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Effect of Internal Pressure on Parametric Vibrations and Dynamic Stability of Thin-Walled Ground Pipeline Larger Diameter Connect with Elastic Foundation

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Abstract. The article describes the research methodology of parametric vibrations and dynamic stability of ground thin-walled large-diameter pipeline. The equation of motion of the middle surface of the cylindrical shell element based on elastic resistance of ground. To determine the frequency of free oscillations using the assumptions of the semimomental theory of cylindrical shells and get a complete system of equations for the case of an articulated fixing of the cylindrical shell. Solving the resulting system in analytical form the expression for determining the square of the frequency of free oscillations of a thin-walled ground gas pipeline of large diameter. The methodology of the study of the dynamic stability of a gas pipeline under unsteady effects of internal operating pressure, and the parameter of the longitudinal compressive force, using Mathieu equations. With the help of the Bogolyubov-Mitropolsky techniques built area of dynamic instability in the form of Ince-Strutt diagram for different values of the internal pressure of the pipeline section, the parameter of the longitudinal compressive force, and parameter of thin-walled h / R.

1 Introduction

Nowadays pipelines are the main means of delivery of the product from the production site to the consumer. There is currently a construction of new and expansion of existing trunk pipeline networks. The linear part of main pipelines is the most expensive metal content and engineering construction, durability and reliability that is necessary to provide for the entire period of operation.

It should be noted the works of the authors based on the classical theory of the beam: S.P.Timoshenko, Y.G.Panovko, V.V. Bolotin [1], V.I. Feodosiev, H. Jeshli, N.A. Alfutov, G.V. Hauzner, A.P. Kovrevskij, V.A. Svetlickij и др. From the position of the theory of cylindrical shells: M.A. Ilgamov, M.P. Paidoussis [2, 3], A.S. Volmir [4], B.K. Mihajlov, Je.I. Ivanjuta, S.N. Kukudzhanov, V.P. Ilyin [5, 6], O.B. Haleckaja, A.A. Efimov [7], A.V. Bereznev [8] и др. It should be noted the works deal with pipelines connect with elastic foundation: P. Djondjorov [9], O. Doare [10], T.V. Maltseva [11], S.V. Lilkova–Markova

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[12], I. Lottati [13] и др. There are many works connect with determine of the free oscillation. But the Problem deal with dynamic calculation of ground pipeline wasn't solved, because in free source not enough information of method which to take into account the effect of soil radial pressure on the outer surface of the pipe on its own and parametric oscillation.

2 Review

The study of parametric oscillations of pipelines with a flowing has researched liquid based on the beam theory. One of the first works in this direction was an article I.I. Goldenblat [14] which deals with the parametric oscillations of a vertical twin pipe with flowing fluid directed in opposite directions. The analysis showed that at certain critical fluid flow velocities, the straight pipe becomes unstable. H.A. Kartvelishvili [15] solved this problem has already been considered closer to the needs of the practice.

There was formulated and solved the problem of parametric vibrations of a horizontal straight pipe with a pulsating fluid flow. It was found Mathieu equation and investigated the oscillation frequency corresponding to the parametric resonance, that is dynamic stability of the pipeline. In that paper it is shown that the fluid flowing in the pipeline with the flow rate of the pulsation, the load acts as a parametric with respect to transverse oscillations of the tube.

The most detailed parametric vibrations and dynamic stability of the straight pipelines with unsteady fluid flow studied in S.S. Chen [16] and M.P. Paidoussis [2,3] within beam theory. The authors of these works have received systems are not separable differential equations Mathieu - Hill, a solution which was made by using numerical methods, the method of S.S. Hsu [17].

The parametric vibrations and dynamic stability of thin-walled pipes of large diameter with a stream flowing pulsating fluid was investigated on the theory of thin cylindrical shells. One of the first works in this field were published by E.I Grigolyuk, which set out a solution of the problem of parametric vibrations of a cylindrical shell, loaded pulsating axial force [18]. The most complete foundations of the general theory of dynamic stability of elastic systems are described in the monograph VV Bolotin [1], which as a special case considered parametric vibrations of a cylindrical shell, loaded periodically changing forces.

