**I.A. Kirpicheva, A.V. Ostankov, A.I. Ryabchunov**

Abstract: antenna arrays with special and cosecant radiation patterns are widely in demand in modern radio engineering systems. In the synthesis of the antenna array by classical methods, the expected radiation pattern outside the cosecant sector is specified, with rare exceptions, by zero values. However, this approach to the formation of a chart template is not optimal. We proposed to supplement the template of the expected radiation pattern with a constant level region equal to the maximum of the diagram and two linear slopes. We developed a technique for optimizing the geometric parameters of the template according to the criterion of the minimum standard deviation of the synthesized diagram from the ideal cosecant diagram with a restriction on the maximum deviation of the diagram in the cosecant sector or (and) the level of the side lobes. We used the method of synthesis of the antenna array by the method of expanding the radiation pattern in the Kotelnikov series and implemented the optimization technique based on the genetic algorithm. Based on the results of testing the technique, we showed that the use of an optimized template can improve the quantitative directivity of the antenna array. In particular, for the 70° cosecant sector and the 12-element grating, we can achieve a gain in the maximum deviation of the diagram of 4 dB while reducing the maximum level of the side lobes by 3 dB. The developed technique can be used to synthesize a lattice with a different beam pattern than the cosecant

Key words: antenna array, cosecant radiation pattern, synthesis, Kotelnikov series, pattern, optimization

Acknowledgments: the reported study was funded by RFBR and CNRS, project number 20-51-15001

## INVESTIGATION OF THE EFFECT OF THE PATCH EMITTER LENGTH ON ITS CHARACTERISTICS

**S.M. Fyedorov, E.A. Ishchenko, M.A. Sivash, I.A. Zelenin**

Abstract: the article considers the effect of the length of the microstrip rectangular patch emitter on the number of operating ranges, the resonance characteristic, and the radiation pattern. The study was conducted on the basis of data obtained in the simulation process. The article describes the basic rules for calculating and selecting the dielectric material for a microstrip patch antenna configured to receive a signal at 37 GHz, which corresponds to one of the fith-generation communication standards (5G). The simulation was performed using two programs – Antenna Magus, which was used for automated calculation of the radiator's geometric parameters; CST Studio Suite for modeling the basic resonant characteristics of the antenna and building directional diagrams. Based on the results obtained, conclusions were drawn about the possibility of forming additional frequency ranges. It was also determined the offset of the main operating frequency, which has a minimum value of return loss and voltage standing wave ratio. The results of modeling are presented in the form of three-dimensional models of emitters, return loss graphs (S11 parameters), rules for converting S11 values to VSWR, directional diagrams in polar coordinates, and the dependence of the max gain and the angular 3dB width of the main lobe on the frequency

Key words: patch emitter, microstrip patch antenna, resonance characteristics, 5G, Antenna Magus, CST Studio Suite

## RESULTS OF NATURAL TESTS OF DIFFERENT RADIOPELEGATOR ANTENNA SYSTEMS FOR A SMALL DRONE

**P.V. Pershin**

Abstract: the article presents the field test results of direction-finding and localization of the ground-based radio emission sources using a different antenna systems variants for a small-size wide-scale radio monitoring station placed on a drone. We considered the single-stage and two-stage variants of antenna systems. The study shows that the studied version of the layout of the two-stage antenna system provides the possibility of direction finding of radio emission sources in the frequency range from 110 to 3000 MHz in azimuth and elevation at given mass and dimensional parameters. Increasing of the elevation from 0 to 40 degrees leads to a direction finding error significant increase of direction finding from 2 to 5 degrees. The study shows the localization possibility of the ground-based radio emission sources using the one-position method with an AS-HP1 single-stage antenna system. The dependency of the radio emission source localization error is revealed depending on the current set of the frequency-azimuth-elevation angle values. The localization error reducing possibility by using of drone special motion modes is experimentally shown, and the final standard deviation of the radio direction finder error in the absence of anomalous errors is 2–3 degrees, depending on the frequency range

Key words: antenna array, radio direction finding, small drone, one-point localization, navigation system

## APPLICATION OF MICROCONTROLLERS IN REALIZATION OF THE CALCULATOR OF CONTINUOUS WAVELET TRANSFORMATION INTENDED FOR WORK IN CONDITIONS OF ARCTIC

