ABSTRACT AND REFERENCES

APPLIED MECHANICS

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NUMERICAL SIMULATION OF THE DYNAMICS OF THE SYSTEM "TROLLEY – LOAD – CARRYING ROPE" IN A CABLE CRANE (p. 6-12)

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We report results of research into patterns in the progress of dynamic processes and into emergence of dynamic loads when a trolley of the cable crane moves with a suspended load. These patterns could be subsequently taken into consideration when calculating actual cranes, in order to improve their reliability and durability, to avoid unfavorable events during motion of a freight trolley, as well as to define parameters of cranes of the new design. The dynamics of a cable crane is considered from the point of view of the interaction between elements of the system "trolley-load-carrying rope". We have improved a mathematical model for the system "trolley-load-carrying rope" by introducing three damping coefficients, each of which characterizes energy dissipation under different physical processes – the motion of a trolley, a load, and the speed of a wind load. Numerical simulation was performed using the software package KiDyM, which at the analytical level allows the construction of motion equations for the systems that are described by a combination of ordinary differential equations. We established patterns of change in the normal and tangential inertial forces occurring during motion of the trolley along a curvilinear trajectory. Their character and magnitude were quantified. We determined dynamic characteristics of the system, taking into consideration the influence of the masses of a swinging load, a trolley, and the curvature of a rope. Emergency mode that occurs at a break of the traction rope was investigated, as well as the influence of wind load on the swinging of the load. We defined causes for the emergence of the reverse speed for a freight trolley, and the ways for its elimination. The influence of wind load on the angle of load deviation from the vertical was examined.

Keywords: cable crane, crane trolley, carrying rope, crane dynamics, numerical simulation.

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DEVELOPMENT OF THE METHOD FOR CALCULATION OF CANTILEVER CONSTRUCTION'S OSCILLATIONS TAKING INTO ACCOUNT OWN WEIGHT (p. 13-19)

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A new method for calculating bending oscillations of vertical cantilever structures with allowance for their own weight is proposed. The method is based on the exact solution of the corresponding partial differential oscillation equation with variable coefficients. In the analytical form with the help of dimensionless fundamental functions, formulas for dynamic parameters – motion, angle of rotation, bending moment and shear force, which completely characterize the state of the rod, are written out.

In general, the frequency equation is written out and the method for finding its roots is determined. It is shown that the problem of determining natural frequencies can be reduced to finding the corresponding dimensionless coefficients from the frequency equations. The formulas for determining mode shapes are found. The algorithm that allows determining natural frequencies and mode shapes of cantilever structures with any given accuracy is described.

The algorithm is implemented on the example of a through lattice tower. It is found that the numerical values obtained by the author's method coincide with the results obtained with the help of the software system that implements the finite element method.

In comparison with approximate methods, this method allows obtaining a more reliable picture of oscillations of cantilever structures, since it is the exact solution that carries information of a qualitative nature and forms the most complete picture of the physical phenomenon under consideration. Using explicit analytical formulas, the accuracy of calculation of bending oscillation is increased.

The proposed method does not require the discretization of the structure and is a real alternative to the use of approximate methods when solving this class of problems of solid mechanics.

Keywords: cantilever structure, own weight, bending oscillations, oscillation frequencies, mode shapes.

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RESEARCH INTO A POSSIBILITY TO PROLONG THE TIME OF OPERATION OF UNIVERSAL OPEN TOP WAGON BODIES THAT HAVE EXHAUSTED THEIR STANDARD RESOURCE (p. 20-26)

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The intensification of utilization of railroad cars predetermines the wear of their bodies as the most loaded element of design and necessitates the introduction of new cars. To reduce the cost of manufacturing new car designs, it is proposed to prolong the operation of universal open top wagon bodies beyond standard 1.5 operation terms.

When carrying out calculations for strength under conditions of wagon building enterprises, the normative magnitudes of loading

are applied, which do not take into consideration possible wear in the elements of bearing structures of open top wagon bodies under operation. This can lead to a significant error when determining a possibility to extend a period of operation of open top wagon bodies that have exhausted their standard resource.

