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DETERMINING THE FEATURES OF OSCILLATIONS IN PRESTRESSED PIPELINES

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This paper considers the structural solution for a main above-ground pipeline with a pre-stressed winding, which makes it possible to improve the efficiency of operation and reduce material consumption. The results from studying experimentally the features in the operation of prestressed pipelines under static operating loads are given. It is shown that the radial movements of the wall of a pre-stressed pipeline are constrained by the strained winding, which prevents its deformation. It was revealed that increasing the tension force of the winding wire reduces circular stresses in the pipeline wall by 1.3...1.6 times and increases meridional ones by 1.2...1.4 times.

The experimental study into the models of prestressed pipelines with free vertical and horizontal oscillations has established the dependence of frequency characteristics on the operating conditions and pre-stress parameters. It was found that the envelope amplitude on the oscillogram of free attenuated oscillations takes the shape of an exponent, which indicates the damping effect of the pre-stress. Analysis of the change in the dynamic characteristics of the models depending on the pre-stress force has revealed that the frequencies of free oscillations increase by 1.5÷1.6 times while the oscillation decrement decreases by 1.2÷1.25 times.

This paper reports the results of studying the influence of pre-stress parameters on the stressed-strained state of the pipeline model under forced horizontal and vertical oscillations.

It is shown that the diagrams of circular dynamic stresses and deformations in the models of a prestressed pipeline are smoother compared to similar characteristics of a conventional pipeline tested at the same experimental parameters.

The study results have made it possible to quantify the features in the operation of a pre-stressed pipeline under static and dynamic influences, taking into consideration the pre-stress parameters and operating conditions

Keywords: pre-stressed pipeline, winding wire, experimental analysis of oscillations, free attenuating oscillations, forced vibration

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1. Introduction

The construction and operation of large-scale pipelines are associated with high material costs, the danger of environmental pollution, and a large scale of destruction during accidents. In this regard, such structures are categorized as especially responsible objects whose design should be based on scientifically based, technically feasible, fundamentally new, and economically justified solutions [1–3].

One of the ways to improve and design new structural solutions, increase the bearing capacity, reduce the material consumption for shell steel structures (pipelines, tanks, gas tanks, etc.) is to use the technique of pre-stressing such structures [4–6]. The idea underlying this technique is to induce initial stresses in the wall of the shell by winding a high-strength profile on the shell body with a certain pre-stress. The stressed winding generates the stresses in the wall of the shell whose sign is inverse to the operational stresses, which are added to the reserve of the bearing capacity of the structure or lead to material savings by reducing the thickness of the shell wall [7, 8]. At the same time, the efficiency of shell operation increases by leveling the circular and longitudinal stresses in the shell wall. Pre-stress can also be used to increase or restore the bearing capacity of structures.

One of the important advantages of such structures is the ability to adjust the stressed state of the structure by selecting such design parameters for pre-stress as the force, pitch, and the winding angle of the winding thread.

The relevance of research into this issue relates to the fact that the gas and oil fields discovered in recent years, unique in their reserves, as well as the increase in oil exports, predetermined the increase in the volume of construction of pipeline transport, one of whose basic links are main pipelines. Transportation of oil and petroleum products to consumption points is largely complicated by the remoteness of the fields from industrial centers. Consequently, it is necessary to build pipelines of exceptionally high capacity and reliability, which is possible only based on fundamentally new structural solutions. One of the effective ways to solve the issue of strength and durability of above-ground main pipelines is considered to be the winding of a high-strength profile (wire, tape, fiberglass, fiber plastic, etc.). Such a profile is wound around the body of the pipeline, produced by the industry according to conventional technology, perpendicular at an angle to the generatrix of the pipeline.

2. Literature review and problem statement

Deformation and limiting conditions of shell structures of tanks for transporting bulk materials are considered in [9]. The influence of operational loads and geometric dimensions of the tank on its stability has been studied. The effect of internal pressure and the filling level of the tank on the critical load value is shown. However, the cited work considers the influence of only the parameters of the operating load on the stressed state and stability of the tank and does not tackle the influence of pre-stress parameters.

The results of theoretical and experimental studies into the stressed-strained state of the cylindrical shell, designed for storage and overloading of various liquid and bulk materials, are reported in [10]. Note that the cited work does not consider the effect exerted on the stressed state of the shell by pre-stress parameters, overall dimensions, and basic operating loads. The dynamics of such structures have not been investigated.

The authors of [11], based on many years of research, designed a special structure of the welded pipe with a bandage of high-strength wire. The experimental study conducted confirmed the possibility of excluding avalanche destruction. However, the cited work does not take into consideration the fact of using design parameters (the angle, pitch, and winding force) to control the stressed state of the shells, as well as the application of optimal parameters to increase the seismic resistance and strength of shell structures.

