Computer modeling of strain process of flexible rods with nonlinear and viscoelastic characteristics

Sh Salimov¹*, G Yusupov² and G Abdieva³

¹Military technical institute of the National Guard of the Republic of Uzbekistan
Tashkent Institute of Irrigation and Agricultural Mechanization Engineers,
Tashkent, Uzbekistan
²Tashkent Institute of Irrigation and Agricultural Mechanization Engineers,
Tashkent, Uzbekistan
³Institute of retraining and training of teachers of the Tashkent region

salimovshoolim@yahoo.com

Abstract. A computer model is a software implementation of a mathematical model, supplemented by various utility programs. A computer model exhibits the properties of a physical model when its abstracts components — the programs — are interpreted by a computer. In addition, a computer model, as a physical device, can be the part of test benches, virtual laboratories. Computer simulation allows without significant difficulties to modify mathematical models, which are the basis for obtaining results with a high degree of accuracy. In the article was considered the application of the developed methods for predicting nonlinear viscoelasticity of flexible rods under various loading conditions based on creep curves is possible only in the case of finite strains Rod oscillations with viscoelastic and nonlinear characteristics are considered in this paper. From the point of view of practice, it is interesting to study the oscillations of flexible rods (yarn) when the rod receives excitation depending on the acting dynamic loads in the form of a real oscillogram.

1. Introduction
A physical model of an object is any other object whose individual properties completely or partially coincide with the properties of the original object. A model is created for the research work which is either impossible or expensive or inconvenient to conduct on a real object. The main targets for which the models are created are:
• to identify the interdependence of variables, the pattern of their changes over time, and to find existing regularities. In the original object the dependencies are determined that directly relate to its functioning;
• to learn to predict the behavior of the object and to control it, experiencing various control options on the model;
• to use models to find optimal ratios of parameters, specific operating models.

Many applied problems for various purposes include the study of vibrational motions of flexible rods (for example, yarns). As is known, a flexible rounder motion performs longitudinal, transverse, and torsional vibrations. The most significant ones are the transverse vibrations. In many technological processes conducted by machines, the forced rods oscillations are observed that occur under the action of external forces. In particular, from the point of view of practice, it is interesting to study the oscillation of rods under existing dynamic loads in the form of a real oscillogram. If, for example, to take a yarn with certain mechanical characteristics as a flexible rod, then it is necessary to know the law of change in tension in the weaving process.

From a comparison of the results of experimental and theoretical studies obtained by various researchers, we can conclude that there is a relationship between the factor of time, strength, and strain in flexible rods. This relationship is expressed by a multifactor nonlinear dependence, in which the values of external forces for yarn tension are variable in magnitude and time.

2. Method

Materials with viscoelastic properties belong to the class of viscoelastic bodies. The process of the strain of such bodies under uniaxial stress state is described by the Boltzmann-Volterra equation

\[ E\varepsilon(\tau) = \left[ \sigma(\tau) + \int_0^\tau K_1(\tau - s)\sigma(s)ds \right], \]

where \( E \) is the instantaneous modulus of elasticity; \( K_1(\tau - s) \) is the influence function; \( s \) is the integration variable.

The given rheological relations describe linear strain relative to \( \sigma \). If to consider the nonlinear properties of the material, then the problem can be reduced to the equation of the cubic theory

\[ E\varepsilon(\tau) = \left\{ \sigma(\tau) + \int_0^\tau K_1(\tau - s)\sigma(s)ds + \int_0^\tau K_3(\tau - s)\sigma^3(s)ds \right\}, \]

\( K_3(\tau - s) \) is the creep kernel for the nonlinear component of strain.

Consider the longitudinal vibrations of a flexible rod with viscoelastic and nonlinear properties. In this case, the problem is reduced to solving an integro-differential equation of the form [2]
under zero boundary and initial conditions: at $t = 0 \ u = u_0(x), \ \frac{\partial u}{\partial t} = \ddot{u}_0(x),$ where $a$ characterizes the wave velocity and accordingly the relaxation kernel, respectively; $e$ is the coefficient of nonlinearity - the external dynamic load.

