Abstracts

Research progress on solid-liquid combined superlubricity (SLCS)

J. Luo

State Key Laboratory of Tribology in Advanced Equipment,
Tsinghua University, Beijing, China

Superlubricity, including liquid, solid and solid-liquid combined superlubricity, has been greatly developed recently in the laboratory. However, it is still difficult to be applied to industrial due to its various limitations. One of the main limitations is the carrying capacity, which is also a key factor to realize superlubricitive engineering[1]. The solid-liquid combined superlubricity (SLCS) system[2] has been proposed recently, such as graphene/ionic liquid system[3], black phosphorus nanoflakes/liquid lubricant system[4], layered double hydroxide (LDH)-liquid system[5]. These systems showed excellent performances in carrying capacity, increasing the contact pressure from MPa level in liquid superlubricity to the GPa level in SLCS system. SLCS lays a good foundation for the realization of superlubricitive engineering. The recent progress on solid-liquid combined superlubricity will be reviewed.

Keywords: Superlubricity, solid-liquid combined superlubricity, superlubricitive engineering

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Real contact area and load-carrying capacity of hard multi-asperity surfaces

M. Kalin

Laboratory for Tribology and Interface Nanotechnology,
University of Ljubljana, Bogisiceva 8, 1000 Ljubljana, Slovenia
e-mail: mitjan.kalin@fs.uni-lj.si

Real contact area is one of the very important parameters that control mechanical, tribological, thermal and other phenomena at contacting surfaces. In spite of many studies and models still there exist no models that would be generally accepted for different materials and different roughness values. In a recent study of a broad range of material properties of metallic surfaces that we consider them "hard", compared to polymer or biological surfaces, we have shown that relatively small real contact area (10-25 %) carry the load even under loads up to the yield strength. This indicates very high load carrying capacity of these surfaces. The question arises, which mechanisms may be responsible for this. We analysed the elastic and plastic deformation contributions at the multi-asperity real-sample surfaces, characterised with a sub-micron lateral and nanoscale vertical resolution, at various loads up to a nominal yield strength. The results elucidate why the asperities were able to carry the load that resulted in as much as a 4–10-times-higher contact pressure than the (initial) bulk yield strength. It is proposed that for the rough surfaces this is due to the work-hardening, while for the smooth surfaces the dominant mechanisms are the work-hardening combined with the hydrostatic bulk stresses.

Keywords: *in-situ* asperity experiment, multi-asperity contacts, real contact area, work-hardening, deformation, steel, roughness

Triboinformatics: Machine Learning methods in Tribology and friction-induced instabilities

Michael Nosonovsky [a,b] and Alexander Aglikov [a]

[a] Infochemistry Scientific Center, ITMO University, Lomonosova St. 9, St. Petersburg, Russia 191002

[b] Department of Mechanical Engineering, University of Wisconsin–Milwaukee, 3200 North Cramer St, Milwaukee, WI 53211, USA, Tel. +1-414-229-2816, nosonovs@uwm.edu

The study of friction is traditionally a data-driven area with many experimental data and phenomenological models governing structure-property relationships. Triboinformatics is new area combining Tribology with Machine Learning (ML) and Artificial Intelligence (AI) methods, which can help to establish correlations in data on friction and wear. This is particularly relevant to unstable motion, where deterministic models are difficult to build. There are several types of friction-induced instabilities including those causes by the velocity dependency of dry friction, coupling of friction with another process (wear, heat generation, etc.), the elastic Adams instabilities, and others. In many cases, new "secondary structures" are formed at the frictional interface due to the instabilities. ML/AI methods, such as the Topological Data Analysis and various ML algorithms, which have been already used for various aspects of data analysis on friction, can be applied also to the frictional instabilities.

Contact Mechanics for Everybody: How to Apply Method of Dimensionality Reduction to Non-Axisymmetric Homogeneous and Power-Law Graded Elastic Bodies

Valentin L. POPOV

Technische Universität Berlin, 10623 Berlin, Germany

The main milestones of contact mechanics, which had (and still have) a lasting effect on practical tribological applications in science and engineering, were the original work of Hertz from 1882 for elliptical parabolic profiles, followed by the solution of Föppl and Schubert from 1941-42 (which became wide-spread thanks to the later paper by Sneddon in 1966) for axially symmetric but otherwise arbitrary indent-er shapes. The solution presented in the paper at hand is an extension of this axisymmetric solution to non-axisymmetric profiles.

It has been believed for a very long time, that the scope of analytic contact mechanics is restricted to very specific geometries, specifically, problems with either axial or plain symmetry – which were solved in general form already in Schubert's paper. However, in the present paper, we have laid out a general procedure for the solution of the Boussinesq problem for compact, but otherwise arbitrary, contact domains, which retains the analytic simplicity of the axisymmetric solution, but which – despite its approximate nature and asymptotic character of its derivation – has proved highly robust in its predictions even in the case of contacts, that are far from axial symmetry.

On the other hand, the procedure can be used to solve other classes of contact problems, that reduce to the Boussinesq problem, e.g., the viscoelastic normal contact – via the elastic-viscoelastic correspondence principle – or the tangential contact with friction, within the framework of the Cattaneo-Mindlin-approximation.

The last point deserves a brief elaboration: It has been shown that the reduction of the tangential contact with friction to the frictionless normal contact problem via the principle of Jäger and Ciavarella, in an approximate sense, is also possible for general three-dimensional and even rough contacts**Fehler! Verweisquelle konnte nicht gefunden werden.**. The quality of this approximation (i.e., of the reduction procedure) is of the same order as the quality of the approximate normal contact solution discussed in the present manuscript. In other words, this approximate contact solution can be applied straightforwardly to incorporate tangential (frictional) forces.

The approximate contact solution presented in this paper can be considered as an extension of the Method of Dimensionality Reduction to non-axisymmetric profiles [1].

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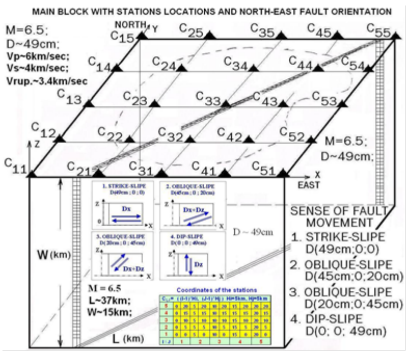
Ground motion prediction on active fault with deifferent slipe orientation

Dr. Alexander Bykovtsev Principal Engineer, Regional Academy of Natural Sciences, 2644 Foghorn Cove, Port Hueneme, CA, USA, e-mail: bykovtsev1@iyahoo.com

Marat Kasimov Senior Researcher, Regional Academy of Natural Sciences, CA, e-mail: manmarkaz@mail.ru

According to the new requirements of the ASCE Standard Chapter 21 Site-Specific Ground Motion Procedures (SSGMP) for Seismic Design at least five recorded or simulated ground motion (SGM) time histories shall be selected from events having magnitudes and fault distances that are consistent with those that control the Maximum Considered Earthquake (MCE). In mean time there are not enough recorded ground motions especially in the near-field of large earthquakes with magnitudes Mw>5 at the distances less than 5 km from the fault, and Deterministic Simulated Ground Motion (DSGM) would be needed for proper Seismic Hazard Analysis and slope stability mitigations. According to ASCE 7-16 Chapter 21 probabilistic and deterministic MCE analyses are now mandatory included in SSGMP. The Probabilistic Seismic Hazard Analysis (PSHA) was conducted to evaluate the likelihood of future earthquakes and provide design ground motions. The PSHA is based on IBC-2006 provide more conservative results and as a result the seismic coefficient in slope stability analyses were overestimated by approximately 20%. The Deterministic Seismic Hazard Analysis (DSHA), including fault segmentation and analyses existing time history records from COSMOS data base, will be used for control and correction of results obtained by PSHA screening procedures. Our expectation is that DSHA will provide more accurate results in near-fault zones and more realistic results for slope stability analyses with time history analysis procedures for DSGM. The results of a screening analysis procedure-Special Publication 117 (SP-117) and a quantitative SSSI based on Deterministic Simulated Ground Motion (DSGM) under ASCE/SEI-7-16 will be presented for several different types of landslides. DSGM will be computed based Boundary Element Method with kinematic rupture representations consistent with seismic, geodetic, and geologic observations and using analytical algorithm Bykovtsev-Kramarovskii-1987. DSGM will be computed for planar fault topology with different sense of fault movement, presented in Fig.1 and within 5 km of a fault zone. Documentation and verification of simulation methodologies for different deterministic models with and without fault segmentations will be presented.



As a result of our previous analyses we conclude (Bykovtsev 2009a,b,c), that SP-117 should be revised for proper definition of DSGM in near-fault zones. Based on result of this project we are going to provide recommendation for improvement existing procedures (SP-117) for determining site-specific design ground-motion parameters for landslides and slope stability analyses with time history procedures for planar and nonplanar fault topology within 5 km of a fault zone.

Analyses DSGM for different site locations and different type of movement on fault will be presented. Analyses of previously obtained results show (Bykovtsev 2009b, Bykovtsev and Kasimov 2009), that for several scenarios, the maximum seismic radiation will be not on the fault zone, but on some distance approximately 1-3km from the fault

On the equivalence of models of an inhomogeneous elastic foundations

Aizikovich S.M., Lapina P.A.

