Розроблено математичну модель поздовжніх коливань триступеневої колони насосних штанг із застосуванням функцій переміщення та навантаження окремих ступеней. Приведено формулу для визначення коефіцієнту дисипації коливань колони та досліджено його зміну в залежності від жорсткостей її ступеней. Встановлено, що безрезонансна робота колони при певній дисипації коливань ступеней забезпечується шляхом вдалого підбору їх жорсткостей

Ключові слова: демпфування, дисипація, змінні навантаження, колона насосних штанг, механічна система, резонанс

Разработана математическая модель продольных колебаний трехступечатой колонны насосных штанг с применением функций перемещения и нагружения отдельных ступеней. Приведена формула для определения коэффициента диссипации колебаний колонны и исследовано его изменение в зависимости от жесткостей ее ступеней. Установлено, что безрезонансная работа колонны при определенной диссипации колебаний ступеней обеспечивается путем удачного подбора их жесткостей

Ключевые слова: демпфирование, диссипация, сменная нагрузка, колонна насосных штанг, механическая система, резонанс

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DETERMINING THE PARAMETERS OF OSCILLATION DISSIPATION IN A COLUMN OF SUCKER RODS

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1. Introduction

In the process of oil extraction by downhole rod pump installations (DRPI), a column of sucker rods (SR) in a string of pumping-and-compression pipes (PCP) is exposed to both static and dynamic load. At present, reliable information about the loading of a SR column can be obtained by the application of dynamometry at different DRPI operational modes [1]. This approach has a significant shortcoming in that it is impossible to employ the results of dynamometry at the stage of completing a SR column when the cost and time of making changes in its design is minimal. A development of dynamic processes over time known in advance makes it possible to evaluate the capability of mechanical system "SR column – fluid – PCP string" to resist external stresses. In addition, it contains information about the structure of the system, degree of its nonlinearity, dissipation mechanism of oscillation energy, allows evaluation of its stability and the capability for the self-excitation of oscillations. An alternative method of estimating the dynamic loading of a SR column is mathematical modeling of oscillating processes, which basically comes down to constructing and solving a system of differential equations of motion.

2. Literature review and problem statement

Study of parameters of dynamic instability of a SR column and its corresponding vibrational characteristics based on a comprehensive mathematical model was conducted in [2]. Determining the nature of influence of dynamic instability on the law of motion of a SR column in the directed well and numerical examining of parameters of its work was expanded in articles [3] and [4]. Paper [5] explored dynamic behavior of rod systems taking into account external force factors that are described by multivalued (subdifferential) relations. The statement of a boundary problem with nonlinearities for friction in the form of variation and quasi-stationary inequalities was presented. The algorithm of numerical calculation of rod columns of DRPI was proposed. Dynamics of the motion of a SR column in the twisted column of PCP is described in [6]. The mathematical model is presented in the form of a system of differential equations of motion with partial derivatives and geometric equations of a spatial curve. A problem on the distribution of elastic waves of impact character in a rod, one end of which moves with acceleration by the assigned law, while the other one is loaded with mass and rests on a spring, was tackled in [7]. The propagation of elastic waves and the development of deformations in a rod are determined using the normal functions. Assessment of the magnitude of dynamic loads for single- and two-stage columns of SR was conducted in [8]. By the results of theoretical studies, the authors proposed ways to reduce the dynamic loads and defined particular conditions for preventing the parametric resonance. Article [9] determines the damping coefficient of oscillations in a column of sucker rods based on the dynamograms obtained during experimental research. The impact of change in the amplitude and period of load oscillations over time on the damping coefficient along the entire length of a SR column was established. By three natural frequencies of longitudinal oscillations they determine the location and dimensions of a cross cut in the vertical rod on an elastic suspension exposed to the action of its own weight [10]. According to research results, the authors substantiated the possibility to determine location and to diagnose a damage in a vertical rod.

The above enumerated articles did not investigate one of the important characteristics of dynamic behavior of a SR column – its capability to dissipate in the irreversible form some part of oscillation energy. Damping properties of oscillations in a SR column are predetermined by certain dissipation parameters whose quantitative assessment still requires a number of studies. That is why determining the dissipation characteristics of multistage SR columns of large length that influence the intensity of their oscillations, as well as defining the parameters of dissipation of a SR column, is an important practical task. Its solution will help increase the accuracy of assessment of the strength and durability of its elements.