A.C. Volmir [4] studied parametric vibrations of a cylindrical shell with pulsed fluid, he is based on the potential flow of an ideal fluid theory, and then he received a solution to determine the hydrodynamic fluid flow pressure on the pipe wall. A system of coupled differential equations of Mathieu and are built boundaries of areas of dynamic instability.

The most detailed study of parametric vibrations of cylindrical shells with unsteady fluid flow, followed by the construction of the upper and lower boundaries of the main and secondary areas of dynamic instability, carried out M.P. Paidoussis [2, 3]. In these studies was used a simplified assumptions of the theory of shells, and the dynamic instability of research carried out based on a complex numerical solution of coupled systems of differential equations of Mathieu.

In all the works devoted to the evaluation of dynamic stability of thin-walled pipes of large diameter with a flowing liquid, based on the theory of thin cylindrical shells, mostly obtained systems did not share, that is coupled differential equations Mathieu. Therefore, the solutions of these equations is necessary to use of numerical methods with subsequent constructions areas of dynamic instability for each particular case. This difficulty is overcome in the works of V.P. Ilyin, V.G. Sokolov [5], AA Efimov [7], which solved the problem of parametric vibrations and dynamic stability of large diameter pipe sections with a pulsating flow of liquid on the basis of a geometrically nonlinear variant semimomental theory of cylindrical shells and potential flow of an ideal fluid theory. In these papers received Separating Systems of differential equations Mathieu, are built and analyzed Ince - Strett diagrams modified for practical use.

3 Problem

Let us consider the straight section of the ground pipeline finite length, lying on the elastic foundation, or on a sand bedding (Fig. 1). To account for the influence of the elastic foundation to the free vibration frequency, as the design scheme of the pipeline circuit adopted homogeneous isotropic cylindrical shell, closed cross-section, the final length L, and radius R of the middle surface, and h means wall thickness of the shell. The shell is exposed to the action of a stationary internal operating pressure p0, longitudinal compressive force F, and the influence of the elastic foundation is $\Psi(\theta)$ (Fig. 2).

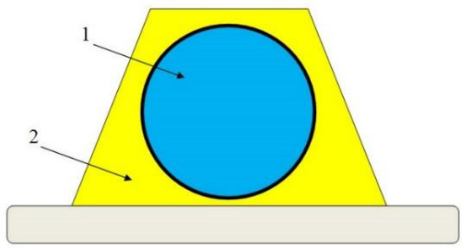

Fig. 1. Ground pipeline: 1 – pipeline, 2 – sand bedding и external covering soil.

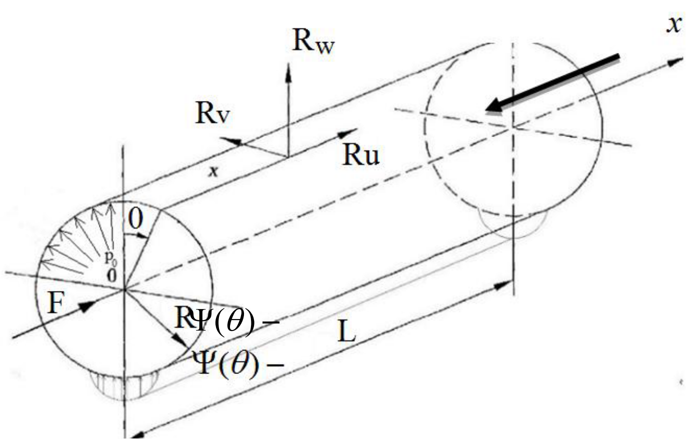

Fig. 2. Ground pipeline on elastic foundation.

In the figure the following notation: Ru, Rv, Rw – components move longitudinally, circumferentially and radially, x – coordinate along the longitudinal axis of the shell, $\Psi(\theta)-$ soil pressure on the radial an external surface of the pipe, θ – polar angle of rotation in the circumferential direction, p0 – internal operating pressure.

