I-res intelligent system for multi-factor risk control of accidents and the technical condition of the main gas pipeline

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Abstract. The paper deals with improving the reliability and safety management system of the linear part of the main gas pipeline. At the Department of Transport of Hydrocarbon Resources, Industrial University of Tyumen, research is being carried out to develop a system for multi-factor risk control of accidents and the technical condition of hydrocarbon transport systems. As an example, an algorithm for monitoring the technical condition and safety of local sections of the pipeline was developed, a software product “I-ReS” (intelligent, reliability, safety) was developed as part of the CI-TREMS system, which allows real-time monitoring of the technical condition and safety of the main gas pipeline.

1. Introduction

In Russia, a system of main pipelines that is unique in length, productivity and safety has been created, operates and is developing. Pipeline transportation is the main method of delivering gas and oil to consumers. According to the annual report of Federal Environmental, Industrial and Nuclear Supervision Service of Russia (Rostechnadzor) for 2017, the total length of the linear part of the main pipelines is more than 257.8 thousand km, of which gas pipelines are 179.5 thousand km. [1] Collaborative intellectual technological reliability and efficiency management of oil and gas systems (CI-TREMS) is a fundamentally new technology of intelligent instrumental neural network engineering control, forecasting and prevention of emergency situations, incidents, accidents, optimization and ensuring the effectiveness of technical solutions in the management of processes of industrial enterprises developed at the Department of Hydrocarbon Resources Transport. CI-TREMS is modular and multi-tasking, flexible and adaptive, based on the theory of neural network programming, the theory of reliability, cybernetics, system analysis, statistics and probability, and others. Currently, the issue of ecology and noosphere culture in the oil and gas industry is relevant and has gained particular importance at facilities from Siberia to the Arctic, and the presence of such systems in hazardous enterprises is a necessity. The theoretical and practical stages of CI-TREMS development provide for individual work with each process facility and specific monitoring and forecasting problems that are implemented within the framework of the modules. The “I-ReS” software product (intelligent, reliability, safety) was developed on the basis of a real gas pipeline and its individual characteristics using the functions provided by c-Mes technology, Asset Management.

Different monitoring and diagnostic kits can be used in different managements of gas or oil pipeline facilities, and to create an integrated monitoring system it is necessary to create different models of periodic monitoring and real-time models. This is due not only to differences in the documents of the diagnostic means and transport systems of one enterprise.
In modern conditions, there is a large amount of various information and each unit requires a separate methodological study and analysis, and the creation of a separate monitoring module. In the framework of this work, the structure of the enterprise for the facilities of the linear part was analysed and algorithms for analysing reliability and safety were compiled, in addition, algorithms for individual indicators of the technical condition were developed.

In accordance with the Federal Law No. 116-FZ "On Industrial Safety of Hazardous Production Facilities" dated July 21, 1997, gas pipelines are classified as hazardous production facilities - high-risk facilities. Hazard identification in sections of main gas pipelines is associated with an analysis of technological risks. When analyzing technological risks (operational risks), the gas pipeline through which natural gas, which is a hazardous substance, is transported, is identified directly as a source of hazard. The identification of hazards during the operation of the linear part of the main gas pipeline consists in describing the characteristics of the transported product (its properties, state parameters), determining the volume of natural gas in the pipeline sections under consideration, considering possible accident scenarios, their causes, consequences and identifying the most dangerous places. The determination of the hazardous properties of the transported product is related to the characteristics of natural gas, in particular, the type of hazardous substance and the actual pressure and temperature in the section of the main gas pipeline.

2. Materials and methods
The purpose of this work is to improve the reliability management system and develop a methodology and expert system that allows you to quickly monitor the technical condition of gas pipelines in its certain high-risk areas through multifactor control and contributes to the adoption of informed decisions on the implementation of measures ensuring industrial safety requirements.

When performing this work, a number of tasks were solved:

- substantiation of the methodology for multifactor control of the risk of accidents and the technical condition of the main gas pipeline;
- factor and structural analysis of main gas pipeline facilities, in particular, its linear part;
- development of an algorithm for multifactor control of the technical condition and safety of the main gas pipeline;
- development of a software product that allows real-time monitoring of the technical condition and safety of sections of the main pipeline.

The work is aimed at solving the following issues:
- updating data on the main hazards of accidents, including information on the assessment of possible damage to third parties in the event of an accident;
- assessing process data and organizational information for the examination of the technical condition of the facility, including the frequency of diagnosis;
- monitoring the degree of emergency hazard and evaluating the effectiveness of measures to reduce the risk of an accident at a hazardous production facility, including for the effectiveness of industrial safety management systems;
- improvement of operational and maintenance instructions, action plans for localization and elimination of consequences of accidents.