**A.B. Stepanov, A.V. Pomogalova, V.S. Gribanov, I.A. Bogoslovskiy, Kh.M.M. Ayed**

Abstract: the paper is devoted to the development of a continuous wavelet transform computer, designed for operation in cold temperatures (up to -60$^{o}$C). MSP430G2553, ATmega328P and STM32F401RET6 microcontrollers are considered as an element base for the implementation of the calculator. The results of continuous wavelet transformation calculation were obtained using microcontrollers, taking into account their clock frequencies and limited internal memory. The dependence of the continuous wavelet transformation calculation speed on microcontrollers at different signal lengths and with different ways of using wavelet in the algorithm is obtained and analyzed: when it is loaded from the internal memory of the microcontroller and when it is calculated directly on the microcontroller. In all the experiments, fragments of an electroencephalogram with a sampling rate of 250 Hz are used as analyzed signals. The device description and functional schemes of the continuous wavelet transform calculator, developed for various types of tests are given: for estimation of the speed of calculation of continuous wavelet transformation and for testing of the device at low temperatures. The results of the test of the calculator in the climate chamber are evaluated. As a result of the research, it is shown that among the devices considered, the STM32F401RET6 microcontroller is best suited for calculating continuous wavelet transformation. It took 0.57 seconds to process a 1 second (250 counts) fragment of the electroencephalogram when used. At the same time, the information content of the wavelet spectrogram was preserved. It took 2516.84 seconds to process a strip of 4500 counts with the wavelet calculation directly on the microcontroller. Studies in the climate chamber have shown that the developed device with an installed battery capacity of 20 A·h worked at a temperature below -40 $^{o}$ C for 129 minutes, of which 101 minutes at a temperature of -60 $^{o}$ C. This time is sufficient for electrocardiological or electroencephalographic examination of 5 people

Key words: continuous wavelet transformation, calculator, implementation, microcontroller, Arctic

## KINETICS OF GROWTH OF GAS-SATURATED (EMBROKEN) LAYERS ON TITANIUM AT VACUUM ANNEALING

**A.B. Bulkov, V.V. Peshkov, V.F. Selivanov, N.E. Mikhalevich**

Abstract: we studied the influence of the parameters of the vacuum annealing regime on the thickness of embrittled layers formed on the surface of titanium as a result of its interaction with the residual gases of the evacuated space. The thickness and structure of the layers were determined on samples of VT6 alloy obtained from 3 mm thick sheet metal. Samples were annealed in the temperature range 500–750 °C with a rarefaction of air from 10 to $3 \cdot 10^{-2}$ Pa. The dimensions of the brittle layers were determined by measuring the brittle propagation zone of the crack in the fracture of the samples and measuring the distance between surface cracks in the brittle layers formed during bending. To quantify the effect of the vacuum annealing regimes of VT6 titanium sheet alloy on the depth of the embrittled part of the formed oxide layer, we proposed to use a parabolic dependence characterized by an exponent and growth constant of the embrittled layer. By processing the experimental data, we established the effect on the growth kinetics of the embrittled layers of the annealing time, temperature, and the degree of rarefaction of the air. Based on the obtained kinetic laws of growth of embrittled layers, nomograms are constructed that allow one to determine the magnitude of the embrittled layer formed at the heating stage at different rates to a given annealing temperature

Key words: titanium alloys, annealing, gas saturated layers, embrittlement

## FORMATION OF ISOTROPIC ZONES IN THE 4 MM STEEL PLATE

**V.N. Semykin, V.N. Protsenko, D.A. Sviridov, A.V. Bes'ko, I.N. Kasatkina**

Abstract: we investigated experimentally the possibility of effectively relieving residual stresses in a St3 plate with dimensions 150×150×4 mm when the latter was treated with small lead shots on one side. The specific kinetic energy of three shots in total was 18 J/cm$^2$. The research methodology included the identification of the fields of the trajectories of the main stresses (isostat) and isotropic zones by the physical non-destructive magnetoelastic method. We used a single-phase measuring instrument of mechanical stress IMN-4M with a 5 mm magnetoelastic sensor base. The principal stresses were separated by the method of difference in tangential stresses. Before and after processing by shots, 392 nodes of the coordinate grid, which were previously marked on the sample, were controlled. It was found that favorable isotropic zones from high-speed exposure to fractions are formed on both sides of the plate. The experiment confirmed the effectiveness of reducing residual stresses by lead shots when processing one side of a 4 mm thick plate. The possibility of preparing thin-walled blanks and parts for precision mechanics and optics products, in which the deformations and instability of geometric shapes caused by manufacturing and operation processes should be minimized, was shown in practice

Key words: residual stresses, pellet gunshots, magnetoelastic method, isostatics, isotropic zones

# RESTORATION OF PLASTICITY OF SURFACE GAS-SATURATED TITANIUM LAYERS UNDER CONDITIONS OF NON-OXIDATIVE ANNEALING

**A.B. Bulkov, V.V. Peshkov, I.B. Korchagin, D.A. Boldyrev**

Abstract: the purpose of this work was to establish the regularities of the process of restoring the plasticity of surface gas-saturated layers of titanium under conditions of non-oxidative annealing. As an object of study, we used samples from rolled sheet of VT6 titanium alloy with a thickness of 2 mm with a gas-saturated layer of 0.6 μm, created as a result of preliminary annealing. The embrittled layers were dissolved under the conditions of isothermal, non-oxidative annealing in the temperature range of 700...850 °C. To assess the process of restoring the plasticity of surface layers, we used the topography of the deformed surface during destruction by bending of the test sample. The temperature-time range of the vacuum annealing efficiency was determined to restore the plastic properties of titanium alloys. We established that this effect is achieved due to the redistribution of oxygen from the surface layers of the product over its volume. We obtained the dependencies that make it possible to estimate the parameters of the annealing regime (temperature and time) necessary for cleaning the titanium surface from the embrittered part of gas-saturated layers, depending on their initial thickness. The materials of this article are of practical value for enterprises and organizations developing technologies for the manufacture of thin-walled structures of titanium and its alloys for aviation and space technology

Key words: titanium, annealing, gas-saturated layers, plasticity, topography