IOP Conf. Series: Materials Science and Engineering **154** (2016) 012020 doi:10.1088/1757-899X/154/1/012020

Forecasting and Evaluation of Gas Pipelines Geometric Forms Breach Hazard

K S Voronin

Industrial University of Tyumen, 38 Volodarskogo st., Tyumen, 625000, Russia

E-mail: voronin_tsogu@mail.ru

Abstract. Main gas pipelines during operation are under the influence of the permanent pressure drops which leads to their lengthening and as a result, to instability of their position in space. In dynamic systems that have feedback, phenomena, preceding emergencies, should be observed. The article discusses the forced vibrations of the gas pipeline cylindrical surface under the influence of dynamic loads caused by pressure surges, and the process of its geometric shape deformation. Frequency of vibrations, arising in the pipeline at the stage preceding its bending, is being determined. Identification of this frequency can be the basis for the development of a method of monitoring the technical condition of the gas pipeline, and forecasting possible emergency situations allows planning and carrying out in due time reconstruction works on sections of gas pipeline with a possible deviation from the design position.

1. Introduction

The main gas pipeline is a complex engineering construction operating in various natural and climatic conditions. Peculiarities of underground laying in conditions of high water-cut of ground cause formation of additional gas pipeline strength parameters in the construction technology. One of the parameters of reliable operation of the gas pipeline system in the northern regions is to provide occurrence depth of a pipeline [10].

As a result of upfloating and discharge of weighting agents, bending of the pipeline geometric shape takes place [9]. Clay and submerged soils, that a gas pipeline is filled with, have a significantly reduced density and, as a consequence, lower sqeezing ability. In such circumstances, the longitudinal motion of a gas pipeline in the ground lead to its elongation. Mechanisms for elongation of the pipeline associated with a sqeezing ability of the ground were considered in a number of studies [5, 6, 10]. Research [5] shows the calculation of longitudinal stability ballasted pipelines on longitudinal sections. However, in these studies, an impact of a variable load on the pipeline caused by pressure vibrations at gas transportation is not studied.

Works on construction of main gas pipelines in the swampland are usually carried out in winter, and putting the gas pipeline into operation is carried out in summer. This results in the a single elongation in the first spring-summer operating period. But in practice, the elongation is systematic.

2. Methods

In literature [6], the impact of alternating pressure on the pipe elongation process is mentioned. At the moment it can be considered generally accepted that the elongation process ultimately contributes to the emergence of geometric shape instability. Instabilities of this type are a consequence of the nonlinearity of dynamic processes. Researches [7, 8] analyzed accidents and catastrophic events, and it was shown that these events are described by a power law of distribution. Such a law of distribution of random events is typical for systems with feedback. In such circumstances, in the system phenomenon preceding emergency events, which are very important for the process of monitoring the work of the pipeline system, should be observed.

This paper researches the phenomena occurring in the pipeline before changing its geometric shape (bending). Let us study the bending vibrations of the cylindrical shell (see Fig. 1) with a radius r. Let us denote the movement of the point along the shell as *u*, along the tangent to the circle - υ, changes along the radius - *w*.

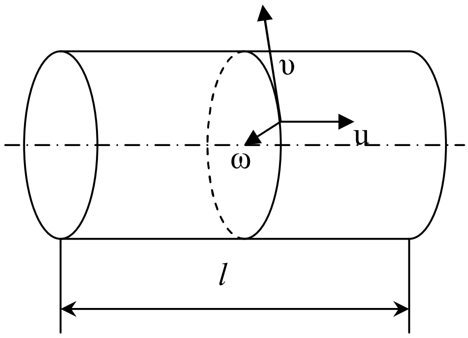

Figure 1. A model of the thin cylindrical shell. u - displacement of point on the surface along the shell, υ - displacement of point on the surface along the tangent to the circle, *w* - displacement of the point on the surface along the radius.