In order to solve the problem of parametric vibrations and dynamic stability of the pipeline is necessary carry out:

- Get the equation of motion of ground thin-walled large-diameter pipeline under unsteady effects of internal operating pressure, and the parameter of the longitudinal compressive force;

- Get the equation in analytic form for determining the square of the frequency of free oscillations of an ground pipeline;
- Using solutions N.N. Bololyubova - YA Mitropolsky define and to explore areas of dynamic instability ground pipeline with the influence of the elastic soil foundation;
- To study the influence of the internal operating pressure, and the parameter of the longitudinal compressive force on the size and location of areas of dynamic instability;
- To investigate the effect of the thin-walled parameter h / R ground pipeline in the dynamic zone of instability.

4 Description of studies

Based on the geometrically nonlinear semimomental theory of cylindrical shells of the average bending and using semimomental assumptions of the theory, we obtain the equation of motion in displacements [20]:

$$\frac{\partial^3 u}{\partial \xi^3}+h_v^2\frac{\partial^3}{\partial\theta^3}(\vartheta_2+\frac{\partial^2\vartheta_2}{\partial\theta^2})+2\frac{\partial^2}{\partial\theta^2}(\frac{\partial^2 w}{\partial\xi^2}\varepsilon_0)-\frac{R}{Eh}p_0\frac{\partial^3\vartheta_2}{\partial\theta^3}+$$
$$+\frac{R}{Eh}\frac{\partial^2}{\partial\theta^2}[\Psi(\theta)w(\xi,\theta,t)]-\frac{R^2\rho}{E}(\frac{\partial^3 u}{\partial\xi\partial t^2}-\frac{\partial^3 v}{\partial\theta\partial t^2}-\frac{\partial^4 w}{\partial\theta^2\partial t^2})=0, \quad (1)$$

were u,v,w – moving components middle surface attributed to the radius R; ϑ_2 – rotation angle of the tangent to the median cross-sectional surface; E – the elastic modulus of the shell material;

$\tilde{v}$ – Poisson's ratio; $h_{\tilde{v}}=\dfrac{h}{R\sqrt{12(1-\tilde{v}^2)}}$ – parameter of the relative thickness of the shell; h – thickness of the shell; $\varepsilon_0=\dfrac{F}{EA}$ - original longitudinal deformation caused by the action of the longitudinal compressive force, which is determined on the assumption of non-deformable cross section, ρ – the density of the shell material;

$$\Psi(\theta)=\frac{kR}{\pi}\left[\frac{\varphi_0^3}{3}+\sum_{m=1}^{\infty}\beta_m\cos m\theta\right];$$
$$\beta_m=(-1)^m m^{-3}\left[2\varphi_m\cos\varphi_m-(\varphi_m^2-2)\sin\varphi_m\right];\quad \varphi_m=m\varphi_0, \quad (2)$$

where $\Psi(\theta)$– soil pressure on the radial an external surface of the pipe [21], k - soil ratio in accordance with the model Fuss-Winkler, $\varphi_0=\sqrt[3]{\dfrac{3Q_{общ}}{2kR^2}}$, $Q_{общ}=Q_y$, – linear pipe weight, Q_y – foundation reaction, N/m, R – the radius of the middle surface.

The equations of motion in displacements (1) has four unknowns u,v,w, и ϑ_2. For complete system of equations we add assumptions of semimomental theory:

$$\frac{\partial v}{\partial\theta}+w=0;\ \frac{\partial v}{\partial\xi}+\frac{\partial u}{\partial\theta}=0;\ \vartheta_2=\frac{\partial w}{\partial\theta}-v, \quad (3)$$

As a result, we obtain a complete system of equations (1), (3). Solve the resulting system by separation of variables (Fourier method) represent the function of the radial displacement $w(\xi,\theta,t)$ for the case of an articulated fastening at a [20]:

$$w=\sum_m\sum_n f(t)\sin(\lambda_n\xi)\cos(m\theta) \tag{4}$$

где $\lambda_n=\dfrac{n\pi R}{L}$; m,n=1,2…– wavenumbers in the circumferential and longitudinal directions,