The effect of damage and defects in the winding wire on the stiffness and natural frequencies of prestressed pipes is considered in [12]. The finite-element method (FEM) was used to estimate the natural frequencies and oscillation shapes of the pipes. It should be noted that the dynamic behavior and changes in the natural frequencies of the structures were considered only to compare intact and damaged pipelines. There is no analysis of the effect of the design characteristics of the prestressed winding on the dynamic characteristics of the structure.

The authors of [13] investigate the nonlinear analysis of the free oscillations of prestressed round cylindrical shells and examine in detail the simultaneous effect of the prestressed state and the elastic base on the natural frequencies of the shells under various boundary conditions. As a parameter of the preliminary stress, the initial tension force is considered. However, the cited work does not consider the effect of fluid movement and liquid loading level on the dynamic characteristics of the shell. There is no experimental confirmation of the reported results.

Paper [14] reports the results of studying the dynamic behavior under small oscillations of the prestressed thin cylindrical shells transporting liquid. The influence of initial tension, internal pressure, fluid flow rate, and various geometric properties of the shell are considered. However, the cited work considers the operating loads and does not tackle the design parameters of the prestressed wire. The features of the dynamic operation of the prestressed shell structures have not been evaluated and there is no experimental confirmation of the reported results.

The results of a study to determine the optimal parameters when winding the wire thread around the pipeline in order to dampen vibrations are considered in [15]. Tests have established that the use of a wire winding prevents the occurrence of resonance. At the same time, the nature of structures operation, under dynamic influences, changes markedly (the amplitude of oscillations decreased by more than five times). The optimal parameters of the winding from the position of dynamic resistance and efficiency of vibration damping are revealed. In the cited work, however, there are no clear conclusions and recommendations on the choice of winding parameters, which does not make it possible to apply the results of work in practice.

Study [16] considers the recommendations for the design, selection of pipes, and construction of underground and above-ground pipelines. Pipes made of cast iron, malleable cast iron, steel, plastic polyethylene, PVC, fiberglass, concrete, fibrous and asbestos-cement pipes were examined. With reference to the relevant standards, the authors tackled the structural design of rigid, semi-rigid, and flexible pipes, longitudinal stresses, the wall thickness of steel pipes, resistance to internal forces, pipe limitation, and thrust blocks. However, the issue of improving the strength characteristics of the operated large-diameter steel pipelines has not been considered, where an important fact is to increase the seismic resistance of existing and operated pipelines.

Studies also addressed the strength of the construction of safe and durable pipelines. For example, work [17] was considered, in which possible seismic problems are not touched upon, although the route of construction of the gas pipeline passes through seismically active areas where the proposed method could be very relevant in terms of ecology, safety, and durability of the structure.

Work [18] describes the risks that lead to losses. Examples include a malfunction in a transportation pipeline that could lead to the release of gas or oil, resulting in negative consequences. In uninhabited areas, the final impact of the release is small, whereas in densely populated areas the consequences can be very serious; such areas are called high-impact areas. From the cited work, we can conclude that it is important to understand what threats increase the likelihood of risk in the pipeline system and how to assess them. However, there are no clear proposals to improve the seismic resistance of pipelines, which is a very important issue related to the safety of the pipeline system.

The results of the reviewed studies [9–18] reveal general issues of construction quality, design, or only those advantages of winding the pipeline with strained wire, which significantly affect the resistance to vibrations and the efficiency of damping vibrations. However, that does not make it possible to accurately assess the impact of winding on the dynamic characteristics of the pipeline. The dependence of the limiting destructive pressures on pre-stress parameters has not been established.

Research on the use of pre-stress in the structures of above-ground main pipelines is clearly not enough. There are practically no studies on the influence of pre-stress parameters (the pitch, tension force, winding angle, and winding thickness) on the stressed-strained state of a pipeline wall and on the dynamic characteristics of the system under static and dynamic influences.

Our review of the theoretical and experimental studies into the prestressed thin sheet structures leads to the conclusion that the prestressed structures can be attributed to active dynamic protection systems. Such systems are adapted to dynamic influences by adjusting changes in the properties of the system in the process of oscillations.

3. The aim and objectives of the study

The purpose of this study is to identify the features in the stressed-strained state and the main dynamic characteristics of the prestressed pipeline model under static and dynamic influences. This will make it possible to define the actual operation, as well as the influence of the design parameters of pre-stress on the overall operation of the pipeline model under statistical and dynamic influences. The results to be obtained could make it possible to practically assess the seismic resistance of linear cylindrical structures.