Don State Technical University, Rostov-on-Don

The paper proposes an approach to the analysis of the equivalence of various models of inhomogeneous elastic foundations by the example of solving antiplane contact problems on the surface shear of inhomogeneous media by a rigid punch in the form of an inhomogeneous half-space, an inhomogeneous layer on an elastic foundation, and an inhomogeneous layer on a rigid foundation. For analysis, an ex-ponential law of change in the shear modulus of an inhomogeneous half-space/layer was chosen, which made it possible to write out the kernels of integral equations in an analytical form. Approximate analytical methods, such as the Wiener-Hopf meth-od, the larger parameter method, and the bilateral asymptotic method, were used to construct solutions to the integral equations of contact problems. The ranges of val-ues of the parameters of the law of change of the shear modulus for an inhomogene-ous elastic half-space, an inhomogeneous elastic layer on an elastic foundation, and an inhomogeneous elastic layer on a rigid foundation were determined, in which the difference between the kernel transforms of integral equations does not exceed a few percent. In such areas, the discrepancy between the values of contact stresses also does not exceed a few percent, which demonstrates the equivalence of the considered models of an inhomogeneous foundation in this region of parameters.

This work was supported by the Russian Science Foundation (project 22-49-08014).

Frictional phenomena: Micro or Macro? Macro-scale effects in dry friction: a mini-review

Mikhail Popov,*

Technische Universität Berlin, Germany
*mpopov@fastmail.fm

Dry friction is known to be a fairly complex phenomenon. While the force of friction can be roughly approximated by Amontons' law, FR = μFN, more accurate quantification often proves difficult in practice, since the coefficient of friction generally depends on relative velocity, macroscopic pressure, vibration, the loading and motion history, e.g., with regard to pre-slip and accelerated creep in stick-slip transitions, along with many other factors. Most of these secondary effects are generally regarded as intrinsic properties of dry friction, which implies that the responsible physical mechanisms should be situated on the micro-scale, although it is also widely acknowledged that coefficients of friction are, in the most general sense, system properties and cannot be completely decoupled from macroscopic dynamics. In this talk it is argued that macro-scale interactions could play a much more central role than normally assumed. A brief review of experimental evidence and theoretical considerations pointing in this direction is presented, including results obtained by multiple authors over the past half century, as well as the present author's own work on the active control of friction by ultrasonic vibration. Topics covered also include stick-slip transitions and elastomer friction. It is also argued that certain dimensionless contact properties make it genuinely hard to pin down the correct scale of some frictional phenomena, since plausible models involving these properties can be constructed both at the micro and macro scales. This makes it more difficult to verify tribological theories by testing against bulk properties such as the coefficient of friction.

The effect of the angle between direction of motion of indenter and elastomer surface on adhesive contact properties: experiment and mathematical model

Iakov A. Lyashenko, Valentin L. Popov

Institut für Mechanik, Technische Universität Berlin, 10623 Berlin, Germany
*E-mails: i.liashenko@tu-berlin.de; v.popov@u-berlin.de

In proposed work, the experiments with indentation of the spherical steel indenter in a soft rubber layer have been performed. Indenter was moved with small velocity v = 1 μm/s to ensure quasistaticity and conditions of controlled displacement (fixed grips). In the left panel of Fig. 1, the procedure of the experiment is schematically shown. Two series of experiments were performed – with indentation of the indenter in a rubber layer (scenario A) up to fixed indentation depth $d_{\max}$ = 0.3 mm and with detachment of indenter beginning from fixed indentation depth $d_{\max}$ (scenario B). The main aim of the work was investigation of effect of the angle α between direction of motion of indenter and horizonal surface of rubber layer on adhesive contact properties. The experiments have been performed for angles α = 10, 20, 30, 40, 50, 60, 70, and 80°. Additionally, cases of pure normal loading (α = 90°) and tangential motion (α = 0°) were investigated. During indenter's motion all three components of the contact force (normal force F_N, friction force F_x and lateral force F_y) and displacements of indenter in two directions (indentation depth d and tangential shift x) were collected. Moreover, the photographs of the contact area during the whole experiment were saved for each second. Based on saved pictures the values of the contact area A were calculated, which allows finding evolution of averaged values of the contact pressure $\langle p \rangle = F_N/A$ and tangential stresses $\tau = F_x/A$. It was found, that in the presence of tangential shift the adhesive strength in normal direction becomes smaller, similar situation was considered in our earlier theoretical work [1].

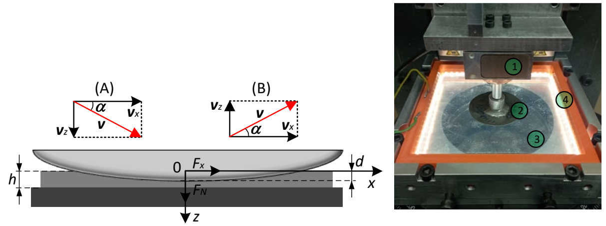


Fig. 1. Scheme of the experiment (left panel) and real photo of the contact area region between indenter (2) and rubber layer (3) with all-sides LED lighting system (4), in position (1) three-axes force sensor is shown (right panel)

Phenomenological model of the indentation with indenter motion simultaneously in normal and tangential directions based on method of dimensionality reduction (MDR) for coated half-space (see [2]) was proposed. Such a model allows to calculate dependencies of normal F_N and tangential F_x forces as well as contact area A vs. time of the experiment (or vs. indentation depth d and tangential shift of the indenter x) for different loading scenarios (A) and (B) (see Fig. 1). The models under several assumptions were considered: case of the motion at constant tangential stresses τ in the contact zone, and situation with using of detachment criterion, as it was proposed in [1].

*This work was supported by Deutsche Forschungsgemeinschaft (Project DFG PO 810-55-3).

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Development of a multilayer coating on the base of TiAlTaSiN: experiment and simulation

A.I. Dmitriev, A.R. Shugurov, Yu.M. Koroteev

Institute of Strength Physics and Materials Science SB RAS, Tomsk

Among the wide variety of protective coatings, coatings based on transition metal ni-trides are most widely used. To date, the most promising are TiAlN coatings doped with addi-tional chemical elements, as well as multilayer compositions, the properties of which effective-ly complement each other. As recent studies have shown [1], one of the most promising alloy-ing elements is Ta, which allows not only to significantly increase the crack resistance of coat-ings, but also to increase the temperature of formation of the wurtzite phase in them, which en-sures the preservation of high hardness of coatings at elevated temperatures. However, such coatings also have certain disadvantages, such as the formation of columnar crystals. Taking into account the available data, a promising direction for improving the properties of coatings based on Ti-Al-N is the simultaneous introduction of Ta and Si, which will make it possible to create coatings with a combination of improved properties characteristic of Ti1-x-yAlxTayN and Ti1-x-yAlxSiyN compositions.

Along with experimental studies, the task of obtaining and studying the mechanical properties of new multicomponent coatings can be significantly accelerated by computer simu-lation. One of the key tasks of building a computer model is to determine the interaction func-tion between the structural elements of the system being modeled. In this work, based on the electron density functional theory, the potentials of interatomic interaction between Si-Ti, Si-Al, Si-Ta and Si-N atoms were calculated. Using the obtained potentials, a molecular dynamics model of the coating was constructed. With the help of MD simulation, the stability of the mod-el to various thermomechanical influences was analyzed. In addition, the concentration of al-loying inclusions of the Ti-Al-Ta-Si-N multicomponent coating was varied in order to predict its optimal composition and structure. A qualitative agreement between the results of modeling and experimental studies is obtained.

This work was supported by the Russian Science Foundation (project code 22-19-00441, https://rscf.ru/project/22-19-00441).

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Mesoscale deformation-induced surface roughening in polycrystalline metals. Experiment and simulation

V.A. Romanova* and R.R. Balokhonov

Institute of Strength Physics and Materials Science (ISPMS), Siberian Branch of the Russian Academy of Sciences (SB RAS), Tomsk, Russia
*varvara@ispms.ru

Deformation-induced surface roughening is a common feature for plastically deformed metals. A large body of experimental observations report that the specimen free surface, flat in the undeformed state, gets rough under plastic deformation though in the absence of external forces. Commonly, surface roughening evolves throughout all length scales from micro to macro with roughness characteristics controlled by many factors, including crystalline structure, grain size, shape and orientations, loading conditions, mechanical properties, etc. This paper reviews the experimental and numerical studies on deformation-induced surface roughening in cast and additively manufactured alloys. A particular consideration is given to the mesoscale where the roughness patterns are formed by grain groups undergoing cooperative out-of-plane surface displacements. A dimensionless roughness parameter is introduced to evaluate the mesoscale roughness patterns and reveal its correlation with local plastic straining. It is shown that the mesoscale roughness can be used as an early precursor of macroscale plastic strain localization and fracture.

Support of Russian Science Foundation through the grant №20-19-00600 (https://rscf.ru/en/project/20-19-00600/) is gratefully acknowledged.

Contact interaction of the underground pipeline with soil under dynamic impacts

Sultanov K.S.

