

The Approach to Probabilistic Prediction of Pipelines Safety for Quantitative Rationale Preventive Measures of Control during Design and Operation

Andrey Kostogryzov^{1,2*}, Leonid Grigoriev³, Sergey Golovin⁴, Andrey Nistratov⁵, George Nistratov⁶ and Igor Zubarev⁶

¹Federal Research Center “Computer Science and Control” of the Russian Academy of Sciences, Moscow, Russia

²Main Research Scientific and Probatory Center of Robotics at the Ministry of Defense of Russian Federation, Moscow, Russia,

³The Gubkin Russian State University of Oil and Gas, Moscow, Russia,

⁴MIREA - Russian Technological University, Moscow, Russia,

⁵The Russian Power Agency of Ministry for the Power Generating Industry, Moscow, Russia,

⁶The Research Institute of Applied Mathematics and Certification, Moscow, Russia

*Corresponding author

Abstract—The approach to probabilistic prediction of pipelines safety is proposed. The probability to lose “acceptable safety” may be predicted by modeling. The approach allows to estimate quantitative levels of risks, reveal “bottlenecks” and define rational recommendations to system preventive measures. The possibilities for revealing new latent effects for a given period “in future” and for quantitative rationale preventive measures of control during design and operation are demonstrated by examples.

Keywords —analysis, diagnostic; model; monitoring; prediction; probability; system; technology

I. INTRODUCTION

The modern technologies provide data monitoring and repair of functional integrity of pipelines as a system. The probability to lose “acceptable safety” are required. But by probabilistic modeling new latent effects may be revealed for a given period “in future” and used preventively with a profit. The proposed approach to probabilistic prediction of pipelines safety is based on a use of author's models for modeling complex systems [1-6 and others]. It is aimed on a transformation of gathered data into scientifically proved recommendations for quantitative rationale preventive measures of control during pipelines design and operation.

II. DESCRIPTION OF THE PROBLEM

The probabilistic prediction of pipelines safety is performed by a gathered general statistical data. So, on an example of 10-year-old statistics for objects of the main pipeline transport of the Russian Tyumen region a frequency of failures on pipelines is about 5 times a year. The causes of failures (losses of integrity) are: external physical influences on pipelines, including criminal inputs which lead to product losses – 34.7%, infringements of norms and rules at building and repair, deviations from project decisions – 24.7%, corrosive damages of pipes, lock and regulating armature – 23.5%, manufactory defects of pipes and equipment – 12.4%,

mistaken actions of the operational and repair personnel – 4.7%.

In conditions of such very much general statistics taking into account additional accessible initial data and application of author’s models [1-6] for the cases of technology 1) of periodical system diagnostics (without monitoring) and technology 2) of periodical system diagnostics with continuous monitoring and reaction in real time it is required: to estimate quantitative levels of risks; to reveal “bottlenecks”; to define rational recommendations to system preventive measures.

III. CHOICE OF PROBABILISTIC MODEL AND METRICS

For probabilistic predictions for a given prognostic period “in future” the next limited space of two elementary events for pipelines, which are analyzed as a system, is set: “acceptable integrity is provided” (when from safety point of view no additional actions are needed to keep pipelines integrity) and alternatively “acceptable integrity is lost” (when some actions are needed for recovering acceptable integrity of pipelines).

Note. The terms “integrity” and “acceptable integrity” are defined from safety point of view.

The probabilistic model “Protection against dangerous influences” [1-6] is chosen. It allows estimate technology 1) periodical system diagnostics (without monitoring) and more general technology 2) periodical system diagnostics with continuous monitoring and reaction in real time. After the next diagnostic the recovery of the lost integrity is started, if needed. The differ of technology 2 is the next: if results of monitoring have revealed symptoms of unacceptable integrity, the recovery of the integrity is started before the beginning next diagnostic.

The next metrics are used for probabilistic prediction of pipelines safety [1-6]: the probability of pipelines safety during given prognostic period (if all time during this given period pipelines will be in elementary event “acceptable integrity is provided”) and the probability to lose “acceptable safety” (if at

least once during this given period pipelines will be in elementary event “acceptable integrity is lost”) - as addition to 1 the probability of pipelines safety.

The input data for probabilistic estimating are [1-6]: the given prognostic period “in future”; the frequency of dangerous influences on pipelines (defining the beginning of influencing); the mean activation time (when “acceptable integrity” of pipelines may be lost after beginning of influencing); the mean recovery time; the time between the end of diagnostic and the beginning of the next diagnostic; the diagnostic time; only for technology 2 – the mean time between operator’s error during continuous monitoring of pipelines integrity.

IV. THE APPROACH TO CONDITIONS FOR MODELING

A system (i.e. analyzed pipelines) is decomposed on subsystems: subsystem 1 – linear part, including taps and looping, lock armature, transitions through natural and artificial barriers, knots of start-up and receiving, flaw detectors, crosspieces; subsystem 2 – power transmission lines; subsystem 3 – engineering stations, including compressors and connection knots, distributing stations, underground gas storehouses, stations of cooling, knots of reduction, measuring stations; subsystem 4 – a set of other components, including installations of electrochemical protection from corrosion, lines and constructions of technological communication, telemechanic means, fire-prevention means, buildings and constructions of linear operation service, capacities for gathering, condensate storages and regassing, roads and helicopter platforms, precautionary signs, the operational and repair personnel.

Owing to looping subsystem 1 includes 2 elements (it means reservation possibilities are considered). At formation of initial data for a component of subsystem 1 it is used auxiliary data. According to statistics the main threats to elements of subsystem 1 are formed basically by technical reasons which share makes 95.3 % (except for mistaken actions of the operational and repair personnel). The mean activation time of a threat is about 2.5 months (as time between failures taking into account these reasons). The time between the end of diagnostic and the beginning of the next diagnostic we will put equal to one year taking into account periodicity of technical maintenance (this time is equal to 1 year also for subsystems 2 and 3). For considering potential possibilities of continuous monitoring with use of intellectual sensors we will put the mean time between operator’s error equal not less, than the mean activation time of a threat, i.e. 2.5 months.

According to statistics the main threats to elements of subsystem 2 are formed basically also by technical reasons which share makes 37.1 %. The mean activation time of a threat is about 6.5 months. For considering potential possibilities of continuous monitoring (for example, with use of satellite systems) we will put the mean time between operator’s error equal not less, than the mean activation time of a threat, i.e. 6.5 months.

According to statistics the main threats to elements of subsystem 3 are formed basically also by technical reasons

which share makes 60.6 %. The mean activation time of a threat is about 4 months. For considering potential possibilities of continuous monitoring (for example, with use of automated systems for technological processes control) we will put the mean time between operator’s error equal not less, than the mean activation time of a threat, i.e. 4 months.

According to statistics the main threats to elements of subsystem 4 are formed basically by the technical reasons and “human factor” which share makes 41.8 %. Then the mean activation time of a threat is about 5.7 months. The time between the end of diagnostic and the beginning of the next diagnostic we will put equal to one month taking into account importance of subsystem composition. Continuous monitoring of conditions for all elements of subsystem 4 is carried out by responsible personnel performing functional duties, rules and safety regulations