To accomplish the aim, the following tasks have been set:

– to perform a static analysis of the stressed-strained state of the wall of the prestressed pipeline model under various operating conditions and pre-stress parameters;

– to investigate the behavior and determine the dynamic characterization of prestressed pipe models under free oscillations, different operating conditions, and pre-stress parameters;

– to assess the effect of operating conditions and pre-stress parameters on the distribution of dynamic stresses in the wall of the prestressed pipeline model under forced oscillations.

4. The study materials and methods

For thin-walled metal structures, in accordance with the tasks of experimental research, the scale within 1/5...4/15 lifesize is optimal. Therefore, taking into consideration these requirements, as well as taking into account the possibility and technique to apply a load, in the measurement of the studied parameters we adopted a modeling scale of 1:5 of lifesize. The material of the model is the material of an actual structure – grade St 8 steel.

Simulation of the effects, geometric dimensions, and parameters of the structure was carried out on the basis of the correspondence of a simple mechanical and affine similarity between the model and the full-scale structure. This theory is based on the analysis of the dimensionalities of physical quantities. At the same time, the constancy of the scale of modeling is established between the parameters of the model and actual structure.

The dynamic tests of pipeline models were carried out under the mode of free and forced resonant oscillations, which made it possible to accurately identify the frequencies and shapes of not only the main tone of oscillations but also the higher tones of oscillations of the models.

Tests were carried out on three models. One of them is without pre-stress, and the other two are pre-stressed. These models are distinguished by the step of winding the wire according to the flowchart of the experimental system for testing pipeline models for dynamic effects. The corresponding flowchart is shown in Fig. 1.

The choice of measuring devices, equipment, and instruments was carried out taking into consideration the tasks assigned to the experimental study.

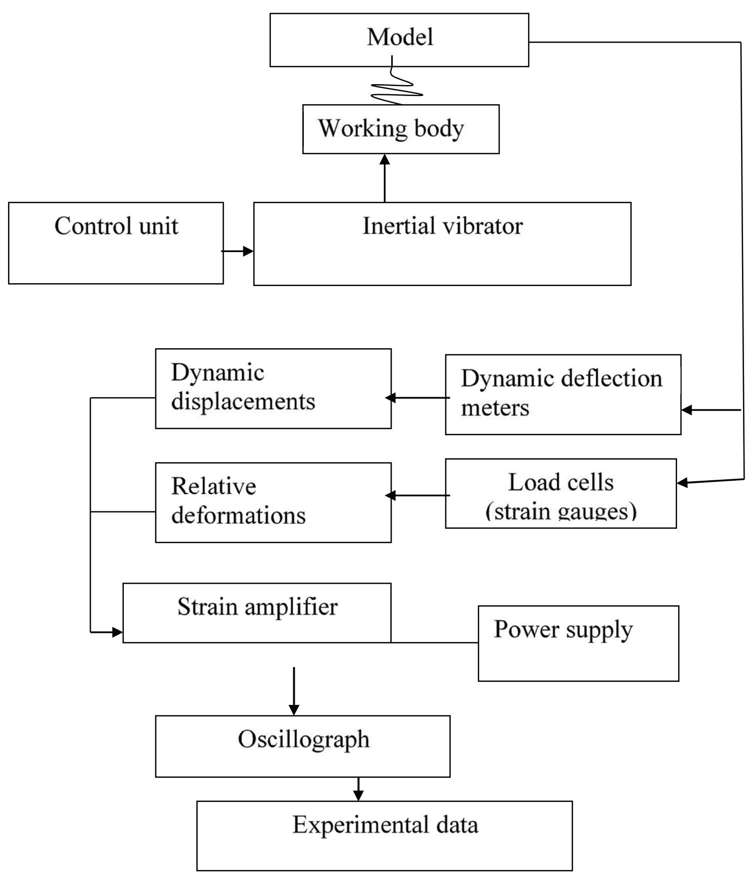


Fig. 1. Flowchart of the experimental system

The stressed-strained state of the pipeline model was investigated by strain gauges.

As primary transducers in the measurement of relative dynamic deformations, single element strain gages on a paper base of 5 and 10 mm were used.

When selecting the exciter of oscillations, the assumed dominant natural frequency, and the amplitude of oscillations, at which the values of dynamic stresses are sufficient for registration, were taken into consideration.

For dynamic testing of pipeline models, a vibratory electrodynamic inductive action bench with an operating frequency range of the vibrator up to 5,000 Hz was used.

The measurement of dynamic movements was carried out by a strain gauge ring displacement transducer.

To record information under dynamic influences, a 24-channel oscillograph with a working frequency band from 0 to 400 Hz was used in our work.

The mode of free attenuation of the model was induced by the initial displacement of the pipeline using a special installation, which, in accordance with Fig. 2, 3, includes a cable and a string of high-strength wire with a diameter of 0.8 mm. Displacement of the pipeline was executed in the middle of the span ($L/2$) and at the end of the model (L).

