ABSTRACT AND REFERENCES
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MATHEMATICAL MODELING OF THE STRESSED-DEFORMED STATE OF CIRCULAR ARCHES OF SPECIALIZED CRANES (p. 4-10)

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We present the possibilities to calculate the stressed-deformed state of circular arches under various conditions of bearing based on the algorithm of a numerical-analytical variant of the method of boundary elements and application of the MATLAB programming and calculation environment. The exact solution to the problem of flat deformation of a circular rod is shown, considering the deformations of bending and stretching-compression, which has not so far been implemented in professional packages of the finite element method. We have constructed solving equations for the boundary value problems on flat deformation of circular arches under various bearing conditions. An example is given for calculating the circular arch SDS employing BEM; by using the MATLAB environment, we represented the results numerically and visually in the form of diagrams. It was established that the boundary element method in the calculation of circular arches has the simplest algorithm logic among other methods and it allows obtaining accurate and reliable results of the stressed-deformed state of crane structures with specialized designation. BEM presented in the given work could be successfully applied to solving boundary value problems for differential equations with variable coefficients. The structure in this case should be discretized while the BEM algorithm does not change. Additional advantage is the minimal requirements to variable coefficients of the differential equation. They may possess first-order discontinuities, breakpoints, and an arbitrary set of continuous functions, which significantly expands the range of problems to be solved.

It is obvious that the boundary element method enables fulfillment of the increased requirements to calculation results, which therefore renders relevance to the present study, as well as scientific and practical value for professionals involved in the design of crane structures.

Keywords: boundary element method, fundamental system of functions, arched systems, specialized crane, MATLAB.

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RESEARCH INTO FRICTIONAL INTERACTION BETWEEN THE MAGNETIZED ROLLING ELEMENTS (p. 11-16)

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Results are presented of theoretical and experimental studies into effect of external magnetic field on the changes in adhesion parameters in a contact between magnetized steel rolling elements when they brought to each other to the level of atomic roughness. In theoretical studies, we calculated the interaction energy, adhesion force, friction and adhesion coefficient between magnetized steel rolling elements. The calculations are based on the general law of interaction between systems of charged particles, described by the Lennard-Jones potential, which takes into account both repulsion forces and attraction forces of these particles. A mathematical model was proposed for the calculation of force and coefficient of adhesion between steel rolling elements, taking into account magnetostrictive phenomena in the surface layers of a metal when magnetized by a constant magnetic field. The calculation of force and coefficient of adhesion was performed on the example of interaction between a wheel of a locomotive and a rail; the proposed model, however, could be applied to other elements of rolling friction.

The technique and results of experimental studies are presented of the effect of external magnetic field on the coefficient of adhesion in the friction model of contact "wheel of a locomotive rail". According to the results, magnetization of metal rolling elements leads to a significant, up to 36 %, increase in adhesion forces, which is important from the point of view of development and implementation of methods to control adhesion in similar tribological systems.

Keywords: friction force, adhesion coefficient, external magnetic field, rolling elements, magnetostriction.

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MODIFICATION OF IMPLICIT ALGORITHM FOR SOLVING A PROBLEM ON THE ELASTIC PLASTICITY OF BULK MATERIALS (p. 17-23)

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A mathematical statement is given of the elastic-plastic behavior of isotropic bulk material using a classic model of Drucker-Prager. We have improved the return-mapping algorithm for solving numerically a problem on the mechanical state of bulk material. In order to solve a system of nonlinear equations by the Newton method, it is proposed, at each step of iterations, instead of finding the inverse

matrix, to solve a system of algebraic equations, linearized by Newton, by applying the Gauss exclusion method. This makes it possible to reduce the number of arithmetic operations by about $3n^2$ (n is the dimensionality of SLAE) at each iteration step for each plastic finite element. We have tested the programming code developed on the high-level programming language Fortran on the example of a model material, characterized by the associative law of current, at different values of the angle of natural repose. Comparison of the obtained results of numerical experiment with the data received by applying the proprietary software revealed a deviation within 0.25–5.3 % depending on the desired magnitude.