Research in the field of monitoring the reliability and safety of main gas pipeline facilities has been the subject of a large number of works by such famous scientists as A. M. Korolenok, Yu.V. Kolotilov, G.G. Vasiliev, M.V. Sukharev, A.B. Shabarov, E.I. Krapivsky, B.V. Moiseev, M.G. Chuchkalov and others [2-9,11,12,14,15].

Operators of hazardous production facilities maintain pipelines in working condition, monitor their technical condition to ensure the required level of reliability and evaluate operational safety at various levels (Figure 1), however, in some cases, some indicators are replaced by others due to the complexity or impossibility of system monitoring.
Operators are constantly carrying out measures to ensure the integrity of main pipeline facilities, including various types of diagnostics, routine maintenance, selective and major repairs, and reconstruction of facilities. However, despite this, accidents periodically occur on main pipelines, including fatal ones, the damage from which amounts to millions of rubles.

From Rostechnadzor accident reports of 2007 - 2017, 184 accidents occurred on sections of main pipelines, of which more than 70% were attributed to main gas pipelines. Moreover, an analysis of the materials of technical investigations into the causes of accidents shows that more than 60% of incidents occurred on gas pipelines that have been in operation for more than 30 years. The main reasons for other accidents are non-compliance with the procedure of work performance in the gas pipeline protected zone, deviation from design decisions, lack of round checks and inspections, due level of technical inspection, diagnostics of the technical condition of pipelines, as well as current repairs and overhaul.

In the annual reports of Rostechnadzor, the following main causes of accidents on gas pipelines are given:

- design flaws;
- defects of construction or manufacture;
- pipe metal corrosion (including stress corrosion cracking);
- human error during operation;
- depreciation of equipment;
- natural weather impact;
- mechanical impact.

The distribution of accidents at the facilities of the main gas pipelines by causes of their occurrence in 2007-2017 is clearly visible in the pie chart (Figure 1.3).
Figure 3. Distribution of accidents at the facilities of the main gas pipelines by causes of their occurrence in 2007-2017

As can be seen from the chart, the main cause of accidents at existing gas pipelines in previous years is corrosion, and there is a growth tendency for such accidents.

It is worth noting that the so-called “industrial safety economy” occupies a special place in risk management. At the same time, it is noted in some works (for example, [11-13]) that limited resources for maintaining the necessary level of industrial safety and risk management are divided into three main areas: safety costs, costs of compensation for damage from accidents, and costs of investing in hazardous production facility safety (Figure 4).

Figure 4. Resource allocation for industrial safety.

In the current documentation in accordance with the requirements of Rostekhnadkhor, there is a classification of possible industry-related events that can occur with a certain degree of probability with a certain technical condition of the object. Prediction issues in such situations remain unresolved [9-12]. Mathematical support issues were published in [7–10]. Mathematical models are provided using a logical-probabilistic mathematical apparatus and the theory of neural networks.
Let us consider an example of the implementation of the concept of monitoring reliability and safety in a real section of a gas pipeline over 30 years old. Conducting diagnostic examinations of the linear part of the main gas pipeline, in particular, in-line flaw detection, provides information on the presence of various kinds of defects in the pipe material, welded joints, as well as geometric shapes and sizes. At the same time, a significant role in the reliability of the information received is played by the data of the questionnaires filled out by the employees of the operator for the entire diagnosed area. It is worth noting that the questionnaires include information on the characteristics of the pipes (diameter, wall thickness, material), category sections, repairs, but they do not contain information and factors that occur in each individual place in the pipeline and have a certain effect on the identified defects. The situation is complicated by the fact that in the area of the pipeline there are long sections with the presence of surrounding objects in hazardous areas.

At present, at the enterprise, most of the information about the technical condition (the results of the diagnostic tests, examinations, etc.) has to be processed by specialists “manually” without the possibility of automatic systematization and processing, as a result of which there is no real-time clear picture of the condition of the hazardous production facility. Therefore, in order to comply with industrial safety requirements, setting priorities in preserving the lives of people and their property requires a completely new approach to monitoring the technical condition, reliability and safety realized through real-time monitoring. To ensure reliable and uninterrupted operation of the linear part of the main gas pipeline, it is necessary to have a system that allows real-time monitoring of the technical condition of the facility using all available information, as well as predicting the state of the system over time.

Based on the foregoing, it is advisable to consider each identified defect from the point of view of its influence on the considered intervalve section and the gas pipeline as a whole. It is proposed to monitor the reliability of each specific place considering factors influencing it.

| Figure 5. Algorithm for monitoring the reliability of a defective part of a pipeline. |
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Let us consider in more detail each element of the proposed algorithm.