We studied the stressed-strained state and the dynamic characteristics of the models of the above-ground steel pipeline under horizontal and vertical dynamic influences, which are the most common and dangerous areas of influence.

The working body of the vibrator was arranged in the middle of the span and at the end of the model, in accordance with Fig. 4.

To study the spatial shapes of oscillations and build amplitude-frequency characteristics, the optimal mode of smooth-step change in the frequency of the perturbing force was chosen. The essence of the latter is in the fact that between the accepted stages, the frequency of the perturbing force changes smoothly at a step of 2....3 seconds until the stationarity of the oscillatory process at each stage is achieved.

Dynamic tests were carried out on the same models on which the operation of the pipeline model under static influences was studied.

The winding force for prestressed pipelines was taken to be less than the critical one and was accepted to be equal to $0.25S_{cr}$ and $0.75S_{cr}$, where S_{cr} is the tension force of the wire, at which there is a loss of stability of the pipe, which is determined from the following formula:

$$S_{cr} = \frac{2}{r}\sqrt{E_1 J E_2 \delta_2}, \quad (1)$$

where E_1, E_2 are the modulus of elasticity of the shell and winding materials, $E_1 J$ is the stiffness of the ring,

$$J = \frac{\delta_1^3}{12\left(1-\mu^2\right)},$$

δ_1, δ_2 is the thickness of the shell and winding.

The pipes were filled with water; the cases of empty ($0H$), partially filled ($0.5H$; $0.75H$), and fully filled pipeline ($1.0H$) were considered. At the same time, we considered options for the absence or presence of internal overpressure (0.5 MPa, 1.0 MPa).

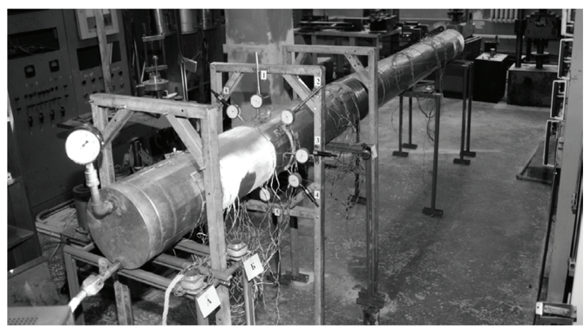


Fig. 2. Photograph of an experimental pipeline model

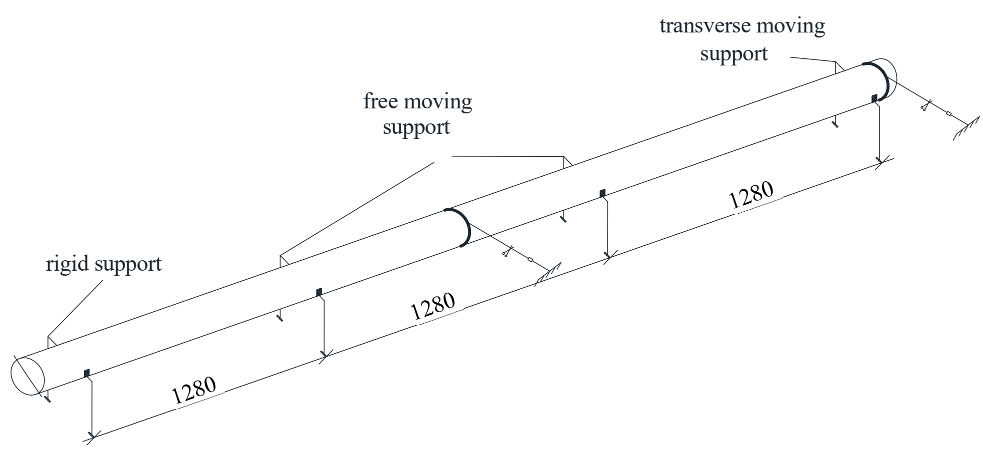


Fig. 3. Schematic showing the excitation of free vibrations of the pipeline

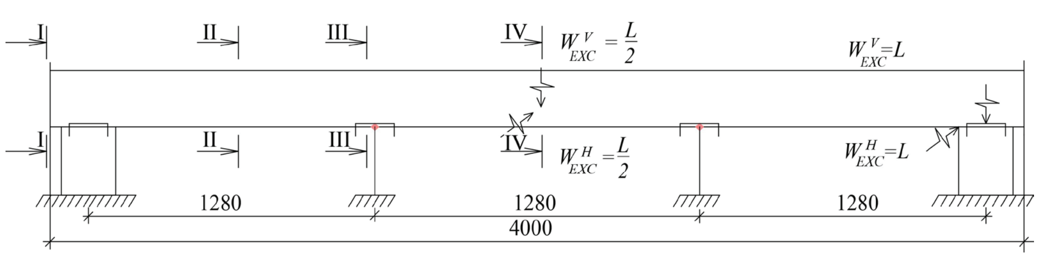


Fig. 4. Schematic showing a dynamic impact application

Thus, these parameters simulate the main, possible variants of the operational modes of main pipelines.