Keywords: bulk material, Drucker-Prager yield criterion, return-mapping algorithm, plastic deformation.

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IDENTIFICATION OF THE ADDITIONAL EXPOSURE ZONE FOR ENSURING A COMPLETE CONTACT OF THE TWO-LAYERED SYSTEM (p. 23-29)

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The problem of identification of the magnitude and zone of exposure on the upper layer of the two-layered structure under the action of a normally distributed load and its own weight for ensuring a complete contact is solved. To solve a direct problem, we use a variational formulation for the corresponding nonlinear boundary value problem with constraints. The possibility of applying the inverse problem method implemented with the recession vector method is investigated. A numerical analysis of the convergence of the model deformation elimination process depending on mechanical and geometric parameters of the system is made. It is found that the pressing zone is separated from the loading zone, the parameters of the zone being dependent on the properties of the layers, the height

of the upper layer, the loading magnitude and the value of the coefficient of friction. As a result of the research, an algorithm that allows determining the state of the contact zone and the corresponding stress-strain state of the two-layered system under consideration was developed. The algorithm uses the finite element method and determines the values of characteristic functions on the basis of the values of variational inequalities. The effect of physical and geometric properties of the system on the parameters of the additional impact, ensuring the absence of a separation zone is investigated. It is shown that the account of friction small influences on the parameters of influence, a large role is rendered by geometrical parameters and level of basic ladening.

The developed algorithms and conducted research will allow increasing the design reliability of airfield pavements, layered structures of industrial buildings, hydraulic structures, foundations of massive structures, wells in rocks, as well as machine parts.

Keywords: plane contact problem, one-way communication, identification of exposure, inverse problem method.

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DERIVING A FUNCTION OF THE BENDING AXIS OF A PROFILED WALL IN THE FORM OF ORTHOTROPIC PLATE (p. 30-37)

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New approaches to calculation of a profiled wall of the proposed beam of box cross section were formulated. A profiled wall of the beam was presented as an orthotropic plate and specifics of its work were taken into account. In calculations of a profiled wall, the actual deformed scheme was changed for the equivalent one. The accepted system at simplification works under load similarly to the original system and has similar characteristics. Power or parabolic displacement function depends on parameters of a corrugated wall (ordinates of a point on the height of the wall, the number of half-waves of stability loss). Solution to a fourth-order equation using the MatCAD computer complex was found. The result of solution to the differential equation is an original displacement function for a generalized model of the wall of a beam with a profiled wall of box cross section of trapezoidal outline. The displacements found allow obtaining values of stresses in the cross section of new structural forms of beams. The paper considers analytical dependence of the coefficient, obtained as a result of calculation, which represents the power of the argument of function of deformation of the middle beam's axis on applied load. The function of square parabola was found to reliably correspond to a change in transverse deformations by height of the wall, which is proved by calculations using the method of finite elements.

We present the possibility of using the resulting dependence for determining the stressed-strained state of the wall of a new structure of the beam with a profiled wall of the box cross section. The results, obtained by a mathematical algorithm of diagram of normal stresses, were graphically compared with traditional calculation. The feasibility of application of the presented methodological approach for beams with a profiled wall was proved because distribution of normal stresses by the traditional calculation method does not correspond to actual work of the wall. According to comparison of results of the conducted trial experiment with the presented method, the bending moment is accepted by flanges and sections of the wall, which are close to the flanges of the developed beams within (0.1÷0.2) hw.

Keywords: steel beam, profiled wall, box cross section, calculation technique, orthotropic plate.

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STRUCTURAL-PARAMETRIC SYNTHESIS OF HYDRO-MECHANICAL DRIVE OF HOISTING AND LOWERING MECHANISM OF PACKAGE-FORMING MACHINES (p. 38-44)

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An analysis of operation of hoisting and lowering mechanisms of package-forming machines and synthesis of the structure of a hydromechanical drive were performed. Operation mode of a hydromechanical drive with a hydro-gas battery was theoretically explored. Objective function of minimizing energy consumption at step-by-step battery filling was formulated. The possibility of accumulation of potential energy is determined by the technology of packing. This is a specific feature of hoisting and lowering mechanisms of package-forming and package-disassembling machines. The need for research in this area is caused by the necessity to further process the data on the influence of the structure and elements of a drive on operation of hoisting and lowering mechanisms and to find ways of minimizing energy consumption at step-by-step drive loading.