3. The aim and tasks of the study

The aim of present work is to determine the coefficient of dissipation of oscillation energy of a SR column based on examining it as a mechanical system with a finite number of degrees of freedom.

To achieve the set aim, the following tasks are to be solved:

– to substantiate basic principles in determining the coefficient of dissipation using the equations of motion of a three-stage SR column;

– to evaluate the coefficient of dissipation of oscillation energy for different configurations of SR columns, formed of fiberglass and steel rods.

4. Substantiation of basic principles for determining the coefficient of dissipation

In the dynamic calculations of a multistage SR column, it is very important to estimate the intensity of its oscillations during transition modes of DRPI operation. In most cases, it is under these modes, over a relatively short period of time, the resonance and near-resonance oscillations may occur [11]. The levels of such oscillations, as a rule, can exceed the oscillations of the systems under the modes of established operation. Quite often high levels of oscillations of a SR column during transitional modes cause the occurrence of damage in the elements of the column and their subsequent destruction under the action of alternating load.

Studying of the dynamics of a SR column during transition modes is, strictly speaking, a partial case of the calculation of mechanical system under the action of random loads [12]. A problem on the oscillations of a SR column during transition modes under the action of alternating load can be reduced with sufficient accuracy to the calculation of the systems with a finite number of degrees of freedom. Given this, further research is conducted for a conditionally vertical three-stage SR column. It is modeled in the form of a mechanical system with three degrees of freedom (Fig. 1). For this purpose, the following designations are accepted for the parameters of a SR system:

– m_1, m_2, m_3 are the masses of the first, second and third stages, respectively;

– y_1, y_2, y_3 are the displacement of masses in the system, respectively;

– μ_1, μ_2, μ_3 are the damping coefficients of the stages, respectively;

– k_1, k_2, k_3 are the rigidities of stages that are brought to the point of suspension of the column, and of the joints between stages, respectively;

– $F_1(t)$, $F_2(t)$, $F_3(t)$ are the external loads, applied to the stages.

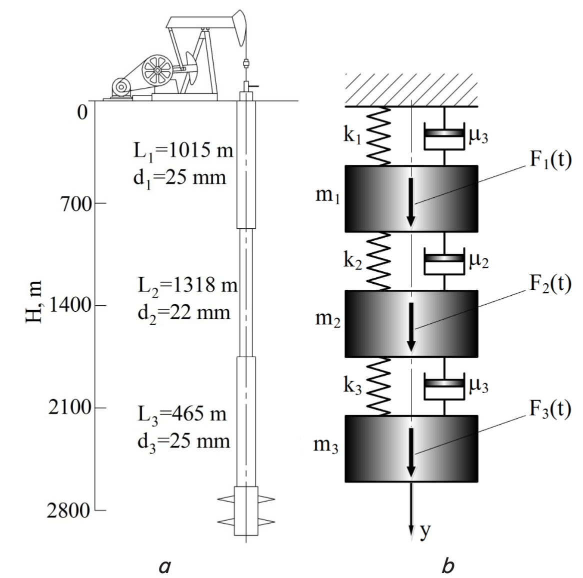

Fig. 1. Three-stage column of sucker rods: *a* – set-up; *b* – dynamic model

With regard to the basic principles of analytical mechanics [13], differential equations of motion for the constructed estimated scheme take the form:

$$\begin{cases} F_1(t) = m_1 \dfrac{d^2 y_1}{dt} + \left(1 + 2\mu_1 \dfrac{d}{dt}\right) k_1 (y_1 - y_2); \\ F_2(t) = m_2 \dfrac{d^2 y_2}{dt} + \left(1 + 2\mu_2 \dfrac{d}{dt}\right) k_2 (y_2 - y_3) - \\ -\left(1 + 2\mu_1 \dfrac{d}{dt}\right) k_1 (y_1 - y_2); \\ F_3(t) = m_3 \dfrac{d^2 y_3}{dt} + \\ +\left(1 + 2\mu_3 \dfrac{d}{dt}\right) k_3 y_3 - \left(1 + 2\mu_2 \dfrac{d}{dt}\right) k_2 (y_2 - y_3). \end{cases} \quad (1)$$

Given the nature of oscillating process of a SR column as a long complex rod, the functions of displacement and load are represented as:

$$y_i(t) = Y_{ai}(\omega) e^{\omega t}, \quad (2)$$

$$F_i(t) = F_{ai}(\omega) e^{\omega t}, \quad (3)$$

where Y_{ai}, F_{ai} are the amplitude values of displacements and forces of the i-th stage of the column; ω is the frequency of forced oscillations.