Therefore, when substantiating a possible prolongation of the operation period of cars it is important to take into consideration, at the stage of strength estimations, the refined magnitudes of dynamic loads acting on them in operation.

To investigate dynamic loading acting on a open top wagon body during an impact at shunting, which is the case of the greatest loading to its structure, we employed mathematical modeling. The results of present research allowed us to conclude that the acceleration that acts on the bearing structure of a open top wagon with the wear characteristic of 1.5 terms of operation during an impact at shunting is about 4g. In addition, research into dynamic loading of the bearing structure of a open top wagon body during an impact at shunting was performed using computer simulation based on the software CosmosWorks. The research results showed that the maximum accelerations of a open top wagon body make up approximately 5g.

To verify the adequacy of the developed models, we used the Fisher criterion. Results of the calculations have shown that the hypothesis of adequacy is not contradicted.

The research results obtained were taken into consideration when determining strength indicators of a open top wagon body with the wear characteristic of 1.5 terms of operation. To this end, we constructed a spatial computer model of the body of a base open top wagon, model 12-757, whose bearing elements are of the thickness corresponding to the minimally defined one. The calculation employed a method of finite elements. Based on the performed calculations it was determined that the maximum equivalent stresses do not exceed the permissible ones and make up about 345 MPa, which makes it possible to draw a conclusion about the possibility of further utilization of a railroad car.

The study conducted would help determine the feasibility of prolongation of service operation of open top wagons that have exhausted their standard resource.

Keywords: transport mechanics, freight cars, open top wagon, operation cycle, structure strength, dynamic loading.

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STUDYING THE COUPLED AXIAL AND LATERAL OSCILLATIONS OF THE DRILLING RISER UNDER CONDITIONS OF IRREGULAR SEAWAYS (p. 27-33)

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Construction of an improved mathematical model of the axial and lateral oscillations of the riser in the plane of action of the velocity vectors of the fluid flow washing the riser was considered. This model makes it possible to study the stress-strain state of the riser with simultaneous impact on it from the sea and the change in the force of tensioning its upper end. In addition, the model specifies the force effect exerted on the riser by the washing fluid flowing in it.

Based on the developed mathematical model, a simulation model of operation of the "drilling ship – rope-type tensioning system of the riser – riser" system was created in the Modelica modeling language and a series of numerical experiments were performed at various levels of seaways. The obtained results show that the proposed model produces 22–40 % higher calculated values of the amplitude of lateral oscillations and 10–25 % higher calculated values of the bending moments in critical sections compared with the results of the classical model of lateral oscillations. The greatest difference between the simulation results was observed with moderate seaways. With a growth of seaways, the difference between the two models decreases. Proceeding from the obtained results, it is not recommended to neglect the effect of variation in time of the forces tensioning the riser in applied problems of studying riser operation in conditions of slight sea.

Keywords: riser, stresses-strained state, simulation model, coupled axial and lateral oscillations, irregular seaways, Modelica.

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A NUMERICAL METHOD FOR AXISYMMETRIC ADHESIVE CONTACT BASED ON KALKER'S VARIATIONAL PRINCIPLE (p. 34-41)

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A numerical method for axisymmetric adhesive contact of elastic bodies is proposed. It allows computing the size of the contact spot, the force of interaction as well as the contact pressure distribution unrestricted to any particular form of the initial gap between the bodies. Therefore, compared to the existing analytical theories, it is a more versatile research tool that can be used to study such phenomena as adhesive strength of conjugate bodies and stability loss induced energy dissipation in oscillating contact. A variational principle that can be used to construct an approximate solution is proposed. The derived nonlinear equations of the discretized minimax problem determine the unknown radius of the circular contact spot and the nodal values of the thought-for contact pressure. Unlike other numerical methods where contact domain is updated by subtracting or adding separate boundary elements of finite size, the proposed approach enables gradual continuous variation of the contact area. The arc-length method was implemented in the numerical routine in order to solve for the unstable sections of the adhesive interaction process. Besides the distance and force variables, the increment of the contact area is included in the control for the sake of convergence. The numerical error of the approximate method with respect to the known analytical solutions is evaluated. Linear convergence with mesh refinement in computed force and contact area is observed. Extension of the proposed approach for arbitrary three-dimensional shape of the contacting bodies is planned for the future. This is required to study the impact of the random surface roughness on their adhesive properties.

