ABSTRACT AND REFERENCES

APPLIED MECHANICS

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INFLUENCE OF THE PARAMETERS OF THE PRE-STRESSED WINDING ON THE OSCILLATIONS OF VERTICAL CYLINDRICAL STEEL OIL TANKS (p. 6–13)

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This paper reports an analysis of the frequencies and shapes of oscillations of the tank with a volume of 3000 m^3 with a winding of high-strength steel wire with a diameter of 3 mm, 4 mm, and 5 mm, applied in increments of 1:3. In addition, for the tension force of the turn in the range from 0.2 to 0.8 of the yield strength of the wire material. The study was carried out on the basis of a finite-element method in the ANSYS software package for a three-dimensional geometric model of the structure. At the same time, the software took into consideration the height-uneven width of the cylindrical wall taking into account the height of the filling to the maximum height and the tension forces of the winding.

It has been established that a change in the diameter of the winding wire does not lead to a significant change in the spectrum for the first ten significant frequencies. And an increase in the tension force of the wire in the winding leads to a decrease in the magnitude of oscillation frequencies. The exception is the sixth frequency. Its values are equal to one-tenth of a Hz for all estimated cases of the force of tension of the turn in the range from 0.2 to 0.8 of the yield strength of the wire material. The oscillation shapes of the tank reinforced by the winding have been determined. The change in the tension force of the wire in the winding does not change the number of waves at the circumferential coordinate at the free edge of the structure. We studied the loss of stability of the tank wall under distributed internal pressure. A comparative analysis of the sixth oscillation shape and the shape of stability loss reveals that they have the same number of waves at the circumferential coordinate.

The results reported here could make it possible to effectively use the pre-stress in order to detune the tank from the resonant frequency when operating in seismically hazardous areas.

Keywords: oil tank, tank oscillations, preliminary stresses, winding tension, numerical method.

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DETERMINING THE THERMOPLASTIC DEFORMATION MECHANISM OF TITANIUM REDUCTION REACTORS AND RECOMMENDATIONS TO INCREASE THE REACTOR SERVICE LIFE (p. 14–20)

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The object of research reported in this paper is the stressed-strained state of reactors when producing titanium sponge by the magnesium thermal method, taking into consideration the conditions of their operation and the physical and mechanical properties of the materials.

The problem considered is the plastic deformation of the reactor in the process of reducing titanium tetrachloride. To solve this task, an axisymmetric geometric model of the reactor was built using a CAD module of the Comsol Multiphysics software package. For the calculation, the Nonlinear Structural Materials module was used. Owing to the method of finite elements, the critical parameters for the formation of the plastic deformation band of the reactor were determined.

Modeling the process of thermoplastic deformation of the reactor under the conditions of obtaining titanium sponge has made it possible to determine the temperature gradient in the upper part of the reactor wall, which leads to local plastic deformation of the wall. The solution to the problem of continuing the reactor service would be to prevent overheating (overcooling) of the reactor wall within the resulting temperature. The physical and mechanical parameters of the material of the reactor wall, necessary to prevent the occurrence of an annular band of plastic deformation, have also been determined. It was shown that at $\Delta T > \Delta T_{crit} = 60$ °C, the walls of a 10-ton reactor during the reduction of titanium tetrachloride with magnesium perceive plastic deformation whose maximum value can reach $\varepsilon^{pl}_{\max} = 5.5\,\%$.

Deformation mechanisms that lead to a change in the shape of the side wall of reactors of magnesium-thermal production of sponge titanium under the action of a heterogeneous temperature field have been determined. The proposed technological solutions are to eliminate local changes in diameter in the upper part of the reactor wall. This will make it possible not only to increase the life of the reactors but will reduce the flow of alloy components into the titanium sponge of nickel, chromium, and iron.

Keywords: titanium sponge, titanium tetrachloride reduction reactor, reactor thermoplastic deformation process simulation, finite-element method.

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IDENTIFICATION OF THE PULSE AXISYMMETRIC LOAD ACTING ON A COMPOSITE CYLINDRICAL SHELL, INHOMOGENEOUS IN LENGTH, MADE OF DIFFERENT MATERIALS (p. 21–34)

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The problem of identifying the load acting on the elements of structures belongs to the class of inverse problems of the mechanics of a deformable solid, which are often incorrect. Solving such problems is associated with the instability of the calculation results, which requires the development of special methods for their research. This predetermines the relevance of this study.