It was experimentally proved that gas compression in the battery of a hoisting and lowering mechanism is described by an adiabat. A hypothetical polytrope index was determined at the level of 1.25. The authors determined parameters of a hydraulic drive, which will provide the minimum of objective function of minimizing energy consumption: loading at level F_{ymax}=26 kN, F_{ymin}=5.7 kN, coefficient of pressure losses of 0.05, piston stroke 0.5 m, at preset speeds of platform motion: V_{min}=0.03 m/s, V_{max}=0.38 m/s.

Accumulation of potential energy at step-by-step loading of a hoisting and lowering mechanism is provided due to throttling of fluid motion from the hydro cylinder to the battery. The authors explored operation modes of a hydro-gas battery as a part of a hoisting and lowering mechanism in its alternating step-by-step loading, which provides analysis of the future design of a drive of a package-forming machine.

Keywords: hoisting and lowering mechanism; hydromechanical drive; battery; package-forming; potential energy.

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EXPERIMENTAL RESEARCH INTO AERODYNAMIC CHARACTERISTICS OF THE MODEL OF A MANEUVERED AIRCRAFT WITH AN AIRFLOW PASSAGE THROUGH ENGINES (p. 45-52)

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We report results of experimental investigation of aerodynamic characteristics of an aircraft maneuvering model with and without a passage of airflow through the engines. During aero-tube experiment, research into the fighter aircraft models with round and rectangular shapes of nozzles was conducted. A basic method for studying aerodynamic characteristics is the weight experiment. When processing experimental data, we applied a method of corrections and calculated correction factors that depend on the shape of working part of the wind tunnel and relative dimensions of the model. The methodology for a comprehensive analysis of corrections and for determining magnitudes of the most important correction coefficients was developed, that is frontal drag and lifting force. Verification of the developed technique was carried out by comparing blowdown results of the fighter aircraft model of the MiG-29 type in the wind tunnel T-1 at Kharkiv National University of Air Forces named after Ivan Kozhedub with the results obtained from reliable semi-empirical dependences. Relative error of determining maximum aerodynamic quality of the aircraft was 3 % compared to the results of aerodynamic characteristics of the actual aircraft. The difference of the developed technique is the possibility of using interchangeable nozzles of engine imitators and the introduction of correction for the resistance of inner channels of the aircraft model's nacelles. We demonstrated feasibility of the developed procedure for aerotube experiment and adequacy of accounting for experimentally-determined corrections.

Keywords: wind tunnel, aerodynamical characteristics, gas-turbine engine, maneuverable aircraft, weight experiment.

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EXAMINING THE EFFECT OF ANNULAR INJECTION ON THE PARAMETERS OF THE AXIAL COMPRESSOR'S STAGE (p. 53-57)

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We performed numerical simulation of the current in a stage of the axial compressor with an annular gas injection before the impeller. The gas-dynamic action was studied during operation of the stage on the verge of detachment. The annular injection was carried out at several fixed values of injection angle γ in the range from 5° to 90°. The research results showed that the gas-dynamic action on a current makes it possible to improve aerodynamic characteristics of the stage of an axial compressor. The gas-dynamic action by annular injection on the flow in a stage of the axial compressor makes it possible to extend the range of detachment-free flow-around. The level of flow non-uniformity after the impeller and the guide device has decreased.

Results of the calculation study showed that at injection angles $\gamma>50°$ the gas-dynamic action leads to an increase in the level of losses in the impeller At injection angles $\gamma\leq50°$, one observes a positive effect. A total pressure loss coefficient in the impeller decreases from $\xi=0.08$ to $\xi=0.03...0.005$. At the rational values of intensity of the gas-dynamic action on the flow a degree of pressure increase in the stage grows from $\pi=1.08$ to $\pi=1.093$.