Keywords: adhesive contact, boundary element method, Kalker's variational principle, wavy roughness, arc-length method.

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SUBSTANTIATION OF ADEQUACY OF LOADING CONDITIONS AT BENCH AND FIELD TESTS OF CONSTRUCTION MACHINES (p. 41-52)

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Loading conditions for construction machines at bench tests were substantiated. Adequacy of loading conditions at bench tests and of the loads acting on construction machines in actual operating conditions was substantiated.

When releasing each machine from the manufacturer's enterprise, it is subjected to tests. Most often, these tests are carried out on specially equipped test sites. Their use requires large financial and time inputs: delivery of the machine, washing and cleaning from dirt after testing, fee to operators. More accurate results are obtained with bench tests at operational loading conditions. Shortening of such test duration is achieved by reducing the work interruptions and improving the shift planning. Except tests for permanent loading, it is expedient to test construction machines and their work elements for impact loads.

This study has established necessity of adherence to the following test conditions: the assembly under study should not approach resonance; the effect of frequencies of the repeated variable loading on the fatigue destruction process should be insignificant. Compliance with these conditions makes it possible to use the mathematical apparatus given in the paper for calculation of endurance at various loading parameters and simulation of various machine operation conditions.

The procedure developed in this work makes it possible to save not only time and money. In manufacture, it shortens design of construction machines and ensures identification of assemblies that reduce reliability or require longer life. This results in a smaller metal consumption or improved quality of the machine. In the mass production, it enables conduction of periodic accelerated qualitative tests of the machine, determination of modernization efficiency, creation of new designs of the bench for testing construction machines. In the process of machine operation, it helps to reduce loads on the machine structures and improve reliability and durability.

Keywords: accelerated bench tests, random loads, hypothesis of spectral summation, chassis.

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DEVELOPMENT OF THE PROCEDURE FOR VERIFYING THE FEASIBILITY OF DESIGNING AN ACTIVE SUSPENSION SYSTEM FOR TRANSPORT CARRIAGES (p. 53-63)

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We have proposed techniques using which made it possible to solve a nonlinear algebraic Riccati equation for dynamic systems with *n* degrees of freedom. A constraint was imposed on the structure of a designed railroad carriage. We employed, as an analogue, a symmetrical carriage whose suspension system contains elastic-

dissipative links with linear characteristics. This allowed us to devise a procedure for designing a suspension system for a railroad carriage. The criterion when choosing the weight coefficients of quality was the requirement to ensure comfortable conditions for passengers and a locomotive crew. Therefore, the system must experience an oscillatory process with small amplitudes; the frequency of natural oscillations of the body should not exceed 2 Hz. We have performed decomposition of the dynamic programming method for continuous stochastic systems, which made it possible to develop a procedure for a phased suspension system design. The procedure is suitable for use when designing suspensions for carriages running at regular and high-speed speed. The first stage implies designing a passive suspension system. The second stage involves a validation of the feasibility of designing devices to control parameters of the elastic-dissipative links in a suspension system of transport carriages using the optimal Kalman-Bucy filters. The modeling proved that control over parameters of elastic-dissipative links improves the dynamics of transport carriages. Damping control alone could reduce the body's center of mass acceleration by more than two times and hence decrease dynamic loads in the system. The Kalman-Bucy algorithm makes it possible to obtain optimal parameters of the elastic-dissipative links in a suspension system in complex dynamic systems. The procedure could be used independently and as part of the technique for a phased design of the suspension system. The procedure was demonstrated using test examples. The procedure is implemented in the simulation system. Control over parameters of the elastic-dissipative links in a suspension system of transport carriages would make it possible, first, to create comfortable working conditions for a locomotive crew and passengers, second, to improve operation reliability and motion safety of rolling stock by reducing dynamic loads.

