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VIBRATION DAMPING OF ROD AND TUBULAR STRUCTURES

Abstract: *The destabilizing effect of vibration increases significantly during resonant oscillations of elements of machine-building structures. The amplitudes of movement, speed and acceleration at the same time significantly increase and can exceed the amplitudes of disturbing oscillations by tens of times. This article contains numerical methods for calculating rod and tubular structures of mechanical engineering (in particular REA).*

Key words: *numerical methods, dynamics, edge problems of mechanics, cell method, Galerkin method, algorithm, basic functions, Bubnov-Galerkin method, variation.*

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Introduction

1. On Methods of Forming a Resolution System of Differential Equations for a Finite Element

Analytical methods for studying oscillation problems (Fig. 1) are often ineffective, and in other cases they cannot be used at all. The complexity of the tasks, the need to obtain more accurate results forced us to turn to numerical methods of research. Different methods are used to solve dynamic problems. These are, of course, difference circuits, and the method of generalized relaxation, and the method of integral relations, and the method of splitting, and the method of cells. In recent years, one of the most effective numerical methods for solving edge problems of continuous medium mechanics, the finite element method (MEA), has gained great popularity.

It is characterized by a simple physical interpretation of basic computing operations, as well as the presence of machine programs, which provides a high degree of automation of labor-intensive operations of compiling and solving systems of equations. This method has a number of varieties. The choice of a method is largely determined by the nature of the tasks and to a large extent by the "taste" of the researcher, although some ideas about these methods have already developed.

For example, as indicated in the book [1,2,3], the difference method leads to more loaded machine memory, which is a certain disadvantage when solving large-order systems. But the difference method gives

the values of functions that are less oscillating. There are other features of this method. Our research is based on the FEM. It should be noted that as the FEM developed, its connection with other approximate methods became obvious. Currently, there is an opinion that all the approximation processes used in solving problems are described by differential equations, in fact, they form a single whole. However, when using certain schemes, various machine algorithms are implemented to form a resolving system of equations [4,5]. In dynamic problems, the initial generalized parameters are functions of coordinates and time. In principle, we can give a discretization of the entire space-time domain [6,7]. That is, we can introduce four-dimensional finite elements. Then the basic functions (functions of the form) can have the form $N_m(x,y,z)T_k(t)$. So, for a linear finite element (Fig.1) and and of the two-point pattern we have

$$N_1 = 1 - \frac{x}{e}; N_2 = \frac{x}{e}; T = 1 + \frac{(t_n - t)}{\Delta t}.$$

Then the function of displacements along the x-axis gets the following form

$$M(x,t) = [N_1, N_2]\begin{bmatrix} k_1 & k_2 & 0 & 0 \\ 0 & 0 & k_1 & k_2 \end{bmatrix}\begin{Bmatrix} U_{1,n} \\ U_{1,n+1} \\ U_{2,n} \\ U_{2,n+1} \end{Bmatrix} \quad (1)$$

However, the introduction of such time – space basis functions proved impractical for a number of reasons [8,9]: in the case of a large time domain, the problem becomes excessively cumbersome; the system of equations is generally unsymmetric even when using methods such as the Galerkin method; the geometric prostate of the time domain does not encourage the use of irregular partitioning into space – time elements; when using basis functions of the form (1), the same results will be obtained as with sequential discretization in space and time. Physically more visual and cost-effective from the point of view of machine time costs are the representation based on the splitting of the solution (the method of partial discretization). We consider that the function within the finite element is approximated by interpolation polynomials that depend only on the coordinates and are multiplied by the nodal parameters that are functions of time

$$q(x,y,z) = \sum_{k=1}^{n} N_k(x,y,z)\phi_k(t). \quad (2)$$

The first stage of FEM research usually consists in obtaining finite element dependencies in the form of ordinary differential equations with respect to time. There are different ways to do this. The nature of the problem largely determines the ways of forming a resolving system of equations for the elements. The most popular are the variational and energy methods, when the energy and work of forces are introduced into consideration, the Bubnov-Galerkin method, in which either dynamic partial differential equations of a continuous medium or equations of state are taken as the initial ones. These methods are based on the fundamental principles of mechanics, the correct understanding and use of which guarantees correctness in the formulation and solution of mechanical problems.