5. Results of studying the oscillations of prestressed pipelines

5. 1. Static analysis of pre-stresses

The deflected modes of pipelines at static internal pressure were experimentally analyzed. The prestressed state is achieved by winding the wire onto the pipeline. As a result of the experimental analysis of the pipe winding, it was found that the circumferential stresses are reduced by 1.2÷3.6 times, and the axial stresses increase by 2÷2.2 times compared to a conventional pipeline without winding. Deformations of the wall in the circular direction due to the pre-stress decreased by 1.2...4.2 times. The greatest effect of pre-stress is achieved at high internal overpressures in the pipeline, in which the joint operation of the pre-stressed winding and the wall contributes to some smoothing of the deformation line and tension of the pipeline wall.

As it follows from the experimental study, winding the pipeline with wire significantly reduces von Mises stress. The contribution of circumferential stresses to von Mises stresses is much higher than the contribution of axial stresses. The values of the circumferential stresses are reduced by winding the pipeline. The static bending mode of the structural wall (Fig. 2) in the longitudinal direction is close to the bending mode of a three-section beam with a constant cross-section.

5. 2. Analysis of free oscillations

The natural frequencies and decrements of attenuation of free oscillations have been experimentally investigated. The influence of the performance characteristics of the structure and pre-stress on free oscillations was analyzed. Table 1 gives data on the experimental analysis. The model type is shown in the first column of the table. The second column shows the winding turn step. The wire tension forces that induce the pre-stress are given in the third column. The level of filling the pipeline with liquid and the values of internal overpressure are shown in the fourth and fifth columns of Table 1. The frequency of free oscillations is given in the sixth column of Table 1. The natural frequencies of horizontal and vertical oscillations are shown in numerators and denominators, respectively. A decrement of oscillations is given in the seventh column of Table 1.

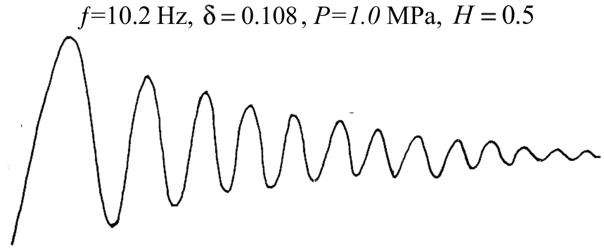
Three cases of filling the pipeline with liquid were investigated. The first case corresponds to a pipeline without liquid, which is denoted H=0. The second and third cases correspond to half-filling and complete filling of the pipeline with liquid, which is indicated by H=0.5 and H=1, respectively. The dynamics of the structure are analyzed at zero internal pressure P=0 and at internal pressure P=1 MPa.

An analysis of free attenuation oscillations is carried out. As follows from the waveforms in Fig. 5, the natural free oscillations are described by an exponent. It is important to note that the wire winding significantly affects the absorption of vibration energy. This follows from the analysis of the decrements of oscillations, which are given in Table 1. The reduction in vibrations is small for a pipeline without winding. The maximum reduction in oscillations is observed in model B where the winding is the densest. As follows from Table 1, the decrement of oscillations increases by 1.2÷2.2 times due to the winding of the pipeline.

As it follows from Table 1, the natural frequencies of the pipeline winding are increased by 1.4÷1.6 times compared to the pipeline without winding. Since the wire works in conjunction with the shell, the rigidity of the structure increases compared to the structure without wire. Consequently, the natural frequencies also increase.

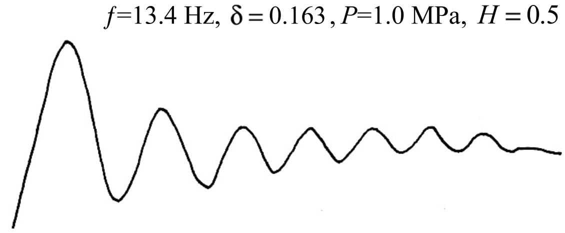
Analysis of the change in the dynamic characteristics of models depending on the pre-stress force from $S=0.25S_{cr}$ to $S=0.75S_{cr}$ leads to an increase in the frequencies of free oscillations by 1.5÷1.6 times and a decrease in the decrement of oscillations by 1.2÷1.25 times.