When deriving equation (1), the nonlinear and viscoelastic properties of the rod are taken into account. In this case, the external dynamic load is determined based on the processing of experimental data. The pattern of change in external dynamic load differs significantly from the ideal law of accelerations due to accompanying vibrations mainly from the first natural frequency.

Further, the problem of forced oscillations using the well-known Bubnov-Galerkin methods in combination with the averaging method is reduced to a system of ordinary nonlinear differential equations with complex coefficients $[1–7].$

The system of equations (2) is replaced by close equations $[3]$ $a_1 = 2b + \lambda \omega_s + \gamma \omega_{s1}, \ a_2 = \lambda^2 (1 - \omega_s), \ a_3 = \gamma (1 - \omega_{s1}).$ $[4]$

The resulting system of equations is solved numerically using the "Mathcad" mathematical software.

3. Results and discussion

It should be noted that the solution has different expressions at different time intervals, therefore their values can be determined using real oscillograms by available formulas for individual sections or in a table form $[8-11].$

In the case of a harmonic external load, force curves in the rod are obtained and presented in the form of graphs in Figure 1.
Figure 1. Tension changes depending on time $t$

($T_1$ is the tension of viscoelastic yarn with account for nonlinearity; $T_2$ is the tension of viscoelastic linear yarn; $T_3$ is the tension without account for nonlinearity; $T_4$ is the tension of linear elastic yarn).

The following initial data were taken as input quantities into the equations of motion: $a = 4$; $A_1 = 0.123$; $c = 0.08$.

$$b_1(t) := 10 \cdot \sin \left(25 \cdot t^2 \right)$$

$$A_2 = 0.0132;$$

$$\alpha_1 := 0 \quad \beta_1 := 0.01$$

$$\alpha_2 := 0.15 \quad \beta_2 := 0.05$$

The graphs show that an account for nonlinearity significantly affects the strained state of a rod.

As a model, the Boltzmann-Volterra integral relation was used, and as a relaxation function - the three-parameter Koltunov-Rzhanitsyn kernel, ensuring the least error in the calculation description of a flexible rod creep in a given region of strains [11, 12].

In most cases, a single experiment or a single run of the model is not enough to achieve the desired result. For example, our task is a parametric optimization of the source data. In solving this problem, a separate model run is used. The optimization algorithm sets some values entering the equations of motion of the parameters. Setting various values of these parameters, as a result of numerical experiments, the most rational values of the incoming parameters are determined [13-17].
A separate task is to find special values of the model coefficients that qualitatively change the pattern of their behavior. For the considered example, determining the rational values of characteristic quantities is not difficult. In the general case, when applying numerical procedures for searching for rational values, input parameters that qualitatively change the behavior of the problem in question, it is necessary to know that they exist and to be able to evaluate the range of parameters to look for them.

In our case, the most rational values of the parameters entering the resolving equations are:

\[ \alpha = 0.2; \ \beta = 0.4; \ \gamma = 0.125. \]

The methods for computer modeling technology of dynamic processes are proposed, using the example of yarn oscillation.

4. Conclusions

1. It was stated that the application of the developed methods for predicting nonlinear viscoelasticity of flexible rods under various loading conditions based on creep curves is possible only in the case of finite strains.
2. For the application of the developed methods for predicting the viscoelastic properties of flexible rods, an adequate description of the creep of flexible rods is necessary.
3. After solving the integro-differential equations of the model as the dependence of the delay time on stress, for the best agreement between the experimental and calculated curves, one should choose those values of the delay time that are comparable with the duration of the load acting on a flexible rod.
4. To correctly describe the creep of the rod, several functions should be applied, in particular, the Boltzmann-Volterra model. As a relaxation kernel, it is advisable to use the three-parameter Rzhanitsin kernel, with which the least error is ensured in the calculation description of the rod relaxation in a given region of strains (stresses).
5. With the known equation of creep and relaxation, elastic and viscous characteristics entering the equation, the integral equations of the model are developed.
6. When predicting relaxation curves of yarn tension by creep curves using the proposed technique, the tension value should be taken into account. Therefore, from a methodological point of view, firstly, it is necessary to predict tensile diagrams corresponding to different tensile rates, and then make a prediction of tension relaxation in flexible rods. It was stated that when combining tensile diagrams corresponding to different strain rates of a flexible rod, the strain rate does not affect the magnitude of the initial tension determined from the tensile diagram.