The problems of mechanics are reduced to the problem of the calculus of variations, if we are talking about a functional and cutting off the necessary conditions for the stationarity of this functional. Usually, if we talk about the variational approach in continuum mechanics, it is called with the Hamilton principle (for stationary connections) or with the Hamilton-Ostrogradsky principle (for stationary connections). Hamilton's principle, as is known [10, 11], states that a certain integral of the Lagrange function $L = T - \Pi$ (T and P are the kinetic and potential energies of the system, respectively), is equal

$$\Im = \int_{t_1}^{t_2} L dt, \quad (3)$$

it takes on a stationary value (the variation of a certain integral $\delta I = 0$) with respect to any possible variations of the system in which the initial and final positions remain fixed.

The Hamilton principle is applicable to an arbitrary mechanical system with holonomic connections. It contains only one statement, covering the entire period of time. In this principle, movement is considered as a whole. Consider a variation of a certain integral whose integrand depends on many independent variables, their derivatives, and the argument t:

$$\Im = \int_{t_1}^{t_2} L(q_1, q_2, \ldots, q_p, q'_1, q'_2, \ldots, q'_p, t)dt, \quad (4)$$

Due to the commutativity property of the variation operation, the variation from a certain integral is equal to a certain integral from the variation:

$$\delta\int_{t_1}^{t_2} L dt = \int_{t_1}^{t_2} \delta L dt.$$

Here L is a given function of variables q_r, q'_r and t does not change during the variation process.

$$q' = \frac{dq}{dt}$$

You can write

$$\delta L(q_r, q'_r, t) = L(q_r + \varepsilon\phi_r, q'_r + 2\phi'_r, t) - L(q_r, q'_r, t) = \in \left[\frac{\partial L}{\partial q_r}\phi_r + \frac{\partial L}{\partial q'_r}\phi'_r\right],$$

where $\in$ is the parameter tending to zero;

φ_r - some arbitrary function that satisfies the same general continuity conditions as the function $q_r + \in \varphi_r$. The function φ_r must be continuous and differentiable.

With a variable parameter $\in$, you can make the change in the function L arbitrarily small, aiming at $\in$ zero, and get

$$\delta\int_{t_1}^{t_2} L dt = \in \sum_{r=1}^{p}\int_{t_1}^{t_2}\left[\frac{\partial L}{\partial q_r}\varphi_r + \frac{\partial L}{\partial q'_r}\varphi'_r\right]dt.$$

An expression in this form is not suitable for further analysis, because although it φ_r is interrelated, this φ'_r relationship cannot be written in algebraic form. This difficulty will be circumvented by applying integration in parts

$$\delta\int_{t_1}^{t_2} L dt = \in \sum_{r=1}^{p}\left\{\left[\frac{\partial L}{\partial q'_r}\varphi'_r\right]_{t_1}^{t_2} + \int_{t_1}^{t_2}\left[\frac{\partial L}{\partial q_r} - \frac{d}{dt}\left(\frac{\partial L}{\partial q_r}\right)\right]\varphi_r dt\right\}. \quad (5)$$

the expression drops out if we vary $\left[\frac{\partial L}{\partial q'_r}\varphi'_r\right]_{t_1}^{t_2}$ at fixed boundary values, L and φ_r then vanishes at moments t_1, t_2 .As already noted, a function φ_r is an arbitrary function that satisfies the same general continuity conditions as a function $q_r + \in \varphi_r$. In mechanical systems, their position is determined by a set of generalized coordinates q_r . Therefore, it is quite acceptable to use a private method of variation.

The FEM procedure provides for a transition from differential dependencies for individual finite elements to a global system of equations for the entire array. For linear problems, this global system in matrix form usually has the form:

$$[M]\{q''\} + [C]\{q'\} + [K]\{q\} = \{F\} \quad (6)$$

Here are $[M], [C], [K]$ the matrices of mass, stiffness, and damping matrix, respectively; q - vector of generalized nodal parameters; $\{F\}$ - external load vector.