Institute of Mechanics and Seismic Stability of Structures named after M.T. Urazbaev of the Academy of Sciences of the Republic of Uzbekistan

Introduction. The rapid development of underground space and the intensive construction of underground structures in seismically hazardous regions require ensuring their strength under various dynamic impacts. Underground structures, depending on their purpose, have different dimensions, shapes, designs, and other features. External loads on underground structures are divided into static ones (own weight, the weight of the overlying soil, etc.) and dynamic ones (explosive, seismic, vibrational). The strength of underground structures under static loads was sufficiently studied by numerous authors. When determining and evaluating the strength of underground structures under dynamic loads, the main issue is the condition of the contact of the underground structure with the surrounding soil [1, 2]. The simplest underground structure is an embedded main pipeline, which can be modeled as a rod. When the rod is located in a casing of limited or unlimited length, upon impact on the rod, the Amonton-Coulomb law is fulfilled on the contact surface of the rod with the casing. Dynamics of elastic rods with external dry Amonton-Coulomb friction were considered in [3] and fundamental analytical solutions were obtained. In [3], it was experimentally proved that when a shock wave propagates along a rod pressed by an external casing, the Amonton-Coulomb law is fulfilled on the surface of their contact. Numerical solutions for the propagation of shock waves in elastic and viscoelastic composite rods (a rod and a casing), taking into account the nonlinear laws of friction at their contact, were obtained in [4, 5]. In cases of an underground pipeline, when soil acts as a casing, the law of friction between the rod and soil becomes more complicated [6, 7]. Using nonlinear laws at the contact of an underground pipeline with soil, developed on the basis of experimental studies in [6, 7], the longitudinal stresses in an underground pipeline under the action of high-frequency (f=50s-1) seismic waves are determined by numerical calculation [1]. In contrast to cases where the rigidity of the rod and the casing are close, in this case, the longitudinal stresses in the pipeline are many times (50 times or more) greater than the stresses in soil through which the seismic load acts [1]. This is due to significant deformations of soil around the pipeline. However, seismic waves are mostly of low frequency. In this study, having overcome the difficulties arising in the calculations on a computer, the longitudinal stresses in an underground pipeline with external friction are determined by numerical solution of the wave problems posed; external friction is determined by the deformation properties of soil around the pipeline.

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Longitudinal-radial vibrations of a three-layer cylindrical viscoelastic shell, with rigid contacts between layers

Khudoynazarov Kh.

Samarkand State University, Uzbekistan

The longitudinal-radial vibrations of a three-layer cylindrical viscoelastic shell of circular cross-section are considered when there is a hard contact between the layers. The following designations are accepted for nonzero components of displacement w_m, u_m and stress $\sigma_{rr}^{(m)}$, $\sigma_{\theta\theta}^{(m)}$, $\sigma_{zz}^{(m)}$, $\tau_{zr}^{(m)}$, $(m=0,1,2)$. The equations of motion of the points of the viscoelastic shell are taken in the form of wave equations with respect to the potentials of longitudinal – φ_m and transverse – χ_m waves in the layers of the shell

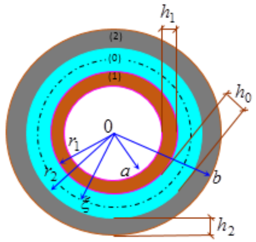

Fig.1. Cross section of the three-layer cylindrical shell

$$\begin{cases} R_m(\Delta_0\varphi_m)=\rho_m\dfrac{\partial^2\varphi_m}{\partial t^2},\ R_m=R_{\lambda_m}+2R_{\mu_m}, \\ R_{\mu_m}(\Delta_0\chi_m)=\rho_m\dfrac{\partial^2\chi_m}{\partial t^2},\ (m=0,1,2),\ a\le r\le r_1, \end{cases} \quad (1)$$

where

$$\Delta_0=\frac{\partial^2}{\partial z^2}+\frac{1}{r}\frac{\partial}{\partial r}+\frac{\partial^2}{\partial r^2};$$

R_{λ_m}, R_{μ_m} - integral operators, defined by formulas

$$R_{(\lambda,\mu)_m}(\varsigma)=(\lambda_m,\mu_m)\left[\varsigma(t)-\int_0^t K_{(\lambda,\mu)_m}(t-\tau)\varsigma(\tau)d\tau\right],$$

here $m=1$, when $a\le r\le r_1$; $m=0$, when $r_1\le r\le r_2$ and $m=2$, when $r_2\le r\le b$ (fig.1).

It is assumed that when $t<0$ the shell was at rest, and at the moment $t=0$ stresses are applied to its inner and outer surfaces, causing longitudinal-radial oscillations, i.e. it is assumed that the boundary conditions have the form

$$\begin{cases} \sigma_{rr}^{(1)}(a,z,t)=F_r^{(1)}(z,t),\ \tau_{rz}^{(1)}(a,z,t)=F_{rz}^{(1)}(z,t),\ at\ r=a, \\ \sigma_{rr}^{(2)}(b,z,t)=F_r^{(2)}(z,t),\ \tau_{rz}^{(2)}(b,z,t)=F_{rz}^{(2)}(z,t),\ at\ r=b. \end{cases} \quad (2)$$

In addition, hard contact conditions must be met on the contact surfaces between the shell layers, which require equal displacements and stresses, i.e. contact conditions have the form

at $r=r_1$, $\quad w_0(r_1,z,t)=w_1(r_1,z,t)$, $\quad u_0(r_1,z,t)=u_1(r_1,z,t)$, $\quad \tau_{rz}^{(0)}(r_1,z,t)=\tau_{rz}^{(1)}(r_1,z,t)$, (3)

at $r=r_2$, $\quad w_0(r_2,z,t)=w_2(r_2,z,t)$, $\quad u_0(r_2,z,t)=u_2(r_2,z,t)$, $\quad \tau_{rz}^{(0)}(r_2,z,t)=\tau_{rz}^{(2)}(r_2,z,t)$ (4)

The initial conditions of the problem are considered zero.

Thus, the problem of longitudinal-radial vibrations of a circular cylindrical three-layer shell made of viscoelastic material, with rigid contacts between layers, is reduced to solving a system of integro–differential equations (1) with boundary – (2), contact - (3), (4) and zero initial conditions at $t=0$

$$\varphi_m=\frac{\partial\varphi_m}{\partial t}=0,\qquad \chi_m=\frac{\partial\chi_m}{\partial t}=0. \quad (5)$$

To solve the problem, the functions of external influences in boundary conditions are considered in the class of functions represented as

$$F_k(z,t) = \int_0^\infty \left.\begin{matrix} \sin kz \\ -\cos kz \end{matrix}\right\} dk \int_{(l)} f_k(k,p) e^{pt} dp, \qquad (6)$$

where $F_k(z,t)$ one of the functions is denoted by $F_r^i(z,t)$, $F_{rz}^{(i)}(z,t)$ и $F_{r\theta}^{(i)}(z,t)$; *(l)* – an open contour in the plane p adjacent to the imaginary axis section $(-i\omega_0, i\omega_0)$ on the right. In addition, the functions $F_r^i(z,t)$, $F_{rz}^{(i)}(z,t)$ and $F_{r\theta}^{(i)}(z,t)$ are assumed to be, that the functions $f_r^{(i)}(z,t)$, $f_{rz}^{(i)}(z,t)$ and $f_{r\theta}^{(i)}(z,t)$ (*i*=1,2) are negligible outside the domain $\{0 < k < k_0, \quad \mathrm{Im}|p| < \omega_0\}$.

A mathematical model of longitudinal-radial vibrations of a three-layer cylindrical viscoelastic shell of circular cross-section, between the layers of which there is a rigid contact, has been developed. General equations of unsteady longitudinal-radial vibrations of a circular cylindrical three-layer viscoelastic shell containing the main parts of longitudinal and radial displacements of points of some intermediate surface of the median layer, which in extreme cases can pass into the inner, outer, median or contact surfaces of the median layer of the shell, are derived. An algorithm for calculating the stress-strain state of an arbitrary point of the shell has been created, consisting of formulas for all nonzero components of the stress tensor and displacement vector, which allow determining the stress-strain state of an arbitrary section of the shell so that the strength characteristics of the materials of the layers and the shell as a whole can be analytically determined. Some approximate and refined equations of longitudinal-radial vibrations of a shell and a round cylindrical rod are given. The limiting and special cases are analyzed.

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A numerical and experimental study on edge effect in non-adhesive and adhesive contacts

Qiang Li

Institute of Mechanics, Technische Universität Berlin, 10623, Germany

The half-space approximation is very often used to solve contact problems in contact mechanics. However, this assumption becomes invalid when the contact area is very close to a sharp edge. Recently, a numerical study on the contact of an elastic quarter-space under a special boundary condition (the so-called freely sliding side) revealed some interesting phenomena, especially in the adhesive contact [1]. In this talk, the contact between a rigid sphere and an elastic quarter-space with a free side is presented and the results are compared with the case in [1]. The numerical simulation of the non-adhesive contact is performed using the Fast-Fourier-Transform-assisted Boundary element method using Hetényi's idea for contact problem of the quarter-space [2]. The dependence of the normal force and mean contact radius on the distance between the center of the indenter and the side edge of the quarter-space is provided. The position of the peak of the pressure distribution is not in the center of indenter (Figure 1).

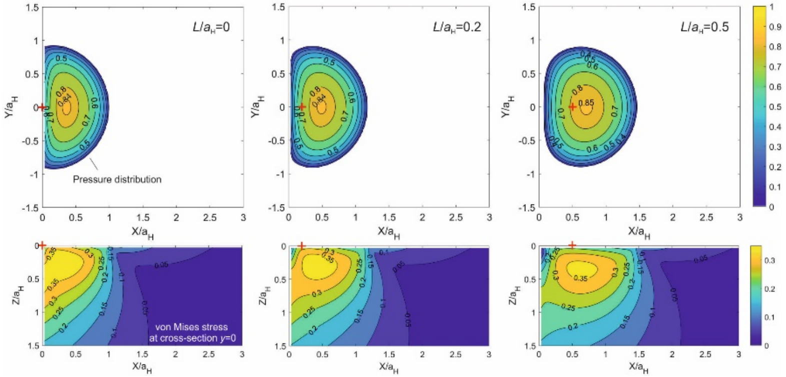

Figure 1 Contact area, pressure distribution and internal von Mises stress in non-adhesive contact between a rigid sphere and an elastic quarter-space for different locations of the indenter from the edge.

The indentation test was also carried out experimentally: a steel ball with diameter 22 mm was indented into a rubber sheet very slowly (at a velocity of 0.01 mm/s). Two rubber materials with different adhesion properties were used for non-adhesive and adhesive indentation tests, respectively. The dependence of the normal force and contact area on the indenter position is presented in the talk.