References

[1] Mirsaidov M M 2010 Theory and methods for calculating earth structures for strength and earthquake resistance (Tashkent, FAN) pp 312

[2] Abdieva G B, Mavlanov T M and Khamraeva S A 2013 Determination of optimal forms of textile shells at internal pressures Materials of the International scientific-practical conference "VII-Okunev's readings St Petersburg pp 93-95
[3] Abdieva G B Mavlanov T M 2013 Determination of creep of textile materials under uniaxial tension Journal Problems of Textile Tashkent 2 pp 56-58
[4] Mavlanov T M 2013 Practical modeling of dynamic systems with flexible yarns Materials of the International scientific-practical conference Kazakhstan Zhetisay pp 580-583
[5] Mirsaidov M M, Abdikarimov R A and Khodzhaev D A 2019 Dynamics of a viscoelastic plate carrying concentrated mass with account of physical nonlinearity of material Part 1 PNRPU Mechanics Bulletin 2 pp 143-153 DOI: 10.15593/perm.mech/2019.2.11
[6] Mirsaidov M M, Sultanov T Z and Rumi D F 2013 An assessment of dynamic behavior of the system "structure - foundation" with account of wave removal of energy. Magazine of Civil Engineering 39 pp 94-105 DOI: 10.5862/MCE.39.10
[7] Mirsaidov M M 2018 Strength parameters of earth dams under various dynamic effects. Magazine of Civil Engineering 77(1) pp 101-111 DOI: 10.18720/MCE.77.9
[8] Maltsev A A, Maltsev V P and Myachenkov V I 1979 Dynamics of axisymmetric shell structures In Applied problems of strength and plasticity Mechanics of deformable systems Interuniversity collection Gorky GSU pp 150 - 158
[9] Maltsev A A 1982 Dynamic loading of thin-walled prismatic structures In book Calculation of transport and building structures using computer Proc MIET 618 M MIET pp 16-23
[10] Alexandrov A V 1963 The displacement method for calculating slab and beam structures In Proceedings of MIIT Transzheldorizdat 174 pp 4-18.
[11] Filatov A N 1974 Asymptotic methods in the theory of differential and integro-differential equations (Tashkent, FAN) p 216
[12] Mavlanov T, Karimov A 1979 On the free forced vibrations of the fundamental slabs of silo structures Reports of AS UzSSR series Tech. Sci 4 pp 43-47
[13] Vestyank AV, Gorshkov A G and Tarlakovskyy D T 1983 Unsteady interaction of deformable bodies with the environment M, AISTI Russian AS 15 pp 69-121
[14] Koltunov V P, Mayboroda A S and Kravchuk 1983 Applied mechanics of a deformable solid (Vysshaya shkola) p 350
[15] Mirsaidov M M, and Khodzhaev D A 2019 Dynamics of a viscoelastic plate carrying concentrated mass with account of physical nonlinearity of material Part 1 PNRPU Mechanics Bulletin 2 pp 143-153 DOI: 10.15593/perm.mech/2019.2.11
[16] Mirsaidov M M, Sultanov T Z and Rumi D F 2013 An assessment of dynamic behavior of the system structure - foundation with account of wave removal of energy Magazine of Civil Engineering 4 pp 94-105 DOI: 10.5862/MCE.39.10
[17] Mirsaidov M M 2018 et al Strength parameters of earth dams under various dynamic effects Magazine of Civil Engineering 77(1) pp 101-111 DOI: 10.18720/MCE.77.9