Analytical methods for solving linear systems of ordinary differential equations are well known. However, due to the high order of the matrices, their practical implementation is possible in most cases only by applied numerical methods. We used in the numerical procedure proposed by [12], the essence of which consists q'' in the assumption that the acceleration variation is linear in the time interval Δt . Using this assumption, we have:

$$\{q'_{n+1}\} = \{q'_n\} + \left(\frac{\Delta t}{2}\right)\{q''_n\} + \left(\frac{\Delta t}{2}\right)\{q''_{n+1}\}; \quad (7)$$

$$\{q_{n+1}\} = \{q_n\} + (\Delta t)\{q'_n\} + \left(\frac{(\Delta t)^{-2}}{3}\right)\{q''_n\} + \left(\frac{(\Delta t)^2}{6}\right)\{q''_{n+1}\}.$$

After substituting (7) into the matrix differential equation

$$[M]\{q''\} + [K]\{q\} = \{P\}$$

we get

$$[H]\{q''_{n+1}\} = \{P_{n+1}\} - [K]\{b_n\} \quad (8)$$

where

$$[H] = [M] + \left[\frac{(\Delta t)^2}{6}\right][K];$$

$$\{b_n\} = \{q_n\} + \Delta t \cdot \{q'_n\} + \left[\frac{(\Delta t)^2}{3}\right]\{q''_n\}$$

Thus, the starting values (the values that take place at the initial moment of time) are the displacements, velocities, and accelerations.

They are used to determine $\{b_n\}$, and then from the expression (8), the acceleration $\{q''_n\}$ at the next moment in time. From formulas (7), the displacements and velocities are found at this next moment in time, and the procedure is repeated. The described two-point pattern makes it possible to efficiently solve equations (8) through the Gaussian elimination procedure at each time step Δt .

2. Finite-elementary solution of a system of ordinary differential equations

We consider a second-order matrix differential equation with a dissipative term (6). We study the behavior $q_k \quad (k = 1,2,..., N)$ of the function over a time T_A interval. We divide T_A the function into finite sections $2(\Delta t)$ and take an approximation of the function q_k in the form:

$$q_k = a_1 + a_2 t + a_3 t^2. \quad (9)$$

Then you can represent this function like this:

$$q_k = [N]\{q_{k,e}\}.$$

$$[N] = \left[1 - \frac{3t}{2(\Delta t)} + \frac{t^2}{2(\Delta t)^2}, \frac{2t}{\Delta t} - \frac{t^2}{(\Delta t)^2}, \frac{t^2}{2(\Delta t)^2} - \frac{t}{2(\Delta t)}\right] \quad (10)$$

form function;

$$\{q_{k,e}\} = \begin{Bmatrix} q_{k,n} \\ q_{k,n+1} \\ q_{k,n+2} \end{Bmatrix}.$$

Here are the time points at the beginning, in the middle, and at the end of the time finite element. For the entire mechanical system with the same duration of all finite time elements, the vector in equation (6) will be equal to:

$$\{q\} = \begin{Bmatrix} q \\ q_2 \\ \vdots \\ \vdots \\ q_N \end{Bmatrix} \quad \begin{Bmatrix} [N]\begin{Bmatrix} q_{1,n} \\ q_{1,n+1} \\ q_{1,n+2} \end{Bmatrix} \\ [N]\begin{Bmatrix} q_{2,n} \\ q_{2,n+1} \\ q_{2,n+2} \end{Bmatrix} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ [N]\begin{Bmatrix} q_{N,n} \\ q_{N,n+1} \\ q_{N,n+2} \end{Bmatrix} \end{Bmatrix} \quad (11)$$

Substituting the expression $\{q\}$ for from (10) and running the Bubnov-Galerkin procedure, we get

$$\int_0^{2\Delta t}([M]N_i\begin{vmatrix}\frac{d^2[N]}{dt^2}\begin{Bmatrix}q_{1,n}\\q_{1,n+1}\\q_{1,n+2}\end{Bmatrix}\\\cdots\cdots\cdots\cdots\\\frac{d^2[N]}{dt^2}\begin{Bmatrix}q_{N,n}\\q_{N,n+1}\\q_{N,n+2}\end{Bmatrix}\end{vmatrix}+[S]N_i\begin{vmatrix}\frac{d[N]}{dt}\begin{Bmatrix}q_{1,n}\\q_{1,n+1}\\q_{1,n+2}\end{Bmatrix}\\\cdots\cdots\cdots\cdots\\\frac{d[N]}{dt}\begin{Bmatrix}q_{N,n}\\q_{N,n+1}\\q_{N,n+2}\end{Bmatrix}\end{vmatrix}+[K]N_i\begin{vmatrix}N\begin{Bmatrix}q_{1,n}\\q_{1,n+1}\\q_{1,n+2}\end{Bmatrix}\\\cdots\cdots\cdots\cdots\\N\begin{Bmatrix}q_{N,n}\\q_{N,n+1}\\q_{N,n+2}\end{Bmatrix}\end{vmatrix}-N_i\{F\})dt=0$$