Keywords: Adhesion; Contact Mechanics; Edge effect; Quarter-space

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A General Approximate Solution for the Slightly Non-Axisymmetric Normal Contact Problem of Layered and Graded Elastic Materials

Fabian Forsbach, Emanuel Willert

Institute of Mechanics, Technische Universität Berlin, Germany
Sekr. C8-4, Straße des 17. Juni 135, 10623 Berlin, e.willert@tu-berlin.de

Contact mechanics of layered and functionally graded elastic materials have received a lot of interest in the framework of modelling tribological properties of, for example, articular cartilage, coatings, biomaterials, or soil. As the – either discrete or continuous – material inhomogeneity severely complicates (or, to put it bluntly, apart from some special cases like the power-law graded elastic half-space, inhibits) an exact closed-form solution of corresponding contact problems, analytical contact solutions of layered materials are often in approximate or asymptotic form. Because of the approximate character of these solutions, their predictions should always be checked against the results of rigorous numerical simulations, a step, which was simplified massively recently for the case of a single elastic layer, with the publication of a boundary element method (BEM) formulation of the corresponding normal contact problem.

An ingenious principle to solve contact problems stems from Mossakovski and later Jäger. It is based on the observation that the incremental difference between two subsequent contact configurations can be understood as an infinitesimal indentation by a flat punch. Hence, the general normal contact can be thought of as a series of incremental flat punch indentations, and therefore, the solution procedure is split into two tasks: the determination of the relation between indentation depth and contact region (which encodes the correct series of flat punches to exactly reproduce the original contact), and the solution of the corresponding flat punch problems.

For the case of axisymmetric indentation of an elastic half-space, both tasks are easily solvable, which leads to the famous solution that is often attributed to Sneddon, although it originated a lot earlier. Very recently, Popov published an approximate analytical solution for the slightly non-axisymmetric version of this contact problem, which has proven (by comparison with rigorous numerical solutions) to give very satisfactory results even for contact geometries that are far from axial symmetry. Popov's solution rests on two fundaments: On the one hand, Barber's extremal principle that the correct contact region at a given indentation depth maximizes the corresponding total normal force; and, on the other hand, Fabrikant's approximation for the pressure distribution under a flat punch of arbitrary (compact) planform.

As we will show, Barber's principle applies to any elastic normal contact problem (at least, with compact contact regions), which can be thought of as a series of flat punch indentations. Moreover, the "essence" of Fabrikant's approximation is to "scale" the axisymmetric pressure distribution under a cylindrical flat punch to the asymmetric arbitrary planform; a procedure which also can be executed very generally, if the indented material is sufficiently isotropic. Hence, both fundaments of Popov's approximate solution for the homogeneous half-space can be generalized for layered or functionally graded materials (albeit in a slightly less rigorous sense, as will be discussed in the talk), and it is thus expected that the solution itself can be generalized for the application with layered media, as well. This is the topic of the talk.

The obtained approximate solution is, of course, compared to rigorous BEM-based numerical results.

Mechanical response of layered structures with internal Layers from metamaterials to dynamic loadings

Vladimi rA. Skripnyak, Maxim O. Chirkov, Evgeniya G. Skripnyak, VladimirV. Skripnyak

National Research Tomsk State University, Tomsk, Russia

The article presents the results of the analysis multilayered structures with metamaterials elements under dynamic loading. These structures can be used in lightweight structures for various purposes in transport and aerospace techniques. Structural elements with layers of the mechanical metamaterials have a low specific gravity and high specific characteristics of strength and rigidity. Multilayer structures with internal layers of metamaterials have a high specific ability to absorb and dissipate the energy of external dynamic loads too.

The results of numerical simulation of multilayer structures response to dynamic impacts obtaining in this work indicate a nonlinear increase in the specific dissipated energy of multilayer structures made of light alloys with layers of an auxetic metamaterials with an increase in the relative amplitude of deflections of structural elements.

Numerical simulation of the multilayer structures response to dynamic impacts was performed in the LS DYNA environment using the original UMAT module, which implements the constitutive equations describing the elastic-plastic behavior and damage of light aluminum and titanium alloys in a wide range of strain rates, temperatures, taking into account the influence of complex stress states.

It is shown that parameters of metamaterials structure affect the mechanical response and energy absorption characteristics of the multilayer structure.

Depending on the amplitude and duration of impulse loading, two modes of deformation of the metamaterials are possible: with contact between structural elements of metamaterials and without contact.

At the first mode the increase in the absorbed mechanical energy of multilayer structures with a middle layer of metamaterials under dynamic loading is determined mainly by the work of equivalent shear stresses at plastic strains taking place under deflection of metamaterials structural elements. In the second mode, dissipative properties are depended by friction between the interacting structural elements of the metamaterials.

The considered multilayer panels with a layers of auxetic metamaterials have 3.5 times higher energy absorption rates compared to light alloy frame structures with equivalent mass density. The results obtained indicate the possibility of creating effective mechanical damping structures.

This work was supported by the Russian Science Foundation (project code 23-29-00349).

Simulation of deformation and fracture of alpha titanium alloys under dynamic punching

Vladimir V. Skripnyak, Kristina V. Iohim, Vladimir A. Skripnyak

National Research Tomsk State University, Tomsk, Russia

The results of original experimental and numerical simulation studies of deformation and fracture of titanium alloys under tension at strain rates from 0.1 to 1000 s^{-1}, as well as during impact punching of plates by a hemispherical punch at rates from 0.0003 to 15 m/s are presented in this work. Tests titanium alloys at constant punching speed were carried out on an Instron VHS 40/50-20 high speed test bench (Instron, High Wycombe, UK) with a 50 kN load cell. Tensile forces and displacements were recorded up to the destruction of the sample with a high time resolution.

The regularities of deformation and damage accumulation were investigated using numerical simulation. The use of the developed physical and mathematical model made it possible to describe the patterns of plastic flow and fracture of the Ti-5Al-2.5Sn and CP Ti alloys in a wide range of strain rates in a biaxial stress-strain state.

The results of simulation obtained of the deformation of the samples, including the forms of cracks and deflections during punching, are consistent with the experimental data. It has been established that the dynamic punching test makes it possible to investigate the kinetics of fracture under complex stress states. The research results showed that under conditions of quasi-static tension in titanium alloys, the limiting strain to failure decreases monotonically with an increase in the triaxiality parameter of the stressed state. The maximum values of the principal plastic strains in the crack zone of fractured plates made of titanium alloy Ti-5Al-2.5Sn significantly exceeded the values of macroscopic elongation δ known in the literature. High local equivalent strains can be realized in thin alpha titanium plates with relatively small deflections during dynamic stamping. The spatial distribution of damage and the shape of the crack in a thin sheet of alpha titanium alloy during stamping are significantly affected by the speed of the punch. An increase in the strain rate under conditions of a biaxial stress-strain state promotes the formation of localized shear bands and the initiation of damage in the titanium alloy. The stress triaxiality parameter in the punching zone of titanium alloy plates changes non-stationary and spatially inhomogeneously with the development of deformation and damage.

The results obtained supplement the results of the studies previously performed by the authors of the patterns of tensile strain at high strain rates of alpha and alpha + beta titanium alloys at a temperature of 295 K.

The results presented in this paper can be used to develop computational methods and models of increased accuracy and adequacy for their inclusion in modern computer-aided design systems for modern lightweight and reliable structures from alpha titanium alloys in various industries, sports and medicine.

This work was supported by the Russian Science Foundation (project code 22-79-00162).

In Silico Analysis of an Articular Cartilage Regenerative Rehabilitation under Conditions of Mesenchymal Stem Cells Implantation and Their Mechanical Stimulation

Aleksandr M. Poliakov
a.m.poljakov@sevsu.ru

Vladimir I. Pakhaliuk
pahaluk@sevsu.ru

Laboratory of Biomechanics, Sevastopol State University, Sevastopol, Russian Federation

One of the most important tasks of modern medicine is to develop effective technologies for the treatment of joint diseases caused by damage of an articular cartilage. The results of experimental studies and a number of successful clinical practices indicate that its solution can be found within the framework of a new medical direction - regenerative rehabilitation, which synergistically combines methods of regenerative and rehabilitation medicine. In particular, the regenerative rehabilitation of articular cartilage defects involves the use of cellular technologies, the effectiveness of which is enhanced by mechanical stimulation of chondrogenic cells, which accelerates their proliferation, differentiation, and the formation of an extracellular matrix. Simulation results indicate that its outcome depends not only on the set of parameters determined by the state of the tissue in the area of the defect, but also on their combination.

One of the main aim of this work is to find the best combination of parameter values that are practically achievable in the process of regenerative rehabilitation of articular cartilage using cellular technologies and mechanical stimulation of cells. Its solution is based on the study of a mathematical model of regenerative tissue rehabilitation, the combination of state parameters of which are determined by the Sobol-Statnikov method, based on a systematic study of parameters space uniformly distributed in multidimensional cube. The practical significance of work results lies in the fact that they can be used to evaluate the effectiveness of various methods of mechanical stimulation of articular cartilage defects in the process of regenerative rehabilitation.

Keywords: Articular cartilage, osteoarthritis, stem cell implantation, mechanical cell stimulation, regenerative rehabilitation, mathematical model

Simulation of bone tissues at their contact with a dental implant under shock wave treatment

Smolin A.Yu., Eremina G.M., Martyshina I.P.

Institute of Strength Physics and Materials Science SB RAS, 634055, Tomsk, Russia

Dental implants are becoming an increasingly important part of contemporary dental treatment. The longest and most important stage in the installation of an implant is its osseointegration. Improvements in osseointegration are now achieved by modifying the implant surface. Promising to increase the rate of osseointegration is the use of external shock wave (SW) therapy, which has proven itself for the treatment of fractures, bone defects, and bone tissue regeneration in surgery and arthroplasty. For proper development of the corresponding treatment method, it is required to completely understand the mechanical stresses that form in the bone tissues under shock waves of different intensities, including the regions of contact of the bone with a metallic implant.

