Power law of distribution of emergency situations on main gas pipeline

K S Voronin and K A Akulov

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

E-mail: voronin_tsogu@mail.ru

Abstract: The article presents the results of the analysis of emergency situations on a main gas pipeline. A power law of distribution of emergency situations is revealed. The possibility of conducting further scientific research to ensure the predictability of emergency situations on pipelines is justified.

1. Introduction
Experience in the operation of main pipelines shows that most of the damage occurs suddenly without external apparent causes. It is believed that these disruptions have a fatigue nature [1, 2]. The main method for assessing the strength reliability is to determine the safety margin. The number of cycles of variable load is usually $10^5$-$10^6$ per year [2]. The absence of a general theory of destruction complicates the theoretical analysis of the mechanisms determining this process. The complexity of the object and the multistage nature of the process of crack formation in the pipe, taking into account the stochastic nature of the operating loads, are the justification that the reliability problem should be solved on the basis of probabilistic methods.

2. Materials and methods
Indeed, the reliability of the pipeline element $H_i(t)$ is defined as the probability of the element's quality parameter remaining in the specified range of permissible values for time $t$. The point is that with time, the chosen quality parameter will necessarily go beyond the range of admissible values due to the stochastic dynamics of the studied system. In this connection, it becomes necessary to determine the probabilistic characteristics, namely the probability density of the parameters of the system behavior and external influences.

When solving the problem of statistical dynamics, it is generally assumed that the external influence and the parameters of the system behavior can be characterized by determinate or random variables. Random variables are determined by the corresponding densities of probability distribution, and stationary random functions are characterized by mathematical expectation and correlation functions. Most often in papers on failure prediction as a result of long-acting cyclic loads, the ones that most significantly influence the strain-stress state of the structure are chosen as input parameters. It is very often assumed that the distribution of these parameters obeys the normal law [3, 4, 5].

At the initial stage of analyzing the reliability of the pipeline system, homogeneous groups of elements are distinguished. In this paper, such group of elements is the linear part of the pipeline. Consequently, the investigated system can be represented in the form of series coupling of elements.
Let us consider the definition of the system reliability, where the reliability of each element is taken $R_k$. A pipeline section of length $L$ is taken as an element for operation period $t$. In (Fig. 1), a system flow-chart is shown.

![Figure 1. System flow-chart of the pipeline](image)

The probability of failure-free operation of each element is taken $P(t, L) = H(t, L)$. Elements interact in such a way that their failures ($R_k = 1 - P_k$) are independent. In this case, the system remains operational if all its elements work reliably. The probability of a joint event consisting of several independent events will be equal to the product of the probabilities of the realization of each event [8, 9].

Such distribution is most often found in nature, and it reflects the linear response of the system to a stationary external disturbance. At the same time, the reliability of the linear part of a pipeline of length $L$ consisting of $N$ sections during operation period $t$ is determined by the formula:

$$P(t, L) = H(t, L) = \prod_{i=1}^{N} H_i(t, \Delta L_i)$$  

where $L$ – pipeline length;  
$N$ – number of pipeline sections;  
t – operational period of the pipeline;  
$\Delta L_i$ – length of the $i^{th}$ pipeline section.

This approach is valid if the failures at each allocated section are independent (due to the linearity of the system). However, in main gas pipelines, the gas flow regime is unstable. A significant pressure change along the pipe length through time is observed. The pressure gradient when the turning off the compressor of the intermediate station makes 0.3-0.4 MPa [2]. The generated high and low pressure waves cause coherent stresses at high distances. This can lead to a violation of linearity in the pipeline. Consequently, the distribution of the parameters responsible for the state of the system may deviate from the normal distribution law.

![Figure 2. Relationship between the number of accidents and the time intervals between them](image)
By the example of one of the gas pipelines in the north of Tyumen region, the laws of distribution of emergency and catastrophic situations during 6 years of operation are considered.

When analyzing emergency situations, probability density \( \rho(x) \) can be replaced by the dependence of the size of the event on its rank. The economic damage caused by the accident can be chosen as the rank of events [10, 11].

From the analysis of dependence \( U(x) \) (Fig. 2), an approximating dependence can be obtained. The curve of emergency behavior demonstrates the power law dependence:

\[
U(x) \sim x^{-(1+\alpha)}
\]  

(2)

This distribution differs significantly from the normal one. A normal distribution is characterized by a rapid decrease in power dependence. This means that large accidents are very rare events and the probability of their implementation falls rapidly to zero.