Original system of equations of forced vibrations of the cylindrical shell by the pressure P (t), neglecting the inertia forces along the shell and along the tangent to the circle $\left(\frac{\partial^2 u}{\partial t^2} = 0; \frac{\partial^2 v}{\partial t^2} = 0\right)$ can be written as follows [6]:

$$\begin{cases} \frac{\partial^2 u}{\partial \xi^2} + \frac{1-\mu}{2}\frac{\partial^2 u}{\partial \varphi^2} - \frac{1+\mu}{2}\frac{\partial^2 v}{\partial \xi \partial \varphi} - \mu\frac{\partial w}{\partial \xi} = 0 \\ \frac{1+\mu}{2}\frac{\partial^2 u}{\partial \xi \partial \varphi} + \frac{\partial^2 v}{\partial \varphi^2} - \frac{1-\mu}{2}\frac{\partial^2 v}{\partial \xi^2} - \frac{\partial w}{\partial \varphi} = 0 \\ \mu\frac{\partial u}{\partial \xi} + \frac{\partial v}{\partial \varphi} - w - k\nabla^4 w = \frac{\rho r^2}{B}\frac{\partial^2 w}{\partial t^2} + P(t) \end{cases} \tag{1}$$

where $\xi = \frac{x}{r}$, x - changing radius of the shell, φ - angle, $k = \frac{\boldsymbol{h}^2}{12r^2}$, h - thickness of the shell, $B = \frac{E\boldsymbol{h}}{1-\mu^2}$, E - elastic modulus, μ - Poisson ratio, ρ - shell weight per unit of area.

Literature [9] studied methods of solution of this system. Assuming that $P(t) = P\sin\omega t$, one can find a solution to the system for changing the shell radius w as follows [2]:

$$w = \frac{16}{\pi^2 \rho \boldsymbol{h}} P \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \frac{1}{mn(\omega_{mn}^2 - \omega^2)} \cos\alpha_m \xi \sin\varphi \sin\omega t \tag{2}$$

where $\alpha_m = \frac{m\pi r}{l}$, l - the shell length, m - number of half-waves in the direction of generator shell, n - number of waves along a circle,

$\omega_{mn}^2 = \frac{Bk}{\omega^2 \rho \boldsymbol{h}}\left[(\alpha_m^2 + n^2)^2 + \frac{1-\mu}{k}\frac{\alpha_m^4}{(\alpha_m^2 + n^2)^2}\right]$ - natural vibration frequency of a shell.

Elastic vibrations by changing the diameter, cause local bending of the pipe wall, whereby there emerges stress not only in radial direction but also along the pipe (longitudinal stresses -σ_x) [5].

$$\sigma_x \approx w\left(\frac{3}{1-\mu^2}\right)^{1/2} E \tag{3}$$

In their turn, the longitudinal stresses cause pipe elongation which can be estimated by the expression [2]:

$$u_x \approx \frac{\sigma_x}{E} \approx \left(\frac{3}{1-\mu^2}\right)^{1/2} \frac{16}{\pi^2 \rho h} P \sum_{n=1}^{\infty} \frac{1}{n(\omega_n^2 - \omega^2)} \cos \alpha_m \xi \sin \varphi \sin \omega t \tag{4}$$

Elongation results in the appearance of internal stresses force F, compressing the pipe:

$$F = \frac{ES}{2} \int_0^l \left[\left(\frac{dz}{dx}\right)^2 + \left(\frac{dy}{dx}\right)^2\right] dx \tag{5}$$

where S – cross-section area of a shell.

Let us assume that a small cross flexure of a pipe is about w. Then the derivatives $\frac{dz}{dx}$ and $\frac{dy}{dx}$ - about $\frac{w}{l}$, so the entire integral that determines the strength is:

$$F \sim ES\left(\frac{w}{l}\right)^2 l \tag{6}$$

Stable equilibrium position of the pipe will be maintained only as long as the compressive force F reaches its critical value. If a = b, rectilinear position of the pipe will be unstable. Then a small impact (e.g. damp soil buoyancy force) is enough to disrupt balance.

$$F_{cr} = \frac{\pi^2 EI}{l^2} \tag{7}$$

where I – axial moment of inertia of the pipe cross section.

At the stage preceding the the moment of bending of the pipeline, there should develop vibrations as a result of instability. Vibrations form must satisfy the geometric boundary condition of the problem. In a linear approximation, one can choose half of a sinusoid:

$$A(x,t) = A(t) \sin\left(\frac{\pi x}{l}\right) \tag{8}$$

where A(t) – amplitude of a pipe vibrations.