Therapeutic treatment methods are mainly being investigated in vivo in experimental animals. An alternative to the experiment is computer simulation (in silico studies). This work aims at a multiscale numerical investigation of the effects of low-energy shock wave therapy of various ranges on the mechanical behavior of bone tissues. Modeling was carried out using the method of movable cellular automata. The advantage of this method is the possibility of explicit consideration the structural features of heterogeneous materials, as well as the processes of damage initiation and development. The bone porosity and interstitial fluid in the pores are taken into consideration implicitly based on the Biot model of poroelasticity in this study.

First, the mechanical behavior of the jaw segment with an implant was investigated, taking into account the different geometry of the interface between the implant and bone tissue. Numerical calculations allowed us to determine the range of SW loading when a certain level of pressure is observed in the model samples, at which differentiation of bone tissue (osteocyte formation) occurs. Then a micromodel of the osteon as the structural unit of bone tissue was developed. The previously obtained range of SW loading was used to conduct microlevel numerical studies of shock wave loading on osteon. The results obtained are compared with the literature data on finite element analysis of uniaxial compression for a similar model. Finally, the features of stress and strain fields in tissues were determined, which allowed assessing the possibility of accelerated osseointegration of the implant.

Acknowledgments. The investigation has been carried out with the financial support of the Russian Science Foundation, grant No. 23-29-00212.

Keywords: dental implant; contact region; osseointegration; bone tissue; osteon; shock-wave therapy

Experimental determination of the Amonton-Coulomb dynamic coefficient of dry friction

Ibrakhim Mirzaev[1], Khamidulla Sagdiev[2], Anvar Yuvmitov[2], Malikjon Turdiev[1] and Bakhtiyor Egamberdiyev[3]

[1] Tashkent State Transport University, Republic of Uzbekistan, Odilhojaev str., 1, 100167, Tashkent, Uzbekistan
[2] Institute of Mechanics and Seismic Stability of Structures named after M.T. Urazbaev of the Academy of Science of the Republic of Uzbekistan, Durmon yuli str., 31, 100125, Tashkent, Uzbekistan
[3] Fergana Polytechnic Institute, Fergana str., 86, 150107, Fergana, Uzbekistan
E-mail: ibrakhim.mirzaev@gmail.com

The aim of the study is to experimentally determine the dynamic coefficient of dry friction between different materials. The seismic isolation of buildings and structures using the principle of dry friction between the grillage and the foundation gives reasonably good results. A measuring complex with corresponding strain gauge channels was organized between the foundation and grillage, simulated by two masses, on a laboratory single-component shaking table to record relative and absolute displacements. A theoretical solution to this nonlinear problem was developed, with the additional use of a special logic algorithm to determine the direction of the dry friction force between the masses. The logical algorithm determines the beginning of upper mass sliding relative to lower mass, as well as the beginning of their joint motion. Numerical calculations were performed with a time step of 0.0001 seconds. The effect of values of material masses and properties of cushioning materials between the masses on the oscillation process and on the value of the dynamic coefficient of dry friction was analyzed. The value of the dynamic coefficient of dry friction was determined by comparing the numerical solution to the problem with the records of experiments using the method of selecting the value of the dry friction coefficient.

The values of masses were changed in the experiment, the tests were conducted with steel-to-steel contact surface treatment and a separate version with contact surface lubrication, with cushions fluoroplastic 4 - fluoroplastic 4. Changing the upper mass by a factor of 4 had no effect on the value of the dynamic coefficient of dry friction. The maximum velocity of the platform in the experiments varied from 0.18 m/s to 0.4 m/s, which corresponds to a magnitude of a 9-point earthquake on the MSK-64 scale, while the calculated dynamic coefficient of dry friction varied by up to 10%. In all experiments, the values of the dynamic coefficient of dry friction were more than two times less when compared to its static value.

Effect of pulsed electron beam irradiation on the microstructure, mechanical and tribological properties of Ni_3Al-TiC composite

G. Purcek[1,], M. Demirtas[2], H. Yanar[1], K.V. Ivanov[3], V.E. Ovcharenko[3]

[1)] Department of Mechanical Engineering, Karadeniz Technical University, Trabzon, 61080, Turkey
[2)] Department of Mechanical Engineering, Recep Tayyip Erdogan University, Rize, 53100, Turkey
[3]Inst. of Strength Phys. and Mat. Sci, Siberian Branch of Russian Academy of Sci, 634055, Tomsk, Russia
E-mail: purcek@ktu.edu.tr

Effect of pulsed electron beam irradiation (PEBI) on microstructure and high temperature tribological behavior of Ni_3Al-15vol.%TiC composite was investigated. PEBI results in structural alterations and phase transformations in the near-surface layer of the composite. The coarse Ni_3Al grains and TiC particles are refined down to some tens of nanometers in the near surface layer of about 1 μm in depth. The microstructural alteration results in an increase in high temperature wear resistance of that composite. The initial results demonstrate that PEBI technique may be one of effective ways to enhance surface properties and wear resistance of the Ni_3Al-TiC composite.

Keywords: Pulsed electron beam irradiation, surface modification, Ni_3Al-TiC composite, tribological properties.

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Study of tribotechnical properties of filled polymeric composite materials

T.O. Almataev-professor, S.A. Yusupov, N.T. Almataev, Kh.R. Odilov - doctoral students, Andijan Machine-Building Institute, Uzbekistan.
M. F.Wani – HAG Professor of NIT, Sirinagar, India,

In this work, the effect of the filler content in polypropylene on its impact strength and relative elongation, the change in the coefficient of friction and wear depending on the friction modes, as well as the effect of surface roughness on the coefficient of friction and wear of local filled polypropylene composite materials for machine-building purposes were studied.

Keywords: filler, viscosity, elongation, coefficient of friction, wear, surface roughness, material.

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A numerical-experimental analysis of deformation and fracture in an Al-Si alloy fabricated by electron beam wire-feed additive manufacturing

R.R. Balokhonov* and V.A. Romanova

Institute of Strength Physics and Materials Science (ISPMS), Siberian Branch of the Russian Academy of Sciences (SB RAS), Tomsk, Russia
*rusy@ispms.ru

Two-scale numerical-experimental study of deformation and fracture of an AlSi12% alloy additively fabricated by layer-by-layer electron-beam melting of a wire has been carried out. Using the methods of transmission and scanning electron microscopy, we experimentally demonstrated that this alloy can be presented as a two-level composite material. At the level of tens of microns (Level 1), individual aluminum dendrites surrounded by the eutectic network are observed. The eutectic material at the micron level (Level 2) represents separate silicon particles of a variety of shapes distributed in the aluminum matrix. In accordance with the experimental data, model structures of aluminum– silicon composite were generated at Levels 1 and 2, and a two-level numerical modeling of deformation and fracture of the AlSi12 alloy was performed. In order to identify the role of residual stresses caused by cooling (RS), two loading scenarios were considered: M – tension and TM – tension after cooling. At Level 2, it has been shown that after cooling of the composite silicon particles are entirely subjected to bulk compressive stresses, while the matrix is experiencing both bulk compression and tension. The higher the volume fraction of silicon particles, the larger the value of compressive stresses in the particles and tensile stresses in the matrix, and the earlier the main crack forms in the composite during its tension.

Using spatial averaging, the effective thermo-elastic-plastic properties of the aluminum–silicon composites and their fracture characteristics have been determined and used as the eutectic material properties at Level 1 for investigating the thermomechanical deformation and fracture of composites with different volume fractions of dendrites (VFD). It has been found out that during cooling of the composites the aluminum dendrites experience bulk tension, while the eutectic matrix undergoes both bulk tension and compression. Fracture occurs in the eutectic network of the dendritic structures, where the main crack propagates along the dendrite boundaries at an angle of 60 degrees to the loading application direction. The residual stresses (RSs) change the plastic strain localization behavior and detrimentally affect the macroscopic strength of the composites subjected to tension. With increasing VFD the crack develops earlier in the M case and later in the TM case, which is due to nonlinear accumulation of localized plastic strain in the TM case.

The work was supported by the Russian Science Foundation (grant № 23-11-00222, https://rscf.ru/en/project/23-11-00222/).

Structural-energy evolution of friction contact, elementary tribosystem and mechanical (nano) quantum.

Sergey Vasiliy Fedorov

Kaliningrad State Technical University,
fedorov@klgtu.ru Sovetsky Prospect, 1, Kaliningrad 236022, Russia

Modern mechanical-mathematical and physical-materials science approaches as equal in the analysis of general problems of deformed solids very often work separately. At the same time, their interaction is necessary, for example, in Tribology, a recognized interdisciplinary field of knowledge. In this direction, it is advisable and fruitful to apply comprehensive approaches that can bring the two mentioned above closer together. For example, these are approaches based on the most general laws of thermodynamics of irreversible processes, molecular kinetics (thermal activation analysis) and the theory of dislocations in their mutual connection on the basis of the most general law of nature – the law of conservation of energy during its transformations. Naturally, here we consider friction as a global phenomenon of nature – the phenomenon of transformation and energy dissipation of the external relative motion of rubbing surfaces.

We can confidently consider the mechanisms of elastic-plastic deformation and destruction of solids as the main channel of transformation and energy dissipation during friction.

Briefly theses.

Structural-energy interpretation of plastically deformable rubbing surfaces.

The equation of the energy balance of the friction process.

Competitive, adaptive-dissipative nature of the friction process.