The object of the study is a single-pass cylindrical shell consisting of two rigidly fastened butt-fastened sections made of different materials. Each of the shells is assumed to be elastic isotropic, having a cross-section of medium thickness. The equations of axisymmetric deformation of shells are used within the framework of Timoshenko hypotheses.

An approach to solving direct and inverse problems for such discretely heterogeneous objects is proposed, which implies the conditional separation of a discretely heterogeneous cylindrical shell along the length, followed by the addition of functions of fictitious loads. The main analytical relationships for building a system of integral Volterra equations are given, for which an analytic-numerical solution is derived.

The final ratios have been obtained, which make it possible to calculate the kinematic and force parameters of the study object in the process of non-stationary deformation. The inverse problem of identifying arbitrary loads acting on a shell that is heterogeneous in length is solved in a general form. An algorithm for the restoration of pulse loads has been developed, which is robust to errors in the initial data (about 5 %).

The material related to solving direct and inverse problems for shells that are discretely heterogeneous in length can significantly advance the methodology for identifying pulse loads acting on structural elements.

Keywords: cylindrical shell, nonstationary deformation, inverse problem, integral equation, Tikhonov regularization.

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IDENTIFICATION OF THE PATTERNS OF INFLUENCE THE NUMBER OF REINFORCING ELEMENTS AND THE INHOMOGENEITY PARAMETER OF THE SHELL MATERIAL ON FREQUENCIES OF A REINFORCED INHOMOGENEOUS ORTHOTROPIC SPHERICAL SHELL WITH A MEDIUM (p. 35–43)

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Spherical shells are used in many areas of the national economy. Spherical domes are widely used in the construction of various structures (technoparks, testing laboratories, entertainment complexes, reservoirs, etc.). They are also used in aircraft, ship structures, radar antennas and other structures. It is known that coatings have sufficient strength and durability even with a small thickness. However, to increase the working life of coatings, to ensure their long-term operation, as well as to increase their hardness, it is necessary to strengthen them on the surface or inside with rods. Sometimes it is possible to reduce the weight of the structure and save material consumption by strengthening it with. One of the advantages of these structures is that they give the maximum useful volume, being both load-bearing and enclosing structures. Checking the shells for stability is a priority task, since it is known that the shells, even with an insignificant thickness, have great strength and therefore their insufficient stability can be a criterion determining the bearing capacity. This article is devoted to identifying the regularities of the influence of the number of reinforcing elements and the inhomogeneity parameter of the shell material on the frequencies supported by an inhomogeneous orthotropic spherical shell with a medium. To solve the problem under consideration, the Hamilton-Ostrogradsky variation principle is applied. The frequency equation is constructed and implemented numerically.

Such studies have not been considered for a reinforced spherical shell with a no uniform filler in thickness.

Keywords: spherical shell, free oscillation, frequency, Legendre polynomial, spherical Bessel functions.

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DETERMINING FEATURES OF THE STRESSED STATE OF A PASSENGER CAR FRAME WITH AN ENERGY-ABSORBING MATERIAL IN THE GIRDER BEAM (p. 44–53)

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The object of this study is the processes related to the emergence, perception, and redistribution of loads in the improved structure of a passenger car frame. The scientific and applied task tackled in this paper is to ensure the strength of the supporting structure of a passenger car under operating loads. In this regard, it is proposed to improve the frame of a passenger car by constructing a girder beam from two rectangular pipes filled with material with energy-absorbing properties. The regularities of the frame load have been determined by taking into consideration the proposed solutions. It was found that the maximum equivalent stresses in the frame, taking its improvement into account, are 11.2 % lower than in the structure without filler, and 11.7 % lower than in the typical design. The results reported here are explained by the fact that the use of rectangular pipes filled with energy-absorbing material contributes to an increase in the moment of resistance of the frame, and, accordingly, reduces stresses.

In addition, the study has determined the natural oscillation frequencies of the frame. The results of the calculation of the strength of the weld in the zone of interaction of the girder beam with the pivot beams are given.

A feature of the results obtained is that the improvement in the strength of the frame is achieved not by strengthening its components but reducing the load.