Keywords: Kalman-Bucy filter, transport carriage, control over parameters of elastic-dissipative links, complex dynamic systems.

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DETERMINATION OF THE RESISTANCE OF THE CYLINDRICALTUBULAR DRILL FOR TRENCHLESS LAYING OF UNDERGROUND COMMUNICATIONS (p. 64-70)

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The determination of the total resistance to penetration of the annular drill into the soil is based on the concept of changing the elastic state of the soil during its compaction, which is defined by the compression modulus of soil deformation. This parameter comprises all the physical and mechanical properties of each type of soil and makes it possible to specify the laws of the normal pressure of penetration resistance acting on the surface of the conical and cylindrical parts of the working body.

The proposed theoretical models of processes occurring during penetration of the annular drill into the soil gives an opportunity to determine the influence of the parameters on the resistance force for each working procedure, depending on the physical and mechanical properties of the soil. It has been found that the maximum length of the annular drill is determined for the conditions of soil movement (unplugged condition), which, for example, with a cylinder diameter of 28 mm, is 0.87 m, 1.04 m and 1.16 m respectively for sandy clay, semi-solid loam and tough clay. It is now clear that a 2-fold increase in the internal diameter leads to an increase in the core length of 1.75 times.

It has been determined that the two-cone drill does not facilitate passage of soil through itself and it causes soil plugging as well as formation of soil plugs on the frontal planes, which leads to an increase in drag force. Therefore, to provide unplugged conditions during pipe jacking, the drill with a single external cone should be used.

The obtained results of the work can be used to substantiate the rational parameters of the working equipment for creating a horizontal borehole in different types of soils.

Keywords: analytical model, trenchless technology, engineering communications, horizontal borehole, punching technology.

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PATTERNS IN CHANGE AND BALANCING OF AERODYNAMIC IMBALANCE OF THE LOWPRESSURE AXIAL FAN IMPELLER (p. 71-81)

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We have studied patterns in the change and balancing of aerodynamic imbalance of the impeller for the axial fan of type VO-06-300 (Ukraine).

We have found the aerodynamic imbalance of the impeller caused by mounting one blade:

– at a different angle of attack;
– with a violation in the step uniformity;
– not perpendicularly to the longitudinal axis of the impeller;
– with all three of the above-mentioned errors present at once.

We have estimated a change in the aerodynamic imbalance due to change in air density. We estimated the influence of air temperature, altitude above sea level, atmospheric pressure, on air density and aerodynamic imbalance.

It was established that a different angle of attack and a violation of the perpendicularity give rise to the dynamic imbalance in which

the moment component is an order of magnitude larger than the static component. A violation of the step uniformity gives rise only to the static component, which is in the plane of the impeller.

Among the errors considered, the most undesirable one relates to mounting a blade at a different angle of attack. At such an error, aerodynamic imbalance is 6–8 times larger than that due to other errors. A ±4-degree change in the angle of attack of a single blade in the impeller can degrade the accuracy of balancing of the impeller to the accuracy class G 6.3 at a frequency of 1,500 rpm, or G 16 – at 3,000 rpm.

It was established that the ordinary and aerodynamic imbalances can be balanced at the same time. It is appropriate to carry out dynamic balancing in two correction planes. It is possible to conduct balancing by rotor mass correction or using passive auto-balancers.

A specific example is used to demonstrate the procedure for taking into consideration the aerodynamic imbalance in differential equations of motion of the axial fan. In accordance with the procedure, the aerodynamic imbalance components are added to the respective components of the ordinary imbalance.

The results obtained are applicable when designing and manufacturing low-pressure axial fans. Employing them would improve vibration characteristics of the specified fans.

Keywords: axial fan, aerodynamic forces, aerodynamic imbalance, dynamic balancing, auto-balancer, auto-balancing.

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