Structural-energy interpretation of the coefficient of friction.

Generalized experimental friction curves.

Structural-energy diagram of the evolution of rubbing surfaces (friction contact).

The critical volume of friction is an elementary tribosystem.

Structural transformation of an elementary tribosystem.

Dynamic dissipative friction structures («third body»).

Elastic symmetry of the most complete evolution of the friction contact.

A mechanical (nano) quantum is an elementary tribosubsystem.

Energy potentials of an elementary tribosystem and a mechanical quantum.

The diversity and semantic metamorphoses of the mechanical (nano) quantum.

Mathematical model and analytical solution of the contact problem on the bending of a plate laying on a nonhomogeneous combined base

Kazokboy Mamasoliev[1], Mirziyod Mirsaidov[2],

[1] Samarkand State University of Architecture and Construction;
[2] National Research University - Tashkent University of Irrigation and Agricultural Mechanization Engineers;
[3] Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan.

A mathematical model, an analytical method for solving the problem, as well as a method for estimating internal force factors that arise in a slab-strip lying on an inhomogeneous elastic combined half-space and loaded with various external loads are proposed. In the mathematical modeling of the problem, a beam slab with a width equal to one, cut from the slab-strip, is considered. A half-space is taken as an inhomogeneous base, the modulus of elasticity of which varies according to a power law. In this case, the bending of the beam slab, which depends on the external load and the reactive pressure of the base, are presented in the form of a fourth-order differential equation. To determine the settlement of an inhomogeneous combined base, depending on the reactive pressure of the base, the hypothesis of I.Ya. Shtaerman, which is represented as a singular integral equation. The relationship between the slab and the combined base, i.e. contact conditions, is presented in the form of identical equalities of deflections of the slab and settlement of the base. The obtained resolving system of equations of the problem forms a closed system. For the kernel of the singular integral, which describes the subsidence of the base, "P-kernels" are used on a finite interval, proposed by G.Ya. Popov. When solving the problem, the method of degenerate kernels was used. Based on the method of degenerate kernels, the solution of the problem is reduced to the study of a system of infinite algebraic equations with an infinite number of unknowns. The regularity of the obtained system of equations is investigated. With the help of numerical calculations, the influence of an inhomogeneous combined base on the internal forces arising in the slab was evaluated.

Hardening of the surface layer of X20Cr13 steel by alloying with WC-Co tool material through friction stir processing

V.P. Kuznetsov, I.A. Vorontsov, M.S. Karabanalov, M.S. Khadyev

Ural Federal University, Yekaterinburg, Russia

Friction stir processing (FSP) of steels and alloys is a method of surface layer hardening using a rotating tool. The main technological parameters of FSP are the rotation frequency and linear velocity of the tool, the applied normal force and the geometry of the tool. The normal force, rotation speed and tool displacement determine the coefficient of friction and the amount of frictional heat generated during FSP.

A promising direction for developing the FSP method is the surface alloying and creation of surface composites by transferring the material of the tool. Great opportunities for implementing these methods are opened when processing the surfaces of parts in modern machining centers and using cemented carbide cylindrical tool with a flat or spherical end.

In this work, the regularities of the change in the structure and phase composition of X20Cr13 steel in the delivery condition (180 HB) after FSP by a cemented carbide tool were studied. FSP was carried out on surfaces of X20Cr13 steel samples with a thickness of 25 mm using a WC-Co cylindrical tool (10%), with a hemisphere-shaped working part with a radius of 10 mm on the Okuma MA-600 machine tool center. The normal force was 3000 N, tool rotation speed 2500 rpm, and feed 50, 75 and 125 mm/min.

It was found that during FSP tungsten transfers to the surface of the steel in the form of W_2C particles, forming a laminated composite structure with different amounts of tungsten in each layer. Three strengthening zones are identified for each of the processing modes. In the areas with high tungsten content, the microhardness is higher than in areas with low tungsten content. A maximum microhardness of 771 $HV_{0.05}$ was achieved at a feed rate of 50 mm/min, and a maximum depth of 610 μm strengthening of the surface layer is characteristic for the feed rate of 75 mm/min. Based on analysis of bright-field TEM images, the average size of the tungsten carbide particles was determined to be 350 ± 20 nm. The martensitic grain size is between 1.5 and 1.7 μm.

Theoretical justification of deformation process and the soil movement in the area affected on chisel plow

Abdurakhim Yuldashev[1], Davronbek Kuldoshev[1,2], Nargiza Djuraeva[1], Aziz Urinov[1], Musallam Mirzaeva[1]

[1] Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
[2] E-Mail: don_02@mail.ru

This article provides analytical and numerical calculation of soil movement in the zone of chisel plow influence. A model of compressible plastic medium was chosen from the Coulomb-Mohr plasticity condition for describing the dynamic of cultivated soil. Based on the calculations performed using this model, it was established that the value of the contact force of interaction depends on the chosen model of the soil environment and the shape of the chisel plow. The resistance force of the soil medium was determined when interacting with a chisel plow in the form of a thin circular cone. The results of numerical calculations confirmed that the magnitude of this force significantly depends on the properties of the soil, the type of contact conditions between the body and the soil, and with an increase in the coefficient of internal friction, the soil resistance force noticeably increases.

Keywords: tillage machine; chisel plow; actuating tool; deformation; modeling; soil resistance; model of a compressible plastic medium.

Magnetoelastic deformation of nonferromagnetic thin plates in a nonstationary magnetic field

Indiaminov Ravshan[1], Narkulov Akram[1], Abdullaev Abdubakir[2], Butaev Ruslan[3], Shodmonov Javohir[4]

1Samarkand branch of the Tashkent University of Information Technologies, Samarkand, Uzbekistan
2Tashkent University of Information Technologies, Tashkent, Uzbekistan
3 Jizzakh State Pedagogical Universities, Jizzakh, Uzbekistan
4 Kattakurgan branch of Samarkand State University, Kattakurgan, Uzbekistan

When a conductive body moves in a magnetic field or when the magnetic field changes with time, induced eddy currents and the non-stationary ponderomotive forces caused by them arise in the body; this, in turn, is accompanied by deformation of the medium and the initiation of stress waves. Non-stationary ponderomotive forces change the stress-strain state of a conductive body and its electromagnetic field. The motion of an elastic medium in a magnetic field is described by a joint system of equations of electrodynamics of a slowly moving medium and equations of the dynamic theory of elasticity, taking into account the ponderomotive forces. This system of equations is non-linear due to the nonlinearity of the relations of the generalized Ohm's law and expressions for ponderomotive forces. Mathematical simulation of the magnetoelastic oscillations of non-ferromagnetic annular plates under the influence of non-stationary electromagnetic forces and mechanical loads is considered in the article, taking into account electric currents. Numerical results are obtained and an analysis is made of the electromagnetic effects of the stress-strain state of non-ferromagnetic annular plates considering geometric nonlinearity and electromagnetic anisotropy.

Keywords: plate, shell, deformation, stresses, electromagnetic field, magnetoelasticity, electromagnetic anisotropy.

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On strength of materials with initial crack

Abirov R.A.

Institute of mechanics and earthquake engineering, Tashkent, Uzbekistan

The stress and strain state of continua with the presence of stress concentrators or initial cracks has a great interest. The description of singularities near the crack tip is most conveniently can be described by boundary integral equations approach.

One of the varieties of this method is the method of discontinuous displacements. This method is based on the analytical solution of the problem of an infinite plane, displacements in which suffer a constant discontinuity. Physically, the displacement gap is represented as a crack, the opposite sides of which are displaced relative to each other.

Here is using the fundamental solution reached on the base of unit discontinuity in infinite body by Papkovich - Neuber potentials solution.

The numerical implementation assumes that discontinuities of displacements continuously distributed along the crack can be replaced by a discrete approximation. Knowing the analytical solution for one constant discontinuity of displacements, and summing up the influence of all elements (into which the body is divided), a numerical solution is found.

The calculation according to incremental plasticity (Prandtl-Reuss) and Il'yushin's deformation theory of plasticity was carried out in this issue.

Diffusive mass transfer in porous media during in-situ gas generation

Geylani M. Panahov, Eldar M. Abbasov , Ibrahim J. Mammadov

Institute of Mathematics and Mechanics
Ministry of Science and Education of Azerbaijan Republic

Thermobaric conditions significantly affect the flow of gas-liquid flows considering the processes of interphase exchanges in fluid-saturated media. These processes are mutually influential and affect the flow, stimulating unsteady mass transfer (Abbasov, A. Bakhtiyarov, S. Bakhtiyarov, Omrani and Panakhov, 2010) (Manyrin and Shvetsov, 2000). The present work investigates the phenomena of gas transfer process in the porous medium. It is known that in solutions that react to form gas, the pressure dynamics of gas separation monotonically increases at different rates depending on the fluids characteristics (Abbasov, Jiang, Panahov and Shakhverdiev, 2022) (Bakhtizin, Mirzajanzadeh and Hasanov, 1999). Pressure dynamics in the presence of porous medium and saturating fluids has a monotonic character, accompanied by pressure decrease at the final stage. In this case, the pressure change during the formation of gas bubbles is written in the form of the following kinetic equation: $\frac{dP}{dt} = a_1 - a_2 P(t) - a_3 P^2 (t-\tau)$, where a_2 and a_3 coefficients, taking into account the gas dissolved in the liquid and gas nucleates, which have already formed and diffused; τ - characteristic moment of diffusion. We can write the diffusion equation as: $D \sim \frac{1}{\sigma n}\sqrt{\frac{T}{\mu}} \sim \frac{T^{\frac{3}{2}}}{\sigma P \sqrt{\mu}}$.