f=10.2 Hz, $\delta = 0.108$, P=1.0 MPa, $H = 0.5$



a

f=13.4 Hz, $\delta = 0.163$, P=1.0 MPa, $H = 0.5$



b

Fig. 5. Waveforms of attenuation oscillations of pipeline models at H=0.5: *a* – without pre-stress; *b* – prestressed with the pitch of winding equal to *d*

Table 1

Experimental values of frequencies and decrements of free oscillations of pipeline models under different operating conditions under horizontal and vertical oscillations

Model type	Pitch of winding	Tension force	Filling level	Internal overpressure, MPa	Frequency of free vibrations, Hz	Decrement of oscillations
Model A	–	–	0	0	12.9/12.8	0.132/0.190
				1.0	12.8/10.2	0.122/0.115
			0.5	0	12.1/9.6	0.117/0.115
				1.0	10.2/8.2	0.108/0.07
			1.0	0	11.0/8.2	0.112/0.102
				1.0	9.2/7.5	0.104/0.062
Model B	*d*	$S=0.75S_{cr}$	0	0	21.8/23.2	0.196/0.230
				1.0	17.6/12.8	0.186/0.171
			0.5	0	15.2/16.8	0.169/0.171
				1.0	13.4/10.8	0.136/0.115
			1.0	0	13.8/15.2	0.162/0.167
				1.0	12.3/10.4	0.126/0.091
Model C	3*d*	$S=0.75S_{cr}$	0	0	18.6/16.8	0.173/0.220
				1.0	15,4/11.6	0.168/0.152
			0.5	0	13.2/14.0	0.158/0.152
				1.0	11.8/10.1	0.122/0.10
			1.0	0	12.4/13.2	0.153/0.148

5. 3. Analysis of forced oscillations

The frequency characteristics of the oscillations of structures with various parameters of pre-stresses and various operating conditions have been analyzed. The properties of stable periodic oscillations of pipelines with wire were considered. The results of measurements of frequency responses are shown in Fig. 6. Forced oscillations of the pipeline without wire are shown in Fig. 6, *a*. The oscillations of pipelines with constant turn pitch *d* and 3*d* are shown in Fig. 6, *b*, *c*, respectively. The forced oscillations of a pipeline half-filled with water and with zero internal pressure are shown in blue lines. The red lines show the oscillations of a pipeline completely filled with water at zero internal pressure. The frequency characteristics of a half-filled filling pipeline with an internal pressure of 0.5 MPa are shown in black lines. The forced oscillations of full-filled pipelines with an internal pressure of 1 MPa are shown by green lines. The liquid is discharged into the pipeline to the required pressure. Pressure is measured by a pressure gauge.

As it follows from the analysis of the frequency response, the winding of pipelines significantly affects the amplitudes and frequencies of resonant longitudinal oscillations. The frequency peaks of pipelines with winding pipelines are less than those of pipelines without winding. If the structure vibrates, there is friction between the pipeline and wire. This friction significantly increases the coefficient of linear attenuation.

The first and second resonance frequencies of the pipeline with the winding of longitudinal oscillations are increased by 1.2...1.5 times compared to the resonance frequencies of the pipeline without winding. The natural frequencies of bending oscillations increase by 1.2...1.6 times. The maximum increase in the resonance frequencies is observed for a structure with winding pitch *d*. In this case, the winding pitch is the smallest.

We analyze the resonant vibrations of pipelines with different levels of water filling, different internal pressure values, and various pre-stress parameters. The resonance frequencies of structures with winding increase by 1.2...1.8 times, and the amplitudes of oscillations decrease by 1.3...2.2 times compared to structures without winding. Experiments have established that the shapes of oscillations of the prestressed pipeline correspond to the oscillation shapes of a three-span rod system of constant cross-section pinched at the ends.

Since winding the wire on the pipeline leads to a decrease in the amplitudes of the resonance oscillations, then this winding can be used for seismic protection of pipelines.