Substituting the force function (3) and second derivative of displacement function by time (2) into system (1), we, after transformations, received:

$$\begin{cases} F_{a1} = -m_1\omega^2 Y_{a1} + (1+2\mu_1\omega i)k_1(Y_{a1} - Y_{a2}); \\ F_{a2} = -m_2\omega^2 Y_{a2} - \\ -(1+2\mu_1\omega i)k_1(Y_{a1} - Y_{a2}) + (1+2\mu_2\omega i)k_2(Y_{a2} - Y_{a3}); \\ F_{a3} = -m_3\omega^2 Y_{a3} - \\ -(1+2\mu_2\omega i)k_2(Y_{a2} - Y_{a3}) + (1+2\mu_3\omega i)k_3 Y_{a3}. \end{cases} \quad (4)$$

The determinant of the system of equations (4) takes the form:

$$\begin{aligned} D(\omega) &= \left[-m_1\omega^2 + (1+2\mu_1\omega i)k_1\right]\times \\ &\times\left[-m_2\omega^2 + (1+2\mu_1\omega i)k_1 + (1+2\mu_2\omega i)k_2\right]\times \\ &\times\left[-m_3\omega^2 + (1+2\mu_2\omega i)k_2 + (1+2\mu_3\omega i)k_3\right] - \\ &-\left[-m_1\omega^2 + (1+2\mu_1\omega i)k_1\right](1+2\mu_2\omega i)^2 k_2^2 - \\ &-\left[-m_3\omega^2 + (1+2\mu_2\omega i)k_2 + (1+2\mu_3\omega i)k_3\right](1+2\mu_1\omega i)^2 k_1^2. \end{aligned} \quad (5)$$

For convenience, the last expression is recorded in the form:

$$\begin{aligned} D(\omega) &\approx m_1 m_2 m_3\left(\omega^2 - 2\mu_{1f}p_1^2\omega i - p_1^2\right)\times \\ &\times\left(\omega^2 - 2\mu_{2f}p_2^2\omega i - p_2^2\right)\left(\omega^2 - 2\mu_{3f}p_3^2\omega i - p_3^2\right), \end{aligned} \quad (6)$$

where μ_{rf} is the damping coefficient that matches the r-th form of natural oscillations; γ_{rf} is the dissipation coefficient; p_i is the frequency of natural oscillations.

Revealing the brackets in expression (5), we shall equal coefficients at ωi. Excluding the magnitudes of second order of smallness, after transformations, we write the following system of equations:

$$\begin{cases} \mu_{1f} + \mu_{2f} + \mu_{3f} = \mu_1 + \mu_2 + \mu_3; \\ m_1 m_2 m_3\left[\mu_{1f}p_1^2\left(p_2^2 + p_3^2\right) + \mu_{2f}p_2^2\left(p_1^2 + p_3^2\right) + \mu_{3f}p_3^2\left(p_1^2 + p_2^2\right)\right] = \\ = (\mu_1 + \mu_2)k_1 k_2(m_1 + m_2 + m_3) + \\ +(\mu_1 + \mu_3)k_1 k_3(m_1 + m_2) + (\mu_2 + \mu_3)k_2 k_3 m_1; \\ m_1 m_2 m_3\left[\mu_{1f}p_1^2 + \mu_{2f}p_2^2 + \mu_{3f}p_3^2\right] = \\ = m_1 m_2(\mu_2 k_2 + \mu_3 k_3) + m_1 m_3(\mu_1 k_1 + \mu_2 k_2) + \mu_1 k_1 m_2 m_3. \end{cases} \quad (7)$$

For convenience, the right sides of equations of the system will be denoted as follows:

$$\begin{cases} A = \mu_1 + \mu_2 + \mu_3; \\ B = (\mu_1 + \mu_2)k_1 k_2(m_1 + m_2 + m_3) + \\ +(\mu_1 + \mu_3)k_1 k_3(m_1 + m_2) + (\mu_2 + \mu_3)k_2 k_3 m_1; \\ C = m_1 m_2(\mu_2 k_2 + \mu_3 k_3) + \\ +m_1 m_3(\mu_1 k_1 + \mu_2 k_2) + \mu_1 k_1 m_2 m_3. \end{cases} \quad (8)$$