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Impact of heat removal from the sliding indenter contact zone on the coefficient of friction and structure formation during the nanostructuring burnishing of X20Cr13 steel

V.P. Kuznetsov, A.S. Skorobogatov, G.S. Anisimova

Ural Federal University, Yekaterinburg, Russia

Nanostructuring burnishing is a finishing technology of frictional surface treatment with a sliding indenter, which ensures the formation of a nanocrystalline structure in a thin surface layer due to severe plastic shear deformation of the material. In the process of nanostructuring burnishing, a number of kinematic schemes of the workpiece and tool movement are implemented, ensuring the development of consecutive (in time) and perpendicular (in the direction) effects of contact forces on the compressional mesovolumes of the surface layer material. However, due to the high tribological load on the tool and the surface layer, local heating of the contact zone occurs, which leads to loss of process stability and destruction of the treated surface. As a result of significant local heating, a permissible sliding speed of the indenter is significantly limited and cannot exceed 14 m/min when processing X20Cr13 steel. To overcome this limitation, a cooling system based on the Peltier thermoelectric modules has been developed, which provides circulation of low-temperature liquid in the inner cavity of the indenter and heat removal from the contact zone.

Application of the heat removal system can significantly increase a permissible sliding speed of the indenter and surface treatment performance. In order to determine the effect of tool cooling and increase of the sliding indenter speed on the coefficient of friction, microstructure and properties of the surface layer, the tribological studies of nanostructuring burnishing under dry processing conditions were performed. A composite sample of the ‘disk’ type made of X20Cr13 (45...46 HRC) heat-strengthened steel was processed with an indenter made of polycrystalline synthetic diamond with a hemispherical working part with a radius of 2 mm at a normal load of 340 N. A three-axis dynamometer KISTLER 9276B was used to measure the reaction forces in the contact zone. The temperature measurement in the contact zone was performed using a semi-artificial thermocouple located in the composite sample. The sliding speed of the indenter varied in the range from 6 to 20 m/min during processing without cooling and from 20 to 80 m/min with heat removal from the indenter contact zone. The heat removal system operated in two modes: the first ensured that the temperature of the coolant inside the indenter was maintained within +10...12 °C; the second – from −2 to 0 °C.

The application of the cooling system helps to stabilize the coefficient of friction at higher sliding speeds than those available without cooling. The most stable friction characteristic occurs while processing with an active cooling system operating in the second mode. Tool cooling also contributes to structure formation process stabilization at high sliding speeds of the indenter. While without cooling at the sliding speed of the indenter 20 m/min, local destruction of the surface layer occurs, nanostructuring burnishing with active cooling of the tool ensures stable formation of the nanostructured layer up to 50 m/min.

Analysis of power spectrum density for controlling a multi-transition finishing of frictional surfaces by burnishing and micro cavities deformation

V.P. Kuznetsov [1], I.V. Tatarintsev [2], A.V. Korelin [1]

[1] Ural Federal University, Yekaterinburg, Russia

[2] Kurgan State University, Kurgan, Russia

The problem of increase of wear resistance of precision surfaces of tribological assembly parts remains relevant. This problem can be resolved by controlling modes of mechanical finishing processes that provide for the decrease of roughness and the increase of surface micro hardness. Moreover, it is possible to employ additional operations or transitions of multipurpose finishing to increase the oil absorption power of the surface.

A multi-transition technology of final finishing which includes fine turning, preliminary burnishing, deformation profiling of lubricating micro cavities by a plateau-honing stone and further finishing and hardening burnishing was developed to create a flat-topped micro pattern with oil-retaining cavities on external surfaces of shafts made of AISI 420 steel (51 HRC).

This paper presents a new approach to determining the influence of amplitude and periodicity of original surface microprofile protrusions and cavities obtained by final turning and formed by deformation profiling using the value of power spectrum density (PSD).

The surface microprofile was determined using a WYKO NT-1100 3D profilometer. According to the PSD graph, the microprofile is dominated by protrusions and cavities with a periodicity of 0.0517 mm, which corresponds to finish turning feed. The microprofile was not smoothed due to the insufficiency of the specified indenter pressure force which was 135 N.

Deformation profiling of micro cavities by a plateau-honing stone resulted in the appearance of multiple regular micro pattern elements with different periodicity values on the surface of the workpiece. The data shows the presence of recurring protrusions and cavities after a deformation profiling by a plateau-honing stone with a period of 1.021 mm. However, also present are elements of the file with a period of 0.0517 mm, characteristic of final turning.

After the final transition of flat-topped microprofile formation, multiple regular protrusion and cavity elements corresponding to different wavelengths are revealed on the treated surface.

In conclusion, the application of the PSD method allowed to establish the necessity of the increase of the preliminary burnishing normal force to 200 N, in order to exclude the impact of final turning on the formation of a flat-topped micro pattern. However, the mode of plateau-honing stone application with 150 N force is selected correctly due to the resulting formation of lubricating micro cavities with the interval of 1.021 mm and the depth of 4...5 μm.

Effect of geometric features on the stress state of unidirectional composites

Askhad Polatov[a)], Akhmat Ikramov[b)]

Department of Algorithms and Programming Technologies, Faculty of Applied Mathematics and Intelligent Technologies, National University of Uzbekistan, Tashkent, Uzbekistan

[a)] Corresponding author: asad3@yandex.ru, [b)] axmad3@yandex.ru

Various ways to reduce the stress concentration factor by establishing reinforcing holes are considered in the article; it provides a study of the effect of the configuration of a hole on the physically nonlinear deformation of a structure made of boron/aluminum. A structural-phenomenological model is used to describe the anisotropy of the mechanical properties of fibrous materials; this model makes it possible to represent the initial material as a complex of two jointly operating isotropic materials: the base material, considered from the point of continuum mechanics, and the material of fibers oriented along the direction of anisotropy of the base material. It is assumed that the parallel fibers are subjected to only axial tension-compression forces and are deformed with the base material. To calculate the effective mechanical parameters of fibrous materials, the authors used relationships that account for the internal structure of the material when calculating periodically non-homogeneous materials based on the asymptotic averaging method and are appropriate for any property values and volume fractions of components. A computational experiment was conducted to study the effect of two vertical holes and the effect of the size ratio of an elliptical hole and a horizontal crack on the stress-strain state of boron/aluminum in the vicinity of concentrators. It was established that an additional hole causes an increase in stresses; however, the mutual influence of the holes reduces the overall stress state in the vicinity of concentrators. The location of the areas with the maximum values of shear stresses, where the separation of high-strength fibers from the matrix is possible, was determined. It is shown that the presence of an elastoplastic matrix creates conditions for the joint operation of the fibers and matrix, providing the loading of high-strength fibers.

Keywords: stress, boron/aluminum, fiber, influence, interference, effective parameters, hole, FEM.

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The Steel dephosphorization process research for railway castings in an induction crucible furnace

Nodirjon Tursunov

Head of the Materials Science and Mechanical Engineering Department. Tashkent State Transport University (Tashkent, Uzbekistan), u_nadir@mail.ru

The process of dephosphorization of steel using solid slag-forming mixtures was carried out in an induction crucible furnace with a capacity of 6 tons. 20GL grade steel was used as the test metal. The quantitative dependences of the metal dephosphorization process technological parameters are obtained, which form the basis of a new technological instruction for the production of steel for railway transport castings in an induction crucible furnace (ICF). A thermodynamic analysis of the dephosphorization process was carried out to evaluate the experimental results obtained on the phosphorus content in steel under slag in the ICF, depending on the bath temperature.

Keywords: induction crucible furnace, steel dephosphorization, basicity, slag oxidation, metal temperature, solid slag-forming mixtures, phosphorus distribution coefficient.

Non-stationary vibrations of a thick-wall elastic spherical shell in acoustic half-space

Shukurov A.M.

Karshi State University, Karshi, Uzbekistan
shukurovamon@yandex.ru

The tasks related to the problems of modeling and studying nonstationary wave processes in continuous media, as well as the interaction of deformable bodies with the environment, are relevant and are of practical and theoretical interest. The relevance of the problems of the dynamics of continuous media is due to the development of various fields of technology, the creation of new structures operating under dynamic loads, as well as the problems of aircraft construction, shipbuilding and many others. Various issues related to the interaction of deformable bodies with the environment are described in scientific papers [1, 2, 3] and others. This work is devoted to the study of the problem of non-stationary oscillations of a thick-walled elastic spherical shell in an acoustic half-space. The aim of the work is to develop an algorithm for solving the problem and study non-stationary wave processes in an elastic shell and in the environment.

Let the center O of a thick-walled elastic spherical shell with an inner radius R_1 and an outer radius R_2 be located in the acoustic half-space $z \geq 0$ at a depth h from the plane $z=0$ of the half-space ($R_1 < R_2$, $R_2 < h$). The motion of media is considered in the spherical coordinate system (r, θ, ϑ).

At the initial moment of time $\tau = 0$, a normal surface load $p_1(\tau,\theta)$ is applied to the inner surface of the thick-walled shell

$$\sigma_{rr}\big|_{r=R_1} = p_1(\tau,\theta) \, . \qquad (1)$$

The conditions of contact between the shell and the acoustic environment are as follows:

$$\sigma_{rr}\big|_{r=R_2} = -p_2\big|_{r=R_2} \, , \qquad \frac{\partial u}{\partial \tau}\bigg|_{r=R_2} = v_2\big|_{r=R_2} \, . \qquad (2)$$

where σ_{rr} is the normal component of the stress tensor, p_2 is the contact pressure in the fluid, u is the radial displacement in the elastic medium, v_2 is the velocity of the fluid particle.

The flat boundary of the half-space is either a free surface or a rigid wall. Taking into account the axial symmetry of the problem, the motion of the shell and the acoustic medium relative to the scalar displacement and velocity φ_2 potentials φ_1 are described by wave equations, the initial conditions are homogeneous, and there are no perturbations at infinity.