After differentiating (8) along the x and t, write down the expression for the potential and kinetic energy:

$$\varepsilon = \frac{1}{2} m \frac{\alpha}{2} \left(\frac{dA(t)}{dt}\right)^2 = \varepsilon_1 \frac{1}{2} \left(\frac{dA}{dt}\right)^2$$
$$V = \frac{1}{2}\left(EI\left(\frac{\pi}{l}\right)^4 \frac{l}{2} - F\left(\frac{\pi}{l}\right)^2 \frac{l}{2}\right) A^2_{(x,t)} \tag{9}$$

From (9) we obtain an expression for vibration frequency [7]:

$$\omega^2 = \frac{V_1}{\varepsilon_1} = \frac{\left(\pi/l\right)^2}{m}\left(EI\left(\frac{\pi}{l}\right)^2 - F\right) \tag{10}$$

where $V_1 = \left(\frac{\pi}{l}\right)^2 \frac{l}{2}\left(EI\left(\frac{\pi}{l}\right)^2 - F\right)$, $\varepsilon_1 = m\left(\frac{l}{2}\right)$.

Given the (6) and (2) find the final equation:

$$\omega_0^2 \approx \frac{\pi^2}{2l}\left[EI\left(\frac{\pi}{l}\right)^2 - \frac{ES}{l}\left(\frac{16}{\pi^2\rho h}P\sum_{m=1}^{\infty}\frac{\cos\alpha_m\xi\sin\varphi}{m\omega_{mn}^2}\sin\omega t\right)^2\right]$$

$$\omega_0^2 \approx \frac{\pi^4 EI}{2l^3}\left[1 - \frac{Sl}{\pi^2 I}\left(\frac{16}{\pi^2\rho h}P\sum_{m=1}^{\infty}\frac{\cos\alpha_m\xi\sin\varphi}{m\omega_{mn}^2}\sin\omega t\right)^2\right] \tag{11}$$

From the expression (11) it follows that at the stage of the pipeline bending there occur low-frequency vibrations, which damp with increasing pressure. Allocation of frequency of these vibrations can become a basis for the development of the pipeline condition monitoring method at a stage preceding its bending. In this case, a breach of the geometrical shape is a consequence of the nonlinearity of pressure surges at an unstable gas flow.

Moment of bending of the pipeline as a result of stability loss corresponds to the condition $\omega_0^2 = 0$. Summand in equation (11) is actually the probability of realization of the following:

$$\rho = \frac{Sl}{\pi^2 I}\left(\frac{16}{\pi^2\rho h}P\sum_{m=1}^{\infty}\frac{\cos\alpha_m\xi\sin\varphi}{m\omega_{mn}^2}\sin\omega t\right)^2 \tag{12}$$

The probability density is a function of distance and time of the pipeline operation:

$$\begin{cases}\xi(x,t) = \dfrac{d\rho(x,t)}{dx} = |A \cdot P_1 K| e^{-kx} + P_2 \\ P = P_0 + P_1 e^{-kx} + P_2 x\end{cases} \tag{13}$$

Figure 2 shows a comparison of the estimated probability density with the same value obtained after the processing of experimental data [8].

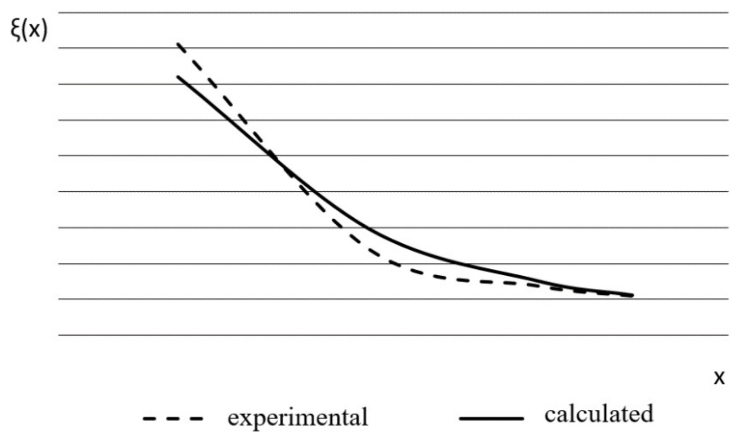

Figure 2. Comparison of the calculated and experimental probability density loss of stability.