We also note that the attenuation coefficient of oscillations of stages of the column is associated with the damping coefficient by dependence:

$$\mu = 2nm. \quad (9)$$

Then, taking into account (9) and the accepted designations, the system of equations (7) can be represented as:

$$\begin{cases} 2\left(n_{1f}m_1 + n_{2f}m_2 + n_{3f}m_3\right) = A; \\ 2m_1 m_2 m_3\left[n_{1f}m_1 p_1^2\left(p_2^2 + p_3^2\right) + n_{2f}m_2 p_2^2\left(p_1^2 + p_3^2\right) + \right. \\ \left. +n_{3f}m_3 p_3^2\left(p_1^2 + p_2^2\right)\right] = B; \\ 2m_1 m_2 m_3\left[n_{1f}m_1 p_1^2 + n_{2f}m_2 p_2^2 + n_{3f}m_3 p_3^2\right] = C. \end{cases} \quad (10)$$

If we accept for coefficients n_{1f}, n_{2f}, n_{3f} the mean value of n_{rf}, which matches the r-th form of natural oscillations, then we can obtain from (10) an approximated formula for the estimation of attenuation coefficient:

$$n_{rf} \approx \frac{\left[A\dfrac{m_1 m_2 m_3 p_1^2 p_2^2 p_3^2}{p_r^2} + Cp_r^2 - B\right]\left(p^2_{1+\mathrm{Rem}(r+1,3)} - p^2_{1+\mathrm{Rem}(r,3)}\right)}{m_1 m_2 m_3\left(p_2^2 - p_1^2\right)\left(p_3^2 - p_1^2\right)\left(p_3^2 - p_2^2\right)}, \quad (11)$$

where $\mathrm{Rem}(r,3)$ is the remainder after dividing the number of natural form r by 3.

The basic oscillations of a SR column are longitudinal. The dissipation of energy of these oscillations occurs as a result of friction between rods and PCP in viscous medium and internal friction in the material of rods. Damping the oscillations of a column through the dissipation of energy leads to a decrease in their amplitude and frequency. That is why intensive dampening of longitudinal oscillations of a SR column is observed at their constant dissipation. This feature is expressed by a direct dependence of damping coefficient μ_{rf} on the coefficient of dissipation γ_{rf}:

$$\mu_{rf} = \gamma_{rf}/(2\omega_0), \quad (12)$$

where ω_0 is the main operational frequency.

After comparing dependences (9), (11) and (12), the coefficient of dissipation is determined as:

$$\gamma_{rf} = 4m\omega_0 \times \\ \times\frac{\left[A\dfrac{m_1 m_2 m_3 p_1^2 p_2^2 p_3^2}{p_r^2} + Cp_r^2 - B\right]\left(p^2_{1+\mathrm{Rem}(r+1,3)} - p^2_{1+\mathrm{Rem}(r,3)}\right)}{m_1 m_2 m_3\left(p_2^2 - p_1^2\right)\left(p_3^2 - p_1^2\right)\left(p_3^2 - p_2^2\right)}. \quad (13)$$

As can be seen from (13), the coefficient of dissipation depends on the masses, frequencies of natural oscillations of a SR column and the rigidities of stages of a SR column. The frequency of natural oscillations of a SR column depends only on the geometrical dimensions of its stages, while the mass and rigidity of each degree depends on its geometrical dimensions and material. Therefore, the study of change in the coefficient of dissipation for the configurations of SR columns with different rigidity is essential to ensure their resonance-free operation.

5. Results of examining the parameters of dissipation

For further research we selected a three-stage SR column. Length and diameters of the column's stages, equipped with steel rods according to [1], are given below:

– the first stage – 3329 feet (1015 m) and 1 inch (25 mm);

– the second stage – 4325 feet (1318 m) and 0.875 inch (22 mm);

– the third stage – 1525 feet (465 m) and 1 inch (25 mm).