$$(i=1,2,3)$$

After the corresponding transformations, we have the following system of three matrix equations of a finite time element:

$$[M]\frac{4}{3(\Delta t)}\begin{vmatrix}q_{1,N}-2q_{1,n+1}+q_{1,n+2}\\\cdots\cdots\cdots\cdots\\q_{N,n}-2q_{N,n+1}+q_{N,n+2}\end{vmatrix}+[S]\begin{vmatrix}-\frac{2}{3}q_{1,N}+\frac{2}{3}q_{1,n+1}\\\cdots\cdots\cdots\cdots\\-\frac{2}{3}q_{N,n}+\frac{2}{3}q_{N,n+1}\end{vmatrix}+$$

$$+[K]\Delta t\begin{vmatrix}\frac{2}{15}q_{1,N}+\frac{16}{15}q_{1,n+1}+\frac{2}{15}q_{1,n+2}\\\cdots\cdots\cdots\cdots\\\frac{2}{15}q_{N,n}+\frac{16}{15}q_{N,n+1}+\frac{2}{15}q_{N,n+2}\end{vmatrix}=\int_0^{2\Delta t}\left[\frac{2t}{\Delta t}-\frac{t^2}{(\Delta t)^2}\right]\{F\}$$

Such a system of equations is compiled for each time finite element. As a result, we get a system of equations in accordance with the number of time segments - elements into which the total time interval is divided T_A.

Next comes the transition to the global system of equations, from which the values of functions are searched for q_k at all considered time points. Thus, there is no step-by-step solution of the problem, when the previous values of the function are searched for subsequent values. In the method under consideration, ultimately, all the values of functions within the time interval are found from a system of algebraic equations at once T_A. Let us now carry out the transformations in a narrow direction. We will not solve equation (6). About the average components of the functions of the form (10) on $2(\Delta t)$ the segment. Such a system of equations is compiled for each time finite element.

In the elements that the total time interval is divided into T_A . Next comes the transition to the global system of equations, from which the values of the functions are searched for q_k at all considered time points. Thus, there is no step-by-step time solution to the problem. In the method under consideration, all the values of functions within a time interval are eventually found from a system of algebraic equations at once T_A. Let us now carry out the transformations in a narrow direction. We will not solve equation (6). We will average the components of the functions of the form (10) on the segment and where $2(\Delta t)$ and $q' = [R](q_e)$ where

$$[R]=\left[\frac{3t}{2(\Delta t)}+\frac{t}{(\Delta t)^2},\frac{2}{\Delta t}+\frac{2t}{(\Delta t)^2},\frac{t}{(\Delta t)^2}+\frac{1}{2(\Delta t)}\right]$$

We will have $2(\Delta t)$

$$N_{1CP}=\frac{\int_0^{\Delta t}N_1 dt}{2(\Delta t)}=\frac{1}{6};\ N_{2CP}=\frac{2}{3};\ N_{3CP}=\frac{1}{6}$$

$$R_{1CP}=-\frac{1}{2(\Delta t)};\ R_{2CP}=0;\ R_{3CP}=\frac{1}{2(\Delta t)}$$

Then we come to the form of Nu Mark difference relations:

$$q=\frac{q_n}{6}+\frac{2q_{n+1}}{3}+\frac{q_{n+2}}{6};\quad q'_{n+2}=\frac{(q_n-q)}{2(\Delta t)};$$

$$q''=\frac{(q_{n+2}-2q_{n+1}+q_n)}{2(\Delta t)}$$

The most important problem of numerical implementation is to provide a stable, oscillating solution within acceptable limits. Much attention is paid to this problem in the literature [13,14,15,16]. It is also closely related to the choice of the type and size of the final element. In the guise of a time step, a method of numerical approximation. It is known that an explicit stability criterion for general problems solved by the FEM has not yet been derived due to the following difficulties. As can be seen from the above, at the first stage we obtain a system of inhomogeneous differential equations (linear equations). Such a system of differential equations must be stable. They will be stable if all the roots of the corresponding characteristic equation are less than one in absolute value. Here, in principle, it is possible that the system will be stable at some time steps, and unstable at others. The choice of the time integration step Δt is crucial for ensuring the stability of the solution. The integration step must be directly related to the dimensions of the final element.