The other components of displacement and rotation angle of the tangent are determined from the semimomental assumptions of the theory, which have the form:

$$\begin{aligned} u&=-\sum_m\sum_n\frac{\lambda_n}{m^2}f(t)\cos(\lambda_n\xi)\cos(m\theta),\\ v&=-\sum_m\sum_n\frac{1}{m}f(t)\sin(\lambda_n\xi)\sin(m\theta),\\ \vartheta_2&=-\sum_m\sum_n\frac{m^2-1}{m}f(t)\sin(\lambda_n\xi)\sin(m\theta). \end{aligned} \tag{5}$$

The result of the differentiation of the term $\dfrac{\partial^2}{\partial\theta^2}\left[\Psi(\theta)w(t,\xi\theta)\right]$ represented as a product of the partial sums. First we multiply the ranks, and then calculate the derivative. We introduce two partial sums:

$$S_1=\sum_m a_m\cos(m\theta);\quad m=1,2,3,\ldots\quad a_0=0,\ S_2=b_0+\sum_m b_m\cos(m\theta);\quad b_0=\frac{\varphi_0^3}{3};\quad b_m=\beta_m\,.$$

Next we have:

$$Z=S_1S_2=z_0+\sum_{k=1}^{\hat{m}}z_k\cos k\theta,$$

Differentiation sums reduces to differentiation of terms:

$$\frac{\partial}{\partial\theta}(Z)=-\sum_{k=1}^{\hat{m}}z_k k\sin k\theta\ ,\quad \frac{\partial^2}{\partial\theta^2}(Z)=-\sum_{k=1}^{\hat{m}}z_k k^2\cos k\theta\ .$$

Further will take the notation k=m:

$$\frac{R}{Eh}\frac{\partial^2}{\partial\theta^2}\left(\Psi(\theta)w(\xi,\theta,t)\right)=\frac{k_sR^2}{\pi Eh}f(t)\sum_{m=1}^{\infty}m^2z_m\cos m\theta, \tag{6}$$

где k – soil ratio [Н/м3], m – волновое число в окружном направлении. Calculating z_m with different wave numbers m=1,2,3… represented in the form:

$$\begin{aligned} z_1&=a_0b_1+a_1b_0+\frac{1}{2}(a_1b_2+a_2b_1+a_2b_3+a_3b_2+a_3b_4+a_4b_3+a_5b_4+a_4b_5);\\ z_2&=a_0b_2+a_2b_0+\frac{1}{2}(a_1b_3+a_3b_1+a_2b_4+a_4b_2+a_3b_5+a_5b_3+a_1b_1);\\ z_3&=a_0b_3+a_3b_0+\frac{1}{2}(a_1b_4+a_4b_1+a_2b_5+a_5b_2+a_1b_2+a_2b_1); \end{aligned} \tag{7}$$

$$z_4 = a_0 b_4 + a_4 b_0 + \frac{1}{2}(a_1 b_5 + a_5 b_1 + a_1 b_3 + a_3 b_1 + a_2 b_2);$$

$$z_5 = a_0 b_5 + a_5 b_0 + \frac{1}{2}(a_1 b_4 + a_4 b_1 + a_2 b_3 + a_3 b_2);$$

$$a_m = 1;$$

$$b_0 = \frac{\varphi_0^3}{3}; \quad b_m = \beta_m ,$$

$$\beta_m = (-1)^m m^{-3}\left[2\varphi_m \cos\varphi_m - (\varphi_m^2 - 2)\sin\varphi_m\right]; \quad \varphi_m = m\varphi_0 .$$

Substituting (4), (5) в (1) and equating coefficients of the same trigonometric functions, we obtain a system of equations of separable:

$$\left\{\widetilde{\lambda}_n^4 + m^4(m^2-1)(m^2-1+p^*) + k^* m^4 - \widetilde{\lambda}_n^4 m^4 P/n^2\right\} f(t) + \rho^* Rh[\widetilde{\lambda}_n^4 h_v + m^2 + m^4] f''(t) = 0, \quad (8)$$

where $\widetilde{\lambda}_n = \dfrac{n\pi R}{L\sqrt{h_{\widetilde{v}}}}$, $p^* = p_0 \dfrac{R}{Ehh_v^2}$, $\rho^* = \rho \dfrac{R}{Ehh_v^2}$, $k^* = \dfrac{R^2 k}{\pi Ehh_v^2} z_m$.