A SR column enables a descent of pump with conditional diameter of 2.25 inches (56 mm) for the depth of 9300 feet (2835 m). Given current trends regarding the use of SR made of composite materials, analytical study was conducted for four variants of the set-up of a three-stage column (Table 1).

Table 1

Variants of the set-up of a three-stage SR column

Column stage	Materials of stages for configuration			
	No. 1	No. 2	No. 3	No. 4
1	Steel	Fiberglass	Fiberglass	Steel
2	Steel	Steel	Fiberglass	Fiberglass
3	Steel	Steel	Steel	Steel

When calculating the parameters B and C (8), rigidities of stages of a SR column were determined by formulas:

$$k_i = \frac{A_i E_i}{l_i}, \qquad (14)$$

where A_i is the cross-sectional area of the stage; E_i is the modulus of elasticity of material of the stage; l_i is the length of the stage.

The masses of stages in a SR column were determined taking into account their length and the resultant mass of one meter of rods.

Table 2

Parameters of a three-stage SR column, equipped with fiberglass and steel rods

Stage	Length, m	Diameter, mm	Material	Mass m_i, kg	Rigidity of the stages k_i, N/m
1	1015	25	Steel	33596.5	$1.016\cdot10^5$
			Fiberglass	1339.8	$2.418\cdot10^4$
2	1318	22	Steel	33345.4	$6.057\cdot10^4$
			Fiberglass	1291.6	$1.442\cdot10^4$
3	465	25	Steel	15391.5	$2.217\cdot10^5$

According to [1], the main circular frequency of forced oscillations of a SR column is ω_0=0.398 rad/s. Circular frequencies that match the first, second and third form of natural oscillations of a SR column are equal to, respectively:

– for set-up No. 1 p_1=4.405 rad/s; p_2=10.8016 rad/s; p_3==72.747 rad/s;

– for set-up No. 2 p_1=3.178 rad/s; p_2=7.078 rad/s; p_3==12.088 rad/s;

– for set-up No. 3 p_1=2.739 rad/s; p_2=6.761 rad/s; p_3==15.956 rad/s;

– for set-up No. 4 p_1=2.877 rad/s; p_2=7.806 rad/s; p_3==12.461 rad/s.

Guided by the theoretical provisions, given in [8], in order to determine and analyze the dissipation parameter (13), we shall use coefficients in the dimensionless form. The first coefficient is determined by relations between rigidities of the adjacent stages $a_1=k_2/k_1$ and $a_2=k_3/k_2$, and the second one – by the relations between dissipation coefficients of the adjacent stages $c_1=\gamma_2/\gamma_1$ and $c_2=\gamma_3/\gamma_2$.

By the results of research [9] for a column, equipped with fiberglass rods, in contrast to the steel column, there is a noticeable damping of the amplitude of oscillations due to internal friction. That is why of practical interest here are determining and examining the dissipatio coefficients of oscillations of a SR column with fiberglass rods. For set-up No. 2, as graph in Fig. 2 shows, with a decrease in relation $a_1=k_2/k_1$ (that is, with increasing the rigidity of first stage k_1), coefficient of dissipation γ_{1f} decreases and approaches 0.12. At the same time, γ_{2f} and γ_{3f} increase, accordingly, to values 0.42 and 0.35. With an increase in relation $a_1=k_2/k_1$ (that is, with decreasing the rigidity of k_1 of the first stage), γ_{2f} and γ_{3f} decreases to values 0.14 and 0.1, respectively; while γ_{1f} increases to value 0.38. It follows from graph in Fig. 3 that with a decrease in the ratio $a_2=k_3/k_2$ (that is, with increasing the rigidity of the second stage k_2), coefficients of dissipation of the second and third stage increase, accordingly, to values γ_{2f}=0.41 and γ_{3f}=0.51; while γ_{1f} for the first stage is reduced to value 0.12. With an increase in the relation $a_2=k_3/k_2$ (that is, when reducing the rigidity of the second stage k_2), γ_{3f} approaches γ_2. As illustrated by the graph in Fig. 4 (set-up No. 3) and as an analysis of formula (13) confirms, γ_{rf} depends on γ_i linearly and at c_1==γ_2/γ_1=1, $\gamma_{2f}\approx\gamma_2$; $\gamma_{1f}\approx\gamma_{3f}\approx(\gamma_2+\gamma_3)/2$=0.4. It follows from the graph in Fig. 5 and formula (13) for set-up No. 4 that γ_{rf} depends on γ_i also linearly, and at $c_2=\gamma_3/\gamma_2$=1; $\gamma_{1f}\approx\gamma_{3f}\approx\gamma_3$=0.3.