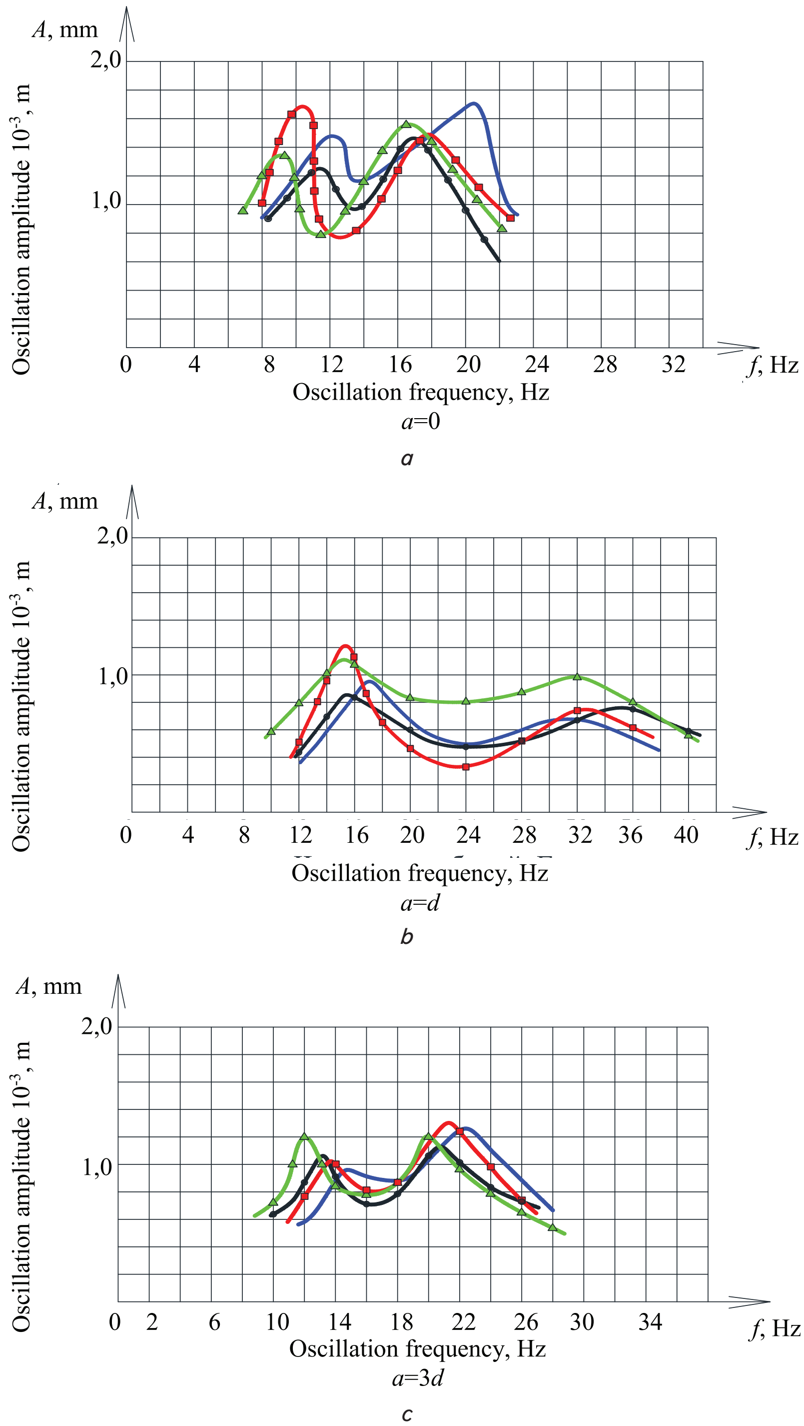


Fig. 6. Amplitude-frequency characteristics of oscillations: *a* – winding pitch is zero *a*=0; *b* – winding pitch is equal to the diameter of the wire *a*=*d*; *c* – winding pitch is equal to triple the diameter of the wire winding *a*=3*d*; *P*=0 MPa: — 0.5 *H*, — 1.0 *H*; *P*=0.5 MPa: — 0.5 *H*, — 1.0 *H*

6. Discussion of results of studying the oscillations of prestressed pipelines

Static analysis of the stressed-strained state of the wall of the prestressed pipeline model under various operating conditions and pre-stress parameters was carried out.

It was found that the circumferential stresses decrease by 1.2÷3.6 times, and the axial stresses increase by 2÷2.2 times compared to a conventional pipeline without winding. Deformations of the wall in the circular direction due to the pre-stress decreased by 1.2...4.2 times. It is shown that the greatest effect of pre-stress is achieved at high internal excess pressures in the pipeline, at which the joint work of the prestressed winding and the wall contributes to some smoothing of the deformation line and tension of the pipeline wall.

The behavior and dynamic characteristics of prestressed pipeline models under free oscillations, various operating conditions, and pre-stress parameters have been investigated. Based on the experimental study of pipeline models at free oscillations, dependences of frequency characteristics on operating conditions and pre-stress parameters have been proposed. The waveforms in Fig. 5 demonstrate that the envelope amplitudes of the free attenuated oscillations take the form of exponents, indicating the damping effect of the pre-stress. This is also indicated by a decrease in the value of the logarithmic decrement of oscillations in Table 1.

The values of frequencies and decrements of free oscillations of pipeline models under different operating conditions under free oscillations (Table 1) show that the use of pre-stress increases the frequency of natural oscillations and reduces the values of the logarithmic decrement of the pipeline model. The values for changing the characteristics of the oscillations depend on the level of filling, the presence or absence of internal overpressure, and the design parameters of pre-stress compared to pipelines without pre-stress.