Considering that the free oscillations are harmonic, represent the function of time $f(t)$ in form:

$$f(t) = \sin\omega_{mn} t, \; f''(t) = -\omega_{mn}^2 \sin\omega_{mn} t, \quad (9)$$

The resulting system is a solution to the problem of free oscillations of a thin-ground large diameter pipelines at steady impact. Substituting (9) in (8) transforming an equation for determining the square of the frequency of free oscillations of a ground pipeline:

$$\omega_{mn}^2 = \frac{\widetilde{\lambda}_n^4 + m^4(m^2-1)(m^2-1+p^*) + k^* m^4 - \widetilde{\lambda}_n^4 m^4 P/n^2}{\rho^* Rh[\widetilde{\lambda}_n^2 h_v + m^2 + m^4]}. \quad (10)$$

The expression (10), allows you to define a wide range of frequencies for enveloped forms at wave numbers m и n=1,2,3…., considering the internal operating pressure parameter of the longitudinal compressive force and elastic soil foundation, at different values of the geometric characteristics.

In actual practice the pipeline is exposed during operation of various kinds dynamic effects and vibrations, including unsteady, caused by the work of compressor stations with a predetermined frequency. In this mode, the internal operating pressure is unsteady changing the law:

$$p(t) = p_0(1 + \mu\cos\gamma t), \quad (11)$$

where γ – frequency of excitation; μ – parameter of excitation, μ≤0,5 ; p0 – internal

operating pressure.

As a result of the work, the unsteady internal operating pressure leads to the excitation of a stationary longitudinal compressive force to the non-stationary:

$$F(t) = F_0(1 + \mu\cos\gamma t), \quad (12)$$

where F_0 - Longitudinal compressive force.

Substituting (11), (12) in system (8) after transformations, we obtain a system of equations with separable unsteady exposure:

$$\left\{\tilde{\lambda}_n^4 + m^4(m^2-1)(m^2-1+p^*) + k^* m^4 - \tilde{\lambda}_n^4 m^4 P/n^2 - \mu\cos\gamma t\cdot m^4\tilde{\lambda}_n^4[P/n^2 - p^*(m^2-1)/\tilde{\lambda}_n^4]\right\} f(t) +$$
$$+\rho^* Rh[\tilde{\lambda}_n^2 h_v + m^2 + m^4] f''(t) = 0. \quad (13)$$

Solving and converting (17) we obtain a separable system of equations of Mathieu:

$$f''(t) + \omega_{mn}^2 (1 - \delta_{mn}\cos\gamma t) f(t) = 0, \quad (14)$$

where ω_{mn}^2 - (10), and δ_{mn} - excitation coefficient:

$$\delta_{mn} = \frac{[P/n^2 - p^*(m^2-1)/\tilde{\lambda}_n^4]\cdot m^4\tilde{\lambda}_n^4}{\tilde{\lambda}_n^4 + m^4(m^2-1+p^*) + k^* m^4 - \tilde{\lambda}_n^4 m^4 P/n^2}\cdot\mu \quad (15)$$

Evaluation of the dynamic stability of the ground pipeline is to construct dynamic instability areas in the parameter plane γ, P for given values of the internal operating pressure, parameter h/R and coefficient of soil. The area of dynamic instability is determined like:

$$\omega_{mn} = \frac{\gamma}{2} k,\ k=1,2,3\ldots \quad (16)$$

Where is the most wide area is realized with k=1, is called the main area of instability. Secondary region of instability for k>1 are narrower in width and is usually the main area of overlap.