The scope of practical application of the reported results concerns railroad transportation, as well as other sectors of mechanical engineering. The conditions for the practical use of these findings are the introduction of closed profiles in the structure of vehicles at the stage of their design and modernization.

This study could help reduce the cost of maintaining passenger cars and improve the efficiency of their operation. In addition, the research might prove useful for designing modern railroad car structures.

Keywords: girder beam, energy-absorbing filler, frame with filler, energy-absorbing frame concept.

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DETERMINING PATTERNS OF THE DEFORMED STATE OF THE TRANSPORT CONCRETE PIPE REINFORCED WITH A METAL CLAMP UNDER THE ACTION OF STATIC LOAD (p. 54–60)

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The object of this study is a concrete pipe and a pipe whose integrity was restored using a metal clamp while filling the layer between the existing pipe and the metal clamp with self-expanding concrete mortar.

It has been established that the most common types of defects and damage to pipes on the roads are transverse and longitudinal cracks, as well as concrete chipping and spalling.

A procedure has been devised to test experimentally a new concrete pipe without reinforcement and a concrete pipe reinforced with a metal clamp under static load.

Experimental tests of the concrete pipe without reinforcement and with reinforcement with a metal clamp were carried out in the laboratory. Digital indicators, an analog-to-digital converter, and a personal computer were used to measure pipe deformations.

It was found that the maximum value of vertical deformations of a new concrete pipe before cracking was 4.75 mm, and that reinforced by a metal clamp – 4.36 mm. At the same time, the maximum deformation at which the destruction of the new pipe occurred was 6.36 mm, and that of the reinforced pipe with a metal clamp – 10.51 mm.

It was established that the reinforcement of the destroyed pipe with a metal clamp in the initial period of loading leads to detachment of the clamp from the concrete of the pipe. Further, when the clamps are included in the work, there is a stable operation of the concrete pipe and the amount of growth of pipe deformations increases smoothly.

The results of measuring vertical deformations at the top of the pipe without reinforcement and with it showed different deformation values. It was established that the complete destruction of the pipe with a reinforced metal clamp takes place during deformations 61 % higher than the deformation at which the non-reinforced new concrete pipe is destroyed.

It was found that one of the methods of restoring the bearing capacity of damaged and defective pipes in the road industry is the use of metal clamps.

Keywords: concrete pipe, metal clamp, deformation diagram, three-layer structure, static load.

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ASSESSING THE VALUE OF THE HYDRAULIC FRICTION FACTOR IN PIPELINES WORKING WITH A FLOW CONNECTION ALONG THE PATH (p. 61–68)

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The results of an experimental study of the hydraulic friction factor of perforated pipelines that work with the collection of fluid along the path are reported. Clarification of this issue will make it possible to solve an important engineering task – to devise a reliable procedure for the hydraulic calculation of perforated pipes. The experiments were carried out on an assembled experimental bench. A steel pipeline with a perforated part of 1–3 m was investigated. Perforation holes were taken with a diameter of 3.6 and 9 mm. In the experiments, fluid flow, pressure loss, and average velocity were measured. Based on the data obtained, the values of the coefficient under study were calculated. It has been established that it is significantly larger than its values with uniform movement and is variable in length of the pipeline. Experimental dependences λ_{col} on the value of the ratio of the velocities of the flowing jets of liquid to the average flow velocity in the corresponding section (U_h/V), as well as on the design characteristics of the channel, were obtained. It is shown that the lower value of the degree of pipe perforation corresponds to the higher values of λ_{col}. This result can be explained by the influence of the attached flow rate on the main flow. The confirmation of this conclusion is the resulting shapes of diagrams of the average flow velocity obtained in the experiments, which differ significantly from standard diagrams with uniform motion. Obviously, additional energy is spent on the reformation of the velocities, and this causes additional head losses. Dependences were obtained for calculating the considered coefficient for prefabricated pipelines, including in the presence of transit flow rate. Their use in the calculation of the pipes under consideration will increase the reliability and efficiency of the sewage treatment plant, in which they are important structural elements.

Keywords: prefabricated perforated pipeline, variable flow rate, hydraulic friction factor.