Models of rectilinear sections of pipelines without compensatory sections have been studied. The influence of operating conditions and pre-stress parameters on the amplitude-frequency characteristics of the prestressed pipeline under forced oscillations has been evaluated.

The properties of stable periodic oscillations of pipelines with wire have been analyzed. The study results (illustrated by the plots in Fig. 6) show that the prestressed winding significantly affects the amplitudes and frequencies of the resonance oscillations of the pipeline model. The frequency peaks of pipelines with winding are less than those of pipelines without winding. When the structure vibrates, friction occurs between the pipeline and wire, which significantly increases the coefficient of linear attenuation. It is noticed that the resonance frequencies of the pipeline with winding with longitudinal oscillations increase by 1.2...1.5 times compared to the resonance frequencies of the pipeline model without winding. The natural frequencies of bending oscillations increase by 1.2...1.6 times. Our analysis of plots in Fig. 6 shows that a maximum increase in resonance frequencies is observed for a structure with the smallest winding pitch.

The results of our experimental study demonstrate a variety of properties and features of the behavior of a prestressed pipeline in comparison with a pipeline of traditional design.

By using the ability to control the stressed-strained state and dynamic characteristics of a prestressed pipeline by changing essential, mainly structural parameters, it is possible to make fuller use of the bearing capacity and adjust the dynamic characteristics. This makes it possible to design an optimal high-tech structure for the given operating conditions.

In this case, the pre-stress is used either to increase the bearing capacity of the pipeline under operation, or to reduce the wall thickness of the newly designed shell. In the latter case, the thick wall is replaced by a relatively thin, wrapped with a pre-strained high-strength wire. As a result, the structure is lighter, metal is saved, the technology is simplified, and the cost of structures is reduced.

Our analysis of the experimental study of prestressed piping models leads to the conclusion that prestressed structures can be attributed to active dynamic protection systems. Such systems adapt to dynamic influences due to the adjustable change in the properties of structures by prestress during oscillations.

The prestressed structures developed could be used not only for new projected pipelines but also for strengthening the pipeline in operation.

It should be noted that our experimental study did not take into consideration the friction between the pipeline body and the winding thread. There are also difficulties in the experimental determination of the force in the winding wire during the test. However, these assumptions do not significantly affect the ability to evaluate the performance of a prestressed structure and can be taken into consideration in additional tests.

The main qualitative features of the processes occurring in a prestressed pipeline, due to the relative simplicity of the mathematical model, were investigated in straight sections of the pipelines. That has made it possible to test a scientific idea, substantiate some assumptions, and choose structural solutions. In this regard, it is necessary to expand the scope of the study into prestressed pipelines towards investigating curvilinear sections of the pipeline, as well as applying pre-stress as a vibration damper of the pipeline in operating conditions.

7. Conclusions

1. Our experimental study of the wall condition of the pipeline model at static loads, simulating operational and pre-stress parameters, in comparison with a conventional pipeline, have established that:

– the circular stresses in the pipeline wall as a result of its preliminary stress and its deformation in the circular direction are significantly reduced (by 1.2÷3.6 times);

– axial stresses increase by 2÷2.2 times. It is revealed that a significant effect of pre-stress is achieved at a pressure in the pipeline model equal to 1.0 MPa compared to the option without internal pressure in the model.

2. Based on the experimental study into the models of prestressed pipelines at free vertical and horizontal oscillations, dependences of frequency characteristics on operating conditions and pre-stress parameters have been proposed. It is established that the envelope amplitude on the oscillogram of free attenuated oscillations takes the shape of an exponent, which indicates the damping effect of the pre-stress. It is noted that the use of pre-stress increases the frequency of natural oscillations by 1.4÷1.6 times, as well as the logarithmic decrement of the pipeline. This increase depends on the level of filling, the presence or absence of internal overpressure, and the design parameters of pre-stress, compared to pipelines without it.

3. The influence of pre-stress parameters on the stressed-strained state of the pipeline model wall under forced horizontal and vertical oscillations has been estimated. It is shown that increasing the tension force of the winding wire from $0.25S_{cr}$ to $0.75S_{cr}$ reduces the circular stresses in the pipeline wall by 1.3...1.6 times and increases meridional ones by 1.2...1.4 times. This phenomenon depends on the level of

filling and the presence or absence of internal overpressure. With an increase in the winding pitch, the circular stresses in the pipeline wall increase. It is revealed that the optimal pitch in terms of stress distribution and material consumption is the pitch of tension of the winding thread within *d*…3*d*. Moreover, a greater effect of the pre-stress is achieved by increasing the internal overpressure in the pipeline model.

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