Using the method of Bogolyubov - Mitropolsky defined upper and lower bounds of the dynamic instability, with the help of modified diagrams Ince-Strutt:

$$1 - \frac{\delta_{mn}}{2} < \left[\frac{2\omega_{mn}^2}{\gamma}\right] < 1 + \frac{\delta_{mn}}{2}. \quad (17)$$

Where the upper and lower limits are determined by equations:

$$\gamma^2 = 4\omega_{mn}^2[1 - \frac{\delta_{mn}}{2}]^{-1},\ \ \gamma^2 = 4\omega_{mn}^2[1 + \frac{\delta_{mn}}{2}]^{-1} \quad (18)$$

Accordance with obtained values of the above procedure, which are summarized in Table 1,2 and illustrated in the form of graphs in Figures 3-11.

Table 1. Definition of the boundaries of dynamic instability of ground pipelines, depending on the parameter P.

Pipe	*MPa*	*k=1.0*10⁷N/m³; L/R=10; h/R=1/31*					
		P					
		0.101	0.15	0.20	0.25	0.30	0.35
1220x20 (*h/R=1/31*)	$p_0=2$	93.72	80.24 / 71.93	67.49 / 47.46	– / 11.00	-	-
		P					
Pipe	*MPa*	0.376	0.40	0.50	0.55	0.60	0.65
1220x20 (*h/R=1/31*)	$p_0=8$	93.80	88.22 / 85.05	64.72 / 36.90	-	-	-
		*k=1.0*10⁷N/m³; L/R=10; h/R=1/41*					
		P					
Pipe	*MPa*	0.126	0.15	0.20	0.25	0.30	0.35

1220x15 (*h/R=1/41*)	$p_0=2$	81.99	75.36 / 71.89	59.22 / 46.70	-	-	-
		P					
Pipe	*MPa*	0.502	0.55	0.60	0.65	0.70	0.80
1220x15 (*h/R=1/41*)	$p_0=8$	82.65	68.25 / 60.94	49.94 / 31.36	-	-	-
The numerators are given excitation frequency values γ upper boundary of the dynamic instability, and the denominator, the excitation frequency corresponding to the lower boundary of the dynamic instability							

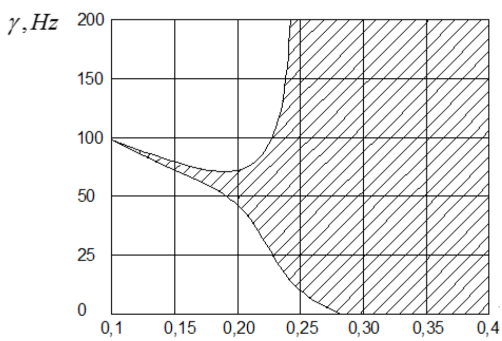

Fig. 3. The area dynamic instability ground pipeline with different values of the parameter *P* with $p_0=2$ *MPa; h/R=1/31* и $k = 1*10^7 N/m^3$, *L/R=10.*

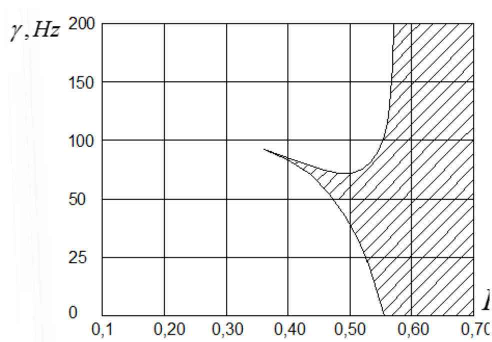

Fig. 4. The area dynamic instability ground pipeline with different values of the parameter P with p0=8 MPa; h/R=1/31 и k = 1*107N/m3, L/R=10.

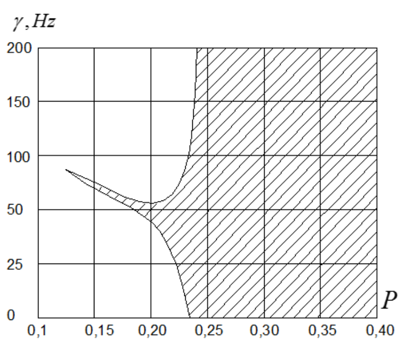

Fig. 5. The area dynamic instability ground pipeline with different values of the parameter P with p0=2 MPa; h/R=1/41 и k = 1*107N/m3, L/R=10.