In most cases, pipeline bending is associated with the degree of water cut, as its main cause. In paper [8], it is shown statistical analysis of the locations of 99 arch emissions, that possible to establish that hazardous in terms of loss of project positions are sections of the pipeline laid on the first 50 km from the exit of the pump station (76 emissions). Further, from 50 th to 80 th km, there was 15emissions, in the section from the 80th km to the next pump station there was 8 emissions in a fully water-cut trenches. From this it follows that in the area remote from pump station, where pressure surges influence is much lower and the number of pipeline bending is also reduced, despite the total water cut of these areas. Thus, the operation result is coherent with the experimental data that indicate the need to review bending mechanisms associated not only with the ground water cut.

3. Conclusion

As a result, the work carried out it was determined that the appearance of low-frequency vibrations is preceded by a change in the geometric shape of the gas pipeline and consequently a breach of its design position, which is of particular importance for pipelines laid in the soft soil. Forecasting possible emergency situations allows planning and carrying out in due time reconstruction works on sections of gas pipeline with a possible deviation from the design position. Diagnostics gas pipeline sections by identifying changes in the frequency of vibrations of the pipe wall can be the basis for the development of a method of monitoring the technical condition of pipeline.

References

[1] Bachernikov V F Paharukov Yu V 2005 *Vibration and destruction in immersion centrifugal pumps for oil extraction* (Tyumen, TSOGU) 325
[2] Voronin K S 2013 *Forecasting development of the damage on the main gas pipeline under the influence of dynamic load* Thesis for scientific degree of candidate of technical sciences. (Tyumen, TSOGU) 111
[3] Voronin K S and Zemenkov Yu D 2012 Dynamic indicators breach of geometrical shape of the gas pipeline *Proceedings of the higher educational institutions. Oil and gas* **3S** 70-2
[4] Voronin K S and Pavlov V P 2012 The impact of pressure vibrations in the gas pipeline on its deviation from the design position *Materials of the All-Russian scientific-practical conference "Problems of Operation of transport systems"* (Tyumen, TSOGU)
[5] Gorkovenko A I 2006 *Bases of the theory of calculating the spatial position of an underground pipeline under the influence of seasonal processes* Thesis for the degree of Doctor of Sciences (Tyumen, TSOGU) 305
[6] Dimov L A and Bogushevskaya E M 2010 *Pipelines in the conditions of swamps and water cut areas* (M, Gornaya book) 391
[7] Ibragimov A A, Podorozhnikov S Yu, Shabarov A B, Medvedev M V and Zemenkova M Yu 2014 Calculation model and algorithm for determining the residual life of pipeline in the conditions of the periodic variations of stress and corrosion *Mining informational and analytical bulletin (scientific and technical journal)* (Moscow, Gornaya Book) **S4** 199-206
[8] Kurganova I N 1990 The theoretical justification of the results of full-scale survey of gas pipelines in the non-project situation *The reliability of pipeline constructions* (M, VNIIGAZ) 147–55
[9] Oksogoev A A and Slepov B I 2003 *Applied physics. The vibrations of elements of constructions* (Tomsk, NTL) 300
[10] Harinovsky V V 2000 *The reliability and service life of pipeline constructions* (Moscow; Nedra) 467
[11] Gizatulin, R.A., Kozyrev, N.A., Valuev D.V., Valueva, A.V.Serikbol, A., Research on operational characteristics of imported rails under conditions of east siberian railway, J. IOP Conference Series: Materials Science and Engineering. 127 (2016) p. 1-7
[12] Antip'ev, Y.N., Nevolin, A.P., Zemenkov, Yu.D. 1981 Operation of intermediate pumping stations on transport of gas saturated oils. (1981) NEFT. KHOZ, 10, pp. 46 ISSN: 00282448

[13] Kurushina V and Zemenkov Y 2014 Innovative cyclical development of the Russian pipeline system WIT Transactions on Ecology and the Environment 190-2 881-8 DOI: 10.2495/EQ140822