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DESIGN AND KINEMATIC INVESTIGATION OF AN ACTUATED PROSTHETIC ANKLE DURING WALKING (p. 68–75)

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Due to the varied needs of persons who have lost a lower limb in their everyday lives, ankle-foot prosthetic technology is continually evolving. Numerous prosthetic ankles have been created in recent years to restore the ankle function of lower limb amputees. Most ankle foot prostheses, on the other hand, are passive, such as the solid ankle cushion heel and the energy storage and release foot (ESAR). The solid ankle foot can only provide steady vertical support during ambulation; however, the ESAR foot can store energy and gradually release it throughout human walking periods, hence increasing the walking pace of amputees. The aim of this work is to describe the design and manufacture of an actuated ankle-foot prosthesis. The main benefit of powered ankles is that they are capable of mimicking natural stride, particularly in steep or uneven terrain conditions. The primary objective is to establish two degrees of freedom of ankle rotation in two planes, plantar flexion and dorsiflexion in the sagittal plane, besides inversion and eversion in the frontal plane. As software can improve the gait stability, an automatic modifiable transmission arrangement was prepared for delivering the current design motions in the sagittal plane based on empirical collected biomechanical data related to passive prosthetic normal gait circumstances. However, the ankle rolling in the frontal plane was guided mechanically by means of mono leaf spring. The majority of the ankle mechanical components are made of 7075-T6 aluminum alloy and are integrated onto ESAR carbon fiber laminated foot. For a unilateral above-knee amputee, the ankle function at self-selected walking was assessed, achieving maximum results of 10° inversion, 10° eversion, 12° plantar flexion and 18° dorsiflexion ankle angles. Also, the patient gait experiment in a normal cadence showed an improvement in plantar flexion behavior for the powered ankle in contrast with the passive ankle.

Keywords: prosthetic ankle, ankle kinematics, above knee amputee, prosthetic gait, energy storage and release foot.

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IDENTIFYING THE INFLUENCE OF DIMENSIONAL PARAMETERS ON THE STRESSES AND DEFORMATIONS OF TWO HELICAL GEARS (p. 76–83)

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In this research paper, focusing on the basic variables of the gear modeling process and setting its dimensions to see which gears are

capable of withstanding transmission operations and its rigidity was done. Because one of the most prominent transmission mechanics is gears, as the types of gears are numerous and common, and one of the most prominent types of gears is the helical gear. The helical gear is one of the most widely used and widespread gears in mechanical fields due to the increase in the contact area during the interlock process, as this increase reduces noise during gear rotation. Three main variables were used to establish the results. The first of which is the pressure angle, the helix deflection angle, and the module number, and they made a number of cases to see which one was able to withstand the movement operations with a proven torque. The results proved that the distortion value in the first case at module 1 was 87×10^{-6} m, while in module 2 the distortion value was 3.75×10^{-6}. The data are useful and important because the values of the stresses that affect the gears must be known by changing the module due to it gives a stronger concept of the extent to which the gears can withstand movement. Pressure angle is one of the basic variables that change the dimensions of wind turbine gears. The value of the greatest stress was 2.13×10^{8} Pa, but at the pressure angle of 20 degrees, the stress value was 1.93×10^{8} Pa. It affects the diameter, stiffness and tensile strength of a wind turbine. The study of this research paper depends on helical gears. It is known that the angles of the helical teeth increase the large contact area between two gears. From the resulting deformation values, it is noted that the deformation value is 4.26×10^{-6} m when the helix angle is 20 degrees.

Keyword: Finite element method, helical gear ,pressure angle, helix angle, stress analysis.

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OPTIMIZATION OF CROSS-SECTION DIMENSIONS OF STRUCTURAL MEMBERS MADE OF COLD-FORMED PROFILES USING COMPROMISE SEARCH (p. 84–95)

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The object of this study is a structural member made from a C-shaped cold-formed profile, investigated to search for optimal cross-sectional dimensions. The parametric optimization task is stated as the problem to find the optimal cross-sectional dimensions of the structural member under axial compression conditions, taking into account its post-buckling behavior (local buckling of the web and flanges, as well as a distortional buckling of the cross-section) and structural requirements. In this case, the material consumption and mechanical characteristics of steel, as well as the design lengths of the structural member, were considered constant and predefined. The considered criterion of optimality was the maximization of the load-carrying capacity of the structural member for the overall buckling under the axial compression. The stated optimization problem is solved using the method of exhaustive search while applying the developed software. Additionally, for fixed steel consumption, compromise solutions were searched that do not depend on the thickness of the profile and the design lengths of the structural member. The resulting cold-formed C-shaped profiles with optimal cross-sectional dimensions are characterized by a higher load-carrying capacity for the overall buckling under axial compression

(to 24.45 % and 22.19 %) at the same steel consumption compared to the profiles offered by the manufacturer. Analysis of the reported results made it possible to devise recommendations for optimal ratios of dimensions and geometric characteristics of the structural members made from C-shaped profiles operating under axial compression. The ratios could be used both at the stage of selection of cross-sections of structural members from cold-formed profiles, and in the development of effective assortments of cold-formed profiles.