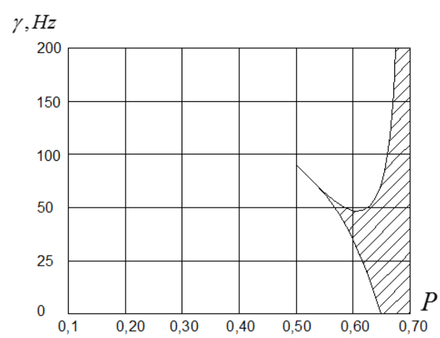

Fig. 6. The area dynamic instability ground pipeline with different values of the parameter P with p0=8 MPa; h/R=1/41 и k = 1*107N/m3, L/R=10.

Table 2: Definition of the boundaries of dynamic instability of ground pipelines, depending on the size of the internal operating pressure p0.

Pipe	*P*	*k=1.0*10⁷N/m³; L/R=10; h/R=1/31;*						
		p_0, MPa						
		1	2	3	4	5	6	6.5
1220x20 (*h/R=1/31*)	*0.3*	-	-	$\frac{-}{7.19}$	$\frac{66.25}{44.09}$	$\frac{77.97}{68.04}$	$\frac{89.61}{87.27}$	95.16
		p_0, MPa						
Pipe	*P*	1	2	3	4	4.2	-	
1220x20 (*h/R=1/31*)	*0.2*	$\frac{-}{14.26}$	$\frac{67.49}{47.46}$	$\frac{79.48}{70.64}$	$\frac{90.99}{89,45}$	94.22	-	
		p_0, MPa						
Pipe	*P*	1	2	2.1	-	-	-	
1220x20 (*h/R=1/31*)	*0.1*	$\frac{80.89}{73.18}$	$\frac{92.91}{91.59}$	93.42	-	-	-	
		$k=1.0*10^7 N/m^3$; L/R=10; h/R=1/41						
		p_0, MPa						
Pipe	*P*	1	2	3	4	4.8	-	
1220x15 (*h/R=1/41*)	*0.3*	-	-	$\frac{43.83}{20.01}$	$\frac{67.93}{60.44}$	82.45		
		p_0, MPa						
Pipe	*P*	1	2	3	3.2	-	-	
1220x15 (*h/R=1/41*)	*0.2*	-	$\frac{59.23}{46.71}$	$\frac{78.95}{77.35}$	82.34	-	-	
		p_0, MPa						
Pipe	*P*	1	1.6	-	-	-	-	
1220x15 (*h/R=1/41*)	*0.1*	$\frac{71.59}{66.11}$	82.25	-	-	-	-	
		$k=1.0*10^7 N/m^3$; L/R=10; h/R=1/51						
		p_0, MPa						
Pipe	*P*	1	2	3	3.8	-	-	
1220x15 (*h/R=1/41*)	*0.3*	-	-	$\frac{47.02}{39.08}$	65.88	-	-	
		p_0, MPa						
Pipe	*P*	1	2	2.6	-	-	-	
1220x15 (*h/R=1/41*)	*0.2*	-	$\frac{54.51}{49.41}$	67.51	-	-	-	

		p_0, *MPa*					
Pipe	*P*	1	1,3	-	-	-	-
1220x15 (*h/R=1/41)*	*0.1*	60.88 / 58.43	65.01	-	-	-	-

The numerators are given excitation frequency values γ upper boundary of the dynamic instability, and the denominator, the excitation frequency corresponding to the lower boundary of the dynamic instability

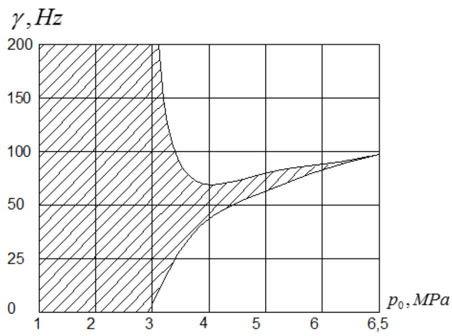

Fig. 8. The area dynamic instability ground pipeline with different internal operating pressure p0 with h/R=1/31 и

k=1.0*107N/m3, L/R=10; P=0.3.