Initially, a database is needed to carry out any control, monitoring, determination of any indicators. In our case, the database is a collection of information stored in the monitoring system, constantly updated and edited, including:
- data from the results of in-line inspections (defects, their types, characteristics, etc.);
- data from a comprehensive examination (defects, isolation status, state of the ECP, etc.);
- data from diagnostic examinations of underwater crossings (defects, violations of regulatory requirements);
- data from inspections (violation of the design depth, erosion, isolation status, condition of the technical corridor, etc.);
- certification (data on the diameter of the pipeline, wall thickness, categorization of the site, the presence of third-party communications, intersections with roads and railways, the presence of third-party objects in the minimum safe distance zone and information about the characteristics of these objects, etc.);
- data on factors affecting each specific type of defect (it is a matrix of factors affecting each specific type of defect with relative shares of each factor and functions for normalizing the values of factors).

For the purposes of this work, the assumption is made that the pipeline is initially in good condition with reliability indicators corresponding to the “normal operation” range.

At the first stage of work, the defect is processed, and a certain level of reliability is assigned to it. It is worth noting that in accordance with the requirements of STO Gazprom 2-2.3-1050-2016, all defects are divided into three reliability classes. Moreover, the distribution of defects occurs according to at least three methods, as well as the application of the expert assessment method.

Having determined the type of defect, as well as its reliability, according to the results of the examination, the system proceeds directly to a multivariate analysis of indicators that influence the development of the defect. The matrix of indicators is developed by experimental research and involves the introduction or removal of individual factors for each specific defect. Since influencing factors belong to different areas and there are different units of measurement, an interpretation of the parameters is necessary. In the framework of this work, this procedure is implemented by normalizing the true values and bringing them to the 0 ... 1 interval according to the normalization formula (linear, sigmoid, probabilistic, logical, etc.), or by expert evaluation.

For example, in the general case, the linear normalization formula has the form:

$$ y = \frac{(x - x_{\min})(d_2 - d_1)}{x_{\max} - x_{\min}} + d_1 $$

where:
- $x$ – the value to be normalized;
- $[x_{\max}, x_{\min}]$ – the $x$ range;
- $[d_1, d_2]$ – the interval to which the $x$ value will be reduced.

As an example, let us give an example of the normalization of some factors of the section safety, the higher the value of the normalized rating, the safer the section (Table 1).

| Factor                          | Estimated indicator                     | True value range | Actual value | Normalized indicator | Normalization method |
|---------------------------------|-----------------------------------------|------------------|--------------|----------------------|---------------------|
| Pressure                        | No possibility of sharp pressure increase | yes no          | yes          | 1.00                 | Logical             |
| Pipe wall thickness             | Relative decrease                       | 0 0.7           | 0.2          | 0.29                 | linear, sigmoid, probabilistic |
| Stress-strain state of the pipeline | No critical deformation                 | yes no          | yes          | 1.00                 | Logical             |
| Parameters of the electrochemical protection | Compliance with GOST requirements | no yes         | yes          | 1.00                 | Logical             |
| Accident rate of the gas pipeline section | Absence of accidents over the previous 10 years | yes no        | no           | 1.00                 | Logical             |
| Coefficient of safety pressure  | Coefficient value                        | 0 1.2           | 0.9          | 0.75                 | linear, sigmoid, probabilistic |

Table 1. An example of the normalization of the section safety factors.
Table 1. Ending.

| Term of the external inspection | Term in years | 0  | 50  | 1  | 0.02 | linear, sigmoid, probabilistic |
|----------------------------------|---------------|----|-----|----|------|-------------------------------|
| Insulation coating condition     | Integral resistance, Ohm m² | 0  | 10000 | 7000 | 0.70 | linear, sigmoid, probabilistic |
| Safety by ECP                   | Compliance with GOST 51164 requirements | yes | no | yes | 1.00 | Logical |
| Ground water level              | HC mark below the lower pipe generatrix | yes | no | no | 0.00 | Logical |
| Corrosive soil aggressiveness   | Specific soil resistance | 0  | 50  | 45  | 0.90 | linear, sigmoid, probabilistic |

An example of some windows of the I-ReS software for a real gas pipeline is shown in Figures 6, 7, 8 (the names of the sections were deleted for information security reasons). The software package provides a trend analysis function for characteristics, reliability and safety indicators, probabilistic analysis and ranking of objects for making real-time decisions on maintenance. The program is based on comprehensive certification and complete information about the reliability of the facility.

Figure 6. Information processing window (I-ReS).

Figure 7. Rating of defects based on reliability assessment (I-ReS).
3. Conclusion
The methodology of multifactor control of the technical condition of the main gas pipeline was developed as part of the project of an intelligent monitoring system of the Department of Transport of Hydrocarbon Resources, Industrial University of Tyumen. The proposed mathematical models, methods and algorithms using system analysis, probability theory, neural networks, coefficient models and software have been tested in calculating the reliability of Gazprom PJSC facilities, they allow for the correct intelligent monitoring of industry-related events on main gas pipeline sections, and implement a maintenance strategy for actual condition, reliability, safety.

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