Keywords: simulation of a current, gas-dynamic action, annular injection, compressor's stage, hydraulic losses.

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CREATION OF THE ENERGY APPROACH FOR ESTIMATING AUTOMOBILE DYNAMICS AND FUEL EFFICIENCY (p. 58-64)

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We have developed an energy approach to estimating the dynamics and fuel economy of cars that makes it possible to determine interrelation between consumption of energy and the kinetic energy of a car. We determined coefficients of the specified interrelation for basic and additional (unproductive) consumption of energy. Based on the obtained coefficients, it is possible to rank energy losses, as well as identify the ways to reduce them. As indicators of energy evaluation of the car's dynamics, we proposed indicators of its dynamics – the level of kinetic energy possessed by a vehicle at full weight and maximal motion speed; energy indicator of the car's dynamics that can be applied as the unit for measuring energy consumption of engine, employed to move the car. The equations were derived that determine the following: a number of units of energy losses caused by the elastic and dynamic losses of car and transmission (per one meter of the distance); additional consumption of engine energy at fluctuations of the car guide wheels in the horizontal plane are caused by their imbalance. We present dependences that allowed us to do the following: determine maximal total consumption of engine energy while driving; assess a reduction in the additional costs for the motion of hybrid cars under the established mode at an increase in the share of torque generated by electric motors. The interrelations were determined between energy indicators of the dynamics and fuel economy of cars. We found that the smaller the number of units of energy consumption by engine, required to move the car, the higher energy efficiency of the vehicle. Calculation of all types of energy consumption in the units of kinetic energy of the car enables their comparison, analysis of their causes, and the identification of possible ways for their reduction. The proposed dependences could be used to determine engine energy consumption, required for the car motion, taking into account various factors. The equations derived make it possible to assess energy efficiency of the car at the stages of its design and modernization.

We have shown the way to improve dynamics and fuel efficiency of a car by reducing additional losses in the vehicle transmission through the use of a combined electromechanical drive of the driving wheels. Applying energy approach allowed us, using hybrid cars as an example, to determine energy saving at their steady motion. This saving for a car with a number of cylinders of 6–8 can reach 25–30 %.

Keywords: evaluation of dynamics, energy efficiency, additional energy losses, torque non-uniformity.

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RESEARCH INTO RESISTANCE TO THE MOTION OF RAILROAD UNDERCARRIAGES RELATED TO DIRECTING THE WHEELSETS BY A RAIL TRACK (p. 65-72)

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Energy saving direction on railway transport is substantiated based on reducing the motion resistance related to directing the undercarriages by a rail track. This motion resistance is defined as the kinematic resistance to motion. We clarified the nature of motion resistance associated with directing the rolling stock by a rail track. This opens up certain prospects in terms of reducing the kinematic motion resistance through design parameters of the trucks and the track. The kinematic resistance to motion could become an additional criterion for the optimal choice of characteristics of mechanical part of the undercarriages. The same applies to the permissible deviations in parameters of the rolling stock and the track.

We model steady motion of a semi-wagon's truck in a circular curve at constant velocity under the action of contact track forces, tractive force from the locomotive, and the unsuppressed centrifugal or centripetal forces of inertia. The kinematic motion resistance is determined as the longitudinal force applied to the truck's pivot in order to balance all external forces.

The dependences were obtained of specific kinematic resistance to motion on the motion velocity, base of the truck, radius of the curve, clearances of the wheelset in a rail track, and elevation of the outer rail. In particular, we derived a value of the motion velocity at which the minimum of resistance is observed. As we established, this speed does not match the equilibrium velocity and is 15–20 % lower.

The study showed the possibility to predict resistance related to directing the undercarriages by a rail track. This opens up the prospect for choosing rational parameters of undercarriage gear of the rolling stock from the point of view of motion resistance.

Keywords: railway transport, train traction, resource saving, motion resistance, directing the undercarriages by a rail track.

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