The initial-boundary value problem is solved using the integral Laplace transform in time τ and using the method of incomplete separation of variables. Given the axial symmetry of the problem, the given load (1) and the desired functions are expanded into series in Legendre polynomials $P_n(\cos\theta)$ [2]. In the image space, the problem is reduced to solving an infinite system of linear algebraic equations. The solution of the system is represented in the form of infinite series in terms of exponents. For the coefficients of infinite series, initial conditions and recurrence relations are obtained that do not require the use of the reduction method. The coefficients of the series of the desired functions are defined as rational functions of the Laplace transform parameter, which makes it possible to find the originals using the theory of residues [4]. Formulas for the parameters of the environment and the shell have been obtained. Numerical experiments have been carried out. The obtained results of the work can be used in the field of design organizations in the construction of structures, as well as in the design of underwater reservoirs.

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Prediction of the "Screw-nut" gear life

O.Zhelezkov , E.Martynov, M. Kharchenko

Zhelezkov Oleg Sergeevich, doctor of technical science, professor, ferumoff@mail.ru, Russia, Magnitogorsk, Magnitogorsk state technical University named after G. I. Nosov,

Martynov Evgeny Mikhailovich, lecturer, e.m.martynov@mail.ru, Russia, Stary Oskol, Starooskolsky branch of the Moscow Institute of Steel and Alloys,

Kharchenko Maxim Viktorovich, PhD, assistant professor, kharchenko.mv@bk.ru, Russia, Magnitogorsk, Magnitogorsk State Technical University named after G.I. Nosov.

A method has been developed for predicting the service life of a screw pair nut with a large thrust thread, which is based on the energy theory of wear. Based on the results of finite element modeling using the DEFORM-3D software package, the dependence of the change in normal pressures on the contact surface of the nut with the screw along the height of the thread projection was established. Using the SMTs-2 friction machine, a series of experiments was carried out and the coefficient of friction and the energy index of wear intensity were determined for bronze of the brand BrA9Zh3L, used in the manufacture of nuts for screw mechanisms with coarse threads. The calculation of the service life of the nut of the pressure device of the rolling stand of the hot rolling mill 2000 has been performed. The limit value of the number of revolutions of the screw is established, the excess of which leads to critical wear and destruction of the threads.

Keywords: screw pair, nut, screw, thrust thread, nut wear, wear rate energy index, contact pressure, nut service life.

Evaluation of nonlinear oscillations of plane structures with consideration of internal dissipation

M.M.Mirsaidov[1,2], A.N.Ishmatov[1], B.Kh.Urinov[1], I.A.Khazratkulov[1]

[1] National Research University - Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 39 Kori Niyoziy Street, 100000 Tashkent, Uzbekistan

[2] Institute of Mechanics and Seismic Stability of Structures, Academy of Sciences of the Republic of Uzbekistan, 33 Durmon Street, 100125 Tashkent, Uzbekistan.

The study is devoted to the investigation of the dynamic behavior of heterogeneous plane structures under non-stationary kinematic loads, taking into account the nonlinear elastic and viscoelastic properties of the material. A detailed analysis of the current state of the dynamics of plane structures is provided. A mathematical model, methodology, and algorithm are proposed for evaluating the dynamic behavior of non-homogeneous plane structures, considering the nonlinear elastic and dissipative properties of the material during the actual operation of the structure. The nonlinear hereditary theory of Boltzmann-Volterra is employed to account for internal material dissipation. A real structure, a non-homogeneous earth dam, is considered as a specific example. Lagrange equations based on D'Alembert's principle are used to describe the dynamic processes in the problem of forced nonlinear oscillations with internal dissipation. The problem is solved as follows: first, the linear elastic problem of natural vibrations of the structure is solved to determine its natural frequencies and vibration modes. Then, the obtained natural modes of vibrations are used as coordinate functions in solving the problem of forced nonlinear oscillations of viscoelastic non-homogeneous systems. This leads to formulating the problem as a Cauchy problem for a system of nonlinear integro-differential equations.

The natural vibrations and nonlinear forced vibrations of the Gissar earth dam are studied, taking into account the actual operation of the structure and the nonlinear viscoelastic properties of the material near resonance vibration modes. A numerical method is employed to analyze the dynamic behavior of the considered structure, evaluating both displacements and stress components at various moments of non-stationary kinematic loads. In resonance vibration modes, the most critical sections of the structure are identified, and potentially vulnerable sections from a strength perspective are determined.

The influence of nonlinear elasticity and nonlinear viscoelasticity of the material on the dynamics of the structure is assessed. The effect of dissipative properties of the material on the dam's vibration dynamics is established. Recommendations are proposed for optimizing the operation of the dam, taking into account these effects.

Numerical investigation of the turbulent structure in the NACA0012 aerodynamic air-flow wake at low Reynolds numbers on the basis of a two fluid model

[1,*]Z.M.Malikov, [1,**]F.Kh. Nazarov, [1,***]M.E. Madaliev, [2,***]D. P. Navruzov

[1]Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan

[2]Bukhara Institute of Natural Resources Management, National Research University "TIIAME",Bukhara, Uzbekistan

[*]malikov.z62@mail.ru, [**]farruxnazar@mail.ru, [***]Madaliev.ME2019@mail.ru, [****]navruzov.d@mail.ru

This paper presents the results of a two-fluid turbulence model for the NACA 0012 airfoil problem using standard Comsol Multiphysics solvers. The flow around the NACA0012 airfoil was studied for Reynolds numbers $10000<Re_c<30000$ and angle of attack $\alpha = 0°$, as well as for $10000<Re_c<25000$ and $\alpha = 5°$. The obtained results are compared with the results of the well-known SST turbulence model and experimental data. Implementation of the Comsol Multiphysics software package showed good convergence, stability and high accuracy of the model.

Keywords: *Navier–Stokes equations, separated flow, two-fluid Malikov model. Comsol Multiphysics*

Simulation of swirling jet flows based on two fluid turbulence model

[1,*]Z.M.Malikov, [2,**]D.P. Navruzov, [1,***]M.E. Madaliev, [2,** **]N. SH. HAMROYEV

[1]Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan

[2]Bukhara Institute of Natural Resources Management, National Research University "TIIAME",Bukhara, Uzbekistan

[*]malikov.z62@mail.ru, [**]navruzov.d@mail.ru, [***]Madaliev.ME2019@mail.ru, [****]sh.hamroyev@mail.ru

This article presents the results of a two-fluid model and a turbulence model of the RSM (Reynolds stress model) family for a swirling jet. The two-fluid model used in this study has been developed recently. Pioneering works show that the basis for constructing this model is the possibility of representing a turbulent flow in the form of a non-homogeneous mixture of two fluids. Therefore, this model is derived on the basis of the dynamics of two fluids. These studies also show that the developed two-fluid model is able to adequately describe complex anisotropic turbulences. The fundamental difference of this model is that the two-fluid model is presented by the equations of dynamics. The two-fluid model reduces computational costs and makes the methodology practical from an "engineering" point of view for modern computing resources. In the numerical implementation in convective terms, the control volume method was used, and the correction for the velocity was conducted according to the SIMPLEC method. The numerical results obtained are compared with experimental data from the ERCOFTAC database. It is shown that the results of the two-fluid model are consistent with the experimental data.

Keywords: *swirling jet, two-fluid model, upwind scheme, swirl, QUICK scheme.*

Stability of longitudinal vibrations of a rod with a liquid section dynamic absorber

Mirziyod Mirsaidov[1,2], Olimjon Dusmatov[3] and Muradjon Khodjabekov[4]

[1]National Research University - Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 39 Kori Niyoziy str., 100000, Tashkent, Uzbekistan

[2]Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan, 33 Durmon str., 100125, Tashkent, Uzbekistan

[3]Samarkand State University, 15 University blv., 140104, Samarkand, Uzbekistan

[4]Samarkand State University of Architecture and Construction named after Mirzo Ulug'bek, 70 Lolazor str., 140147, Samarkand, Uzbekistan
E-mail: uzedu@inbox.ru

Abstract. In this work, the stability of longitudinal nonlinear vibrations of a hysteresis-type elastic dissipative characteristic rod with a liquid section dynamic absorber under the influence of kinematic excitations is considered. Using Lyapunov's first approximation method and Routh's criterion, a methodology for exploring the stability of the rod protected from vibrations has been developed. Stability conditions are obtained analytically for different values of system parameters. This makes it possible to determine the fields and borders of stability in the longitudinal vibration of the rod protected from vibrations, and to select the appropriate parameters of the dynamic absorber.

Keywords: rod, dynamic absorber, kinematic excitations, liquid, hysteresis, longitudinal vibrations, stability conditions.

Introduction. In modern techniques and technologies: elimination of harmful vibrations in the elements of machines, mechanisms and accessories - extinguishing, reduction, as a result, ensuring long-term efficient operation is one of the urgent problems. In order to solve these problems, it is effective to use different types of dynamic absorbers. This work is devoted to the problem of checking the stability of longitudinal vibrations of a distributed-parameter hysteresis-type elastic dissipative characteristic rod with liquid section dynamic absorber.

Conclusion. The method of exploration the stability of nonlinear longitudinal vibrations of the rod with elastic dissipative characteristic hysteresis type and liquid section dynamic absorber was developed. The characteristic equation of the system was determined, and the problem of determining the stability borders and areas of the vibration-protected system was solved based on the stability conditions obtained using the Routh’s criterion. Stability conditions were determined depending on the dissipative and liquid properties of the system and other structural parameters. This allows to choose the parameters to ensure stability in longitudinal vibrations of the rod protected from vibration.

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