The practice of computing allowed us to develop certain criteria. It is known that the simultaneous reduction in the size of the element and the time step usually significantly reduces the range of oscillations.

In practice, it usually turns out that in order to get acceptable results and ensure the stability of the account, it is necessary to ensure this stability not Δt^* at any (unconditional stability), but only in the case when the step does not exceed a certain critical value (conditional stability). It is usually defined as $\Delta t^* = \frac{k}{\omega_{\max}}$. Where k is a certain numerical coefficient, $\omega_{\max}$ is the highest natural frequency.

For example, for the value of Bernoulli-Euler beams on impulse loads, good results are obtained if, for the length of the finite element $t = 7{,}62$ sm of the cross-sectional area of the beam $\rho = 1{,}61$ sm^2, the moment of inertia of the cross-section $T = 0{,}217$ sm^4 is $\Delta t = 10^{-6} s$ taken. With $t = 1{,}9$ sm, you have to apply $\Delta t = 10^{-7} s$, and with $t = 0{,}782$ sm, $\Delta t = 5 \cdot 10^{-8} s$

3. Damping of resonant vibrations of rod and tube vibrations.

To reduce resonant vibrations (Fig. 1), layers of vibration-absorbing materials are used. At the same time, the resonant vibrations can be reduced in a wide frequency range with a slight increase in the mass and overall dimensions of the structures. The effectiveness of the use of vibration-absorbing materials is illustrated in Fig. 1. The use of a board consisting of three layers of fiberglass with thin layers of vibration-absorbing (VP) material drawn between them reduced the resonant vibrations by 3 times. Figure 2 shows examples of using vibration-absorbing materials to suppress resonant vibrations in structures. The solution of the boundary value problem (6) is found in the form:

$$\cdot\cdot \quad q_*(t) = \theta_k(x) e^{-k\omega t}, \qquad (12)$$

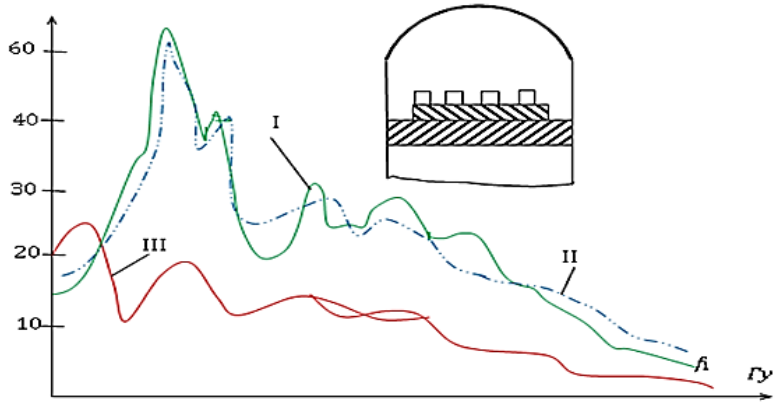

Figure 1. Change of vertical movement from time to time.1-without taking into account the viscosity, 2-taking into account the viscosity of the base, 3 - with vibration-absorbing layerswhere $\vartheta_k(x)$is the complex waveform, and $\omega = \omega_R + i\omega_I$ is the desired complex frequency.

The problem is reduced to solving homogeneous algebraic equation

$$\left|\Delta(\omega_R, \omega_I) = 0\right|, \qquad (13)$$

The solution of the eigenvalue problem is carried out by the Muller method without explicitly allocating the complex parameter.

These examples fully reflect the fundamental possibilities of using multilayer damping structures. These examples fully reflect the fundamental possibilities of using multilayer vibration-absorbing coatings to reduce resonant vibrations of radio engineering structures

Conclusions

With a rigid mount, the dynamic gain $\mu = 42$ at a resonant frequency of about 33 Hz. Installing the panel in plastic guides reduces the dynamic gain to $\mu = 17$. The use of damping leads to an even greater reduction $\mu = 5$ in the dynamic gain. The integrated use of plastic guides and damping allows you to $\mu = 4{,}2$ reduce the dynamic gain to, and high frequencies (up to 200 Hz and above) $\mu = 1$ to (with $\mu \approx 3$ a rigid mount).

References:

1. Taliskiy, E.N. (2001). *Zashita elektronnix sredstv ot mehanicheskix vozdeystviy*. Teoreticheskie osnovi: Ucheb. posobie. (p.256). Vladimir.: Vladim. gos. un-t..
2. Yurkov, N.K., & Jadnov, V.V. (2012). *Osobennosti konstruirovaniya bortovoy kosmicheskoy apparaturi.* Uchebnoe posobie. (p.112). Penza: PGU.
3. Steinberg, D.S. (1973). *Vibrations analysis for electronic equipment*. (p.456). New York.
4. Truxman, V.M. (1983). *Issledovanie kolebaniy nesushix sistem odnostoechnix KRS i razrabotka myeropriyatiy po povisheniyu ix dinamicheskogo kachestva.* Dis.. kand.texn.nauk. (p.201). Moscow.
5. (1978). *Vibrasii v texnike*: Spravochnik: V 6 t. Moscow: Mashinostroenie.
6. (2013). *Osnovi teorii nadejnosti elektronnix sredstv*: ucheb. posobie / N.K. Yurkov, A.V. Zatilkin, S.N. Polesskiy, I.A. Ivanov, A.V. Lisenko. (p.100). Penza: Izd-vo PGU.
7. (2014). K voprosu zashhiti elektronnih sredstv ot vneshnih mehanicheskih vozdeystviy / A.V. Lisenko, A.V. Zatilkin, G.V. Tan'kov, M.A. Apenbin // *Nadejnost' i kachestvo-2014*.Stat'i Mejdunarodnogo simpoziuma: v 2 t. pod red. N. K. Yurkova. – Penza: Izd-vo Penz. GU, - 1 tom., pp. 362-364.
8. Kolesnikov, A.E. (1988). *Shum i vibraciya*: Uchebnik. (p.248). L.: Sudostroenie.
9. Makvecov, E.N., & Tartakovskiy, A.M. (1993). *Mehanicheskie vozdeystviya i zashhita radioelektronnoy apparaturi:* Ucheb. dlya vuzov. (p.200). Moscow: Radio i svyaz.
10. Bojko, A. (1987). *Passivnaya i aktivnaya vibrozashhita sudovih mehanizmov*. Sudostroenie, p.176.
11. Lisenko, A.V. (2013). *Klassifikaciya amortizatorov radioelektronnix sredstv na osnove fasetnoy strukturi*. Innovacionnie informacionnie tehnologii: Matyeriali mejdunarodnoy nauchnoprakticheskoy konfyerencii. Tom 2. / Gl. red. S.U. Uvaysov; Otv. Red. I.A. Ivanov. (pp.300-306). Moscow: MIEM NIU VShE.
12. Tokarev, M.F., Talickiy, E.N., & Frolov, V.A. (1984). *Mehanicheskie vozdeystviya i zashhita radioelektronnoy apparaturi:* Ucheb. posobie dlya vuzov / Pod red. V.A. Frolova. (p.224). Moscow: Radio i svyaz'.
13. Lisenko, A.V. (2012). Struktura i programmno-informacionnoe obespechenie informacionno-izmyeritel'nogo laboratornogo kompleksa /A.V. Lisenko, N.V. Goryachev, N.K. Yurkov // *Izvestiya YuFU. Tehnicheskie nauki*, 5 (130), pp. 169-173.
14. (n.d.). Physbook.ru [Elektronniy resurs] Uchebnik fiziki. Rejim dostupa: http://www.physbook.ru/index.php/Slobodyanyuk_A.I._Fizika_10
15. Lisenko, A.V. (2013). *Sposob snijeniya velichini vibracionnix nagruzok v nesushhix konstruksiyax ES i metodika ego realizuyushhaya* / A.V. Lisenko. *Nadejnost i kachestvo slojnix sistem*, №4, pp. 41–44.
16. (2013). *Raschet plat s amortizatorami*. A.V. Grigor'ev, A.L. Drjeveckiy, A.V. Zatilkin, A.V. Lisenko, V.F. Selivanov // Molodej'. Nauka.Innovacii: Trudi VI mejdunarodnoy nauchno-prakticheskoy konfyerencii. (pp.149-151). Penza: Izd-vo PF FGBOU VPO «RGUITP».