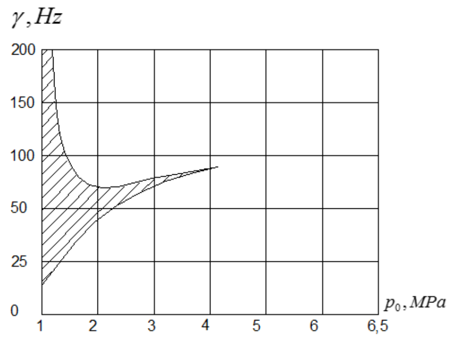

Fig. 9. The area dynamic instability ground pipeline with different internal operating pressure p0 with h/R=1/31 и

k=1.0*107N/m3, L/R=10; P=0.2.

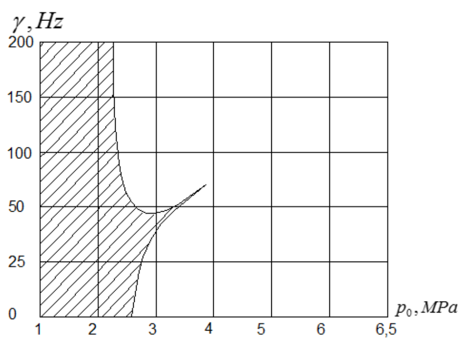

Fig. 10. The area dynamic instability ground pipeline with different internal operating pressure p0 with h/R=1/51 и k=1.0*107N/m3, L/R=10; P=0.3.

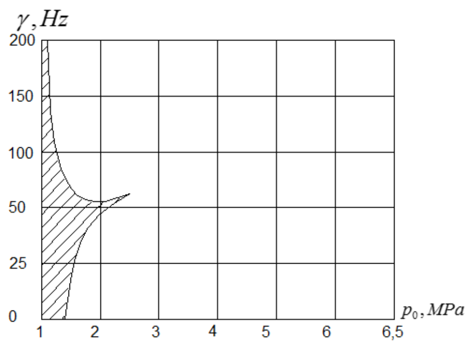

Fig. 11. The area dynamic instability ground pipeline with different internal operating pressure p0 with h/R=1/51 и k=1.0*107N/m3, L/R=10; P=0.2.

5 Conclusion

Based on the results it follows that an increase in the value of the internal operating pressure of the dynamic instability of the region is shifted upward parameter P values testify to the values in Table 1 and the graph in Figure 3-6. Such a change in the dynamic of instability zones means that with an increase in the loss of dynamic stability of internal operating pressures possible for large values of P. Next we note that for thinner pipes h/R=1/41 influence of the internal operating pressure considerably more than for thicker pipe h/R=1/31. This effect is observed when comparing such areas in figures 4 и 6, with p0=8 MPa.

Further study is aimed at studying the effect of the internal operating pressure on the size and boundaries of areas of dynamic instability, the values obtained (Table 2) and a built area of dynamic instability in Figures 9-14. According to the results, it follows that an increase in the value of the internal working pressure the area of dynamic instability is narrowed, and for certain values of p0 refers to the point. It should be noted that an increase in the parameter of the longitudinal compressive force, the dynamic instability area expands as it was proved in [19]. This increase the parameter P values increases the likelihood of dynamic stability losses several times.

It was further found that the internal operating pressure significantly effect for thinner pipe, for example h/R=1/51. This is because the internal operating pressure prevents the deformation (ovalization) of the cross section, increasing the rigidity of the pipeline section.

The results obtained in the paper can be used for optimal selection of the thickness of the pipe wall and can help for the detuning from the resonance of the linear part of pipe. This approach ensures the reliability of the pipeline on the entire period of operation. Building of dynamic instability zones, depending on the tested parameters, allow an assessment of the dynamic stability of the pipeline. In the case when the value of (γ, P) enters the shaded area, this means that the pipeline is located in a dynamically unstable position, which significantly increases the amplitude of the oscillations, which contributes to the appearance of fatigue fracture of the metal. Otherwise, when the value falls into the free the area of the hatching dynamic stability provided by pipeline.

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