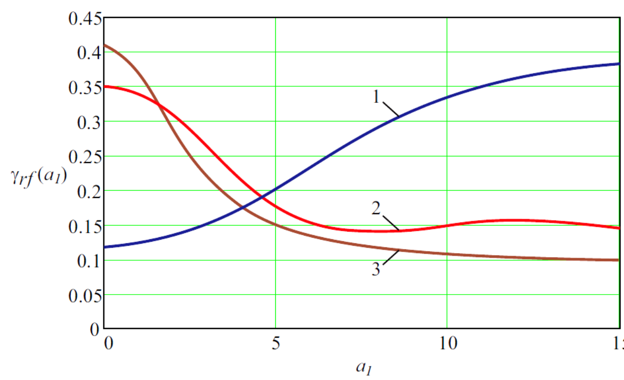

Fig. 2. Graph of dependences of dissipation coefficients γ_{rf} on the dimensionless parameter a_1 (at a_1=2.5 γ_1=0.14; γ_2=0.28; γ_3=0.24): 1 – curve $\gamma_{1f}(a_1)$; 2 – curve $\gamma_{2f}(a_1)$; 3 – curve $\gamma_{3f}(a_1)$

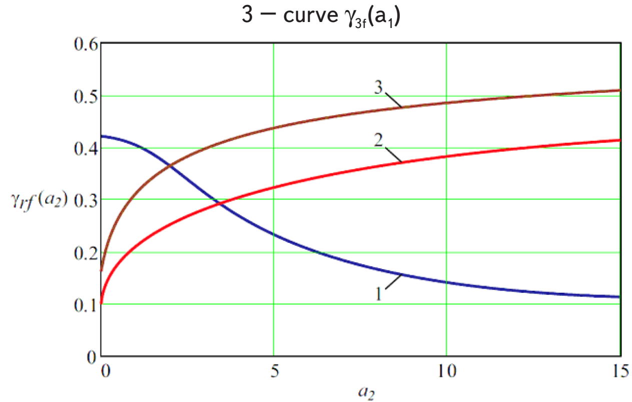

Fig. 3. Graph of dependences of dissipation coefficients γ_{rf} on the dimensionless parameter a_2 (at a_2=2.5 γ_1=0.14; γ_2=0.28; γ_3=0.24): 1 – curve $\gamma_{1f}(a_2)$; 2 – curve $\gamma_{2f}(a_2)$; 3 – curve $\gamma_{3f}(a_2)$

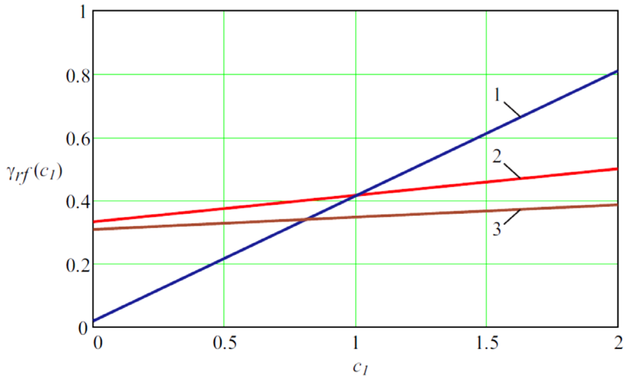

Fig. 4. Graph of dependence of dissipation coefficients γ_{rf} on the dimensionless parameter c_1: 1 — curve $\gamma_{1f}(c_1)$; 2 — $\gamma_{2f}(c_1)$; 3 — curve $\gamma_{3f}(c_1)$