Keywords: cold-formed profile, load-carrying capacity, flexural-torsional buckling, post-buckling behavior, parametric optimization.

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DETERMINING EXPERIMENTALLY THE PATTERNS OF THE MANIFESTATION OF THE SOMMERFELD EFFECT IN A BALL AUTO-BALANCER (p. 96–104)

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This paper proposes an experimental method for studying the Sommerfeld effect in auto-balancers or exciters of resonant vibrations of pendulum, ball, or roller type. The method is based on the processing of signals acquired from analog sensors of rotations and vibration acceleration using regression analysis. The method is tested on a specially designed rotor bench on isotropic viscoelastic

supports, which executes spatial motion, and an auto-balancer with one ball.

Checking the accuracy of the method using stroboscopic lighting demonstrates the accuracy of determining the speed of rotation of the rotor, ball, oscillation frequency of the rotor, etc. with an error of several hundredths of a percent.

When fixing the ball relative to the rotor, a classic inertial vibration exciter is obtained. The rotor has two resonant velocities. The Sommerfeld effect is almost not manifested. With a gradual increase in the frequency of the current, the rotor speed increases monotonously. There is no significant slip or jump in the rotor speed. There are two distinct peaks on the amplitude-frequency characteristic. Therefore, such a vibration exciter is not suitable for the excitation of resonant vibrations.

With the free placement of the ball in the oil, the behavior of the system changes significantly in the vicinity of the first resonant velocity. The first narrow resonant peak disappears in the roto. Instead, there is a long, gentle resonant rise. It lasts at a current frequency of 9.4 Hz to 19.3 Hz. The amplitude at the reference point on the resonant rise increases from 0.7 mm to 2.84 mm. Therefore, by changing the frequency of the current, it is possible to smoothly change the amplitude of the rotor oscillations by almost 4 times. The maximum amplitude of rotor oscillations is the same as at the first resonance with a fixed ball. Due to the gentleness of the resonant rise, a freely installed ball itself is a reliable exciter of resonant vibrations.

Keywords: inertial vibration exciter, resonant vibratory machine, steady state motion, Sommerfeld effect, autobalancing, motion stability.

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SOLVING APPLIED PROBLEMS OF ELASTICITY THEORY IN GEOMECHANICS USING THE METHOD OF ARGUMENT FUNCTIONS OF A COMPLEX VARIABLE (p. 105–113)

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When solving many tasks related to mine workings, rock pressure management, development systems, support structures, the issues of strength and stability of rocks become relevant. Limitations and gaps

are identified, emphasizing the need for further research and development of new methods for solving applied problems of elasticity theory.

It is of theoretical and practical interest to determine the influence of half-space geometry on the stressed state of the medium and to assess whether it would suffice, in this case, to confine oneself to radial stress when characterizing the stressed state. To build a mathematical model of the stressed state of the array, a complex variable function argument method was used. Based on the developed complex variable function argument method, the applied problem of mechanics on loading the wedge with a concentrated force in polar coordinates was solved.

A feature of the proposed approach is the introduction of tangential stresses with the need to meet boundary conditions along inclined faces. The introduction to the consideration of tangential stress shows that it cannot be neglected at a certain stage of the search for a solution. First of all, this is due to the half-space geometry, the angle at the apex, and the depth of the array. When changing the angle of the wedge, the interface surface changes fundamentally and can pass from a convex shape to a concave one. Simplification of the proposed expressions leads to a complete coincidence with the solutions by other authors obtained by the stress method, which indicates the reliability of the result reported here. This method may be advanced by complicating the half-space geometry, as well as loading, and by building a mathematical model for assessing the effect of tangent stresses on the strength and stability of soils.

Keywords: soil arrays, soil mechanics, stressed state, argument functions, half-space.

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