It follows from the graph (Fig. 2) that the probability of the event of a large accident is not equal to zero in the pipeline system. Indeed, the catastrophic event occurred on the considered gas pipeline [12, 13]. Its scale exceeds far the average statistical emergency situations. In Fig. 3 and 4, a comparison of the exponential, normal, and power distributions is shown.

\[
U = \lambda e^{-\lambda x}
\]

\[
U = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

\[
U = x^{-(1+\alpha)}
\]

**Figure 3.** Typical form of the probability density of quantities

In the papers [1, 6, 7], the description of emergency and catastrophic phenomena from the point of view of nonlinear dynamics is given. It is known that the power law of the distribution of random events is observed in systems with feedback. This means that the disturbance can spread through the pipeline as far as possible. Pressure jumps for an unstable gas flow in a pipe can be considered as a disturbance object.
3. Conclusion
This approach opens a program for developing an algorithm for monitoring emergency and catastrophic events. At the first stage, it is necessary to develop methods that allow us to minimize the information about the processes occurring in metal caused by a number of disturbances and aggressive environmental influences in the functional dependence. At the second stage, methods should be developed for analyzing the probability of transmission of disturbances in a hierarchical environment. The fact is that the causes of the appearance of cracks lie at lower structural levels (defects, dislocations, micro cracks). Thus, further research is required to ensure the predictability of accidents on main gas pipelines.

References:
[1] Venttsel 'E S, Ovcharov V A 2000 The theory of probability and its engineering applications. (Moscow: Vysshaya skola)
[2] Harinovsky V V 2000 Reliability and resource of gas pipeline constructions. (Moscow: Nedra)
[3] Box D, Jenkins G 1974 Time series analysis, forecast and management.
[4] Ostreikovskii V A 2003 The reliability theory. (Moscow: Vysshaya shkola)
[5] Kashian R, Rao A 1983 Constructing the dynamic stochastic models on experimental data. (Moscow: Nauka)
[6] Malinetsky G G, Podlazov A V, Kuznetsov I V 2006 National system of scientific monitoring. Novoe v sinergetike 1 28-48
[7] Agrafenin S I, Perov S N 2006 Methodology of ensuring the reliability of pipeline systems in their design. Neftyanoe hozyaistvo 11 102-106
[8] Voronin K S, Ogudova E V 2016 The Effect of Dynamic Processes in the System “Pipe-Soil” on the Pipeline Deviation from Design Position. Transport and Storage of Hydrocarbons. IOP Conf. Series: Materials Science and Engineering 154 012019 doi:10.1088/1757-899X/154/1/012019

Figure 4. Typical form of the probability density of quantities in logarithmic coordinates.
[9] Voronin K S 2016 Forecasting and Evaluation of Gas Pipelines Geometric Forms Breach Hazard. Transport and Storage of Hydrocarbons. IOP Conf. Series: Materials Science and Engineering 154 012020 doi:10.1088/1757-899X/154/1/012020

[10] Dudin S, Voronin K, Yakubovskaya S, Mutavaliev S 2016 Modeling Hydrodynamic State of Oil and Gas Condensate Mixture in a Pipeline. MATEC Web of Conferences. DOI: 10.1051/matecconf/20167302021

[11] Pirogov S P, Cherentsov D A, Gulyaev B A 2016 Prospects of applying vibration-resistant pressure gauges in the oil and gas industry. IOP Conference Series: Materials Science and Engineering 012013

[12] Pirogov S P, Cherentsov D A, Chuba A Y 2016 Study of elastic sensing elements for vibration-resistant pressure gauges. IOP Conference Series: Materials Science and Engineering 012015

[13] Pirogov S P, Cherentsov D A 2016 Theoretical foundations of the design of vibration-resistant manometers. Measurement Techniques 1-5

[14] Kozyrev N A, Galevsky G V, Valuev D V, Shurupov V M, Kozyreva O E 2015 Surfacing with Tungsten-containing Ores J. IOP Conference Series: Materials Science and Engineering 91(1)

[15] Mamadaliev R A, Kuskov V N, Popova A A, Valuev D V 2016Alloying Elements Transition into the Weld Metal When Using an Inventor Power Source J. IOP Conference Series: Materials Science and Engineering 127

[16] Fedoseev S N, Valuev D V, Mamadaliev R A, Sokolov P N 2017 Application of integrated methods to improve the technological properties of steel J. Key Engineering Materials 736 110-115

[17] Saprykina N A, Saprykin A A, Matrunchik M S 2014 Formation of Surface Layer of Cobalt Chrome Molybdenum Powder Products with Differentiation of Laser Sintering Modes J. Applied Mechanics and Materials. 682 294-297

[18] Gizatulin R A, Kozyrev N A, Valuev D V, Valueva A V, Serikbol A 2016 Research on operational characteristics of imported rails under conditions of east siberian railway J IOP Conf. Series: Materials Science and Engineering 127

[19] Valuev D V, Serikbol A 2014 Stress state and its definition in hardfacing heat-resistant steel cold rolling mill rollers J. Advanced Materials Research 1040 703-707

[20] Malushin N N, Valuev D V, Valueva A V, Serikbol A 2014 Testing of metallurgical equipment on contact strength and wear resistance J. Applied Mechanics and Materials 682 53-57