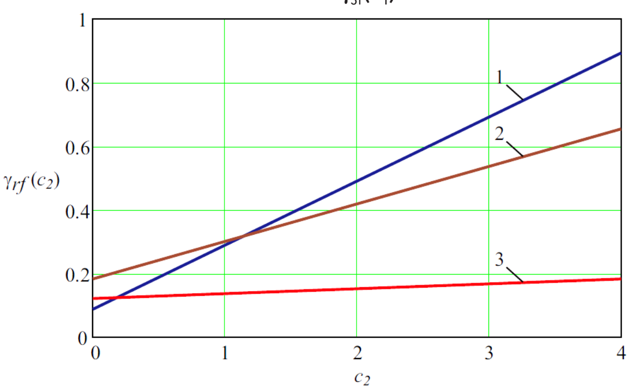

Fig. 5. Graph of dependence of dissipation coefficients γ_{rf} on the dimensionless parameter c_2: 1 — curve $\gamma_{1f}(c_2)$; 2 — $\gamma_{2f}(c_2)$; 3 — curve $\gamma_{3f}(c_2)$

6. Discussion of results of examining the coefficient of dissipation

Based on the above results of calculation and constructed graphic dependences, we can argue that by a proper selection of rigidities of a column's stages, it is possible to provide the required energy dissipation of its oscillations and, in addition, to prevent the occurrence of resonance. A change in rigidities of separate stages of a SR column may be carried out either by changing their geometrical dimensions or changing the material that they are made of. As research results reveal, the inclusion in set-up No. 2 of the first fiberglass stage instead of the steel one (at a_1=2.5) causes an increase in the attenuation coefficient in the fiberglass stage to γ_{1f}=0.38 and its simultaneous reduction in the steel ones to γ_{3f}=0.1 The use of the first fiberglass stage instead of the steel one reduces its rigidity by 4.2 times and leads to an increase in the coefficient of dissipation of oscillations by 3.8 times. An increase in the rigidity of the weighted steel bottom (at a_2=3.7) in a narrow range reduces coefficient of dissipation of the upper fiberglass stage by 3.6 times. However, the linear increase in dissipation coefficients in set-ups No. 2, No. 3 and No. 4 with fiberglass stages predetermines a corresponding decrease in the amplitude and frequency of their oscillations. Such approach makes it possible to prevent the phenomenon of resonance in the operation of conditionally vertical SR column during transition modes of its work under the action of alternating load. On the other hand, it will help to minimize the probability of occurring fatigue damage in the elements of a SR column and their subsequent destruction.

5. Conclusions

1. Given the nature of the occurrence of dissipation forces and their impact on the dynamic state of a SR column, we substantiated the possibility of determining parameters of the oscillation dissipation in the stages of a SR column, considering parameters of its set-up.

2. By constructing and solving the system of equations of motion of a conditionally vertical three-stage SR column, we obtained values of dissipation coefficients of oscillations for the stages, formed of fiberglass and steel rods. It is established that the use of a fiberglass stage instead of that made of steel reduces its rigidity by approximately 4 times, and increases the oscillation dissipation coefficient almost as much. The research results obtained allow us to estimate dynamic behavior of a SR column and establish optimal modes of the DRPI operation with the aim of preventing resonance under actual operating conditions.

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THE STUDY OF STRENGTH OF CORRUGATED METAL STRUCTURES OF RAILROAD TRACKS

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Наведено основні дефекти металевих гофрованих водопропускних труб, які виникають внаслідок експлуатації, та висвітлено проблеми забезпечення їх довговічності та міцності. Проаналізовано проблеми адаптації закордонних нормативних документів щодо проектування металевих гофрованих конструкцій на залізничних та автомобільних дорогах України. Наведено результати експериментальних та теоретичних розрахунків несучої здатності металевих гофрованих конструкцій

Ключові слова: залишкові деформації, проектування, пластичний шарнір, рухомий склад залізниць, щільність ґрунтової засипки

Приведены основные дефекты металлических гофрированных водопропускных труб, возникающие вследствие эксплуатации, и освещены проблемы обеспечения их долговечности. Проанализированы проблемы адаптации иностранных нормативных документов по проектированию металлических гофрированных конструкций на железных и автомобильных дорогах Украины. Приведены результаты экспериментальных и теоретических расчетов несущей способности металлических гофрированных конструкций

Ключевые слова: остаточные деформации, проектирование, пластический шарнир, подвижной состав железных дорог, плотность грунтовой засыпки

1. Introduction

Metal corrugated structures (MCS) have been known since the end of the XIX century [1, 2]. In Russia, the first mention of the MCS constructions were found as early as in 1875, when about 1300 linear meters of pipes were laid on the Transcaspian railway. From 1887 to 1914, another 64000 linear meters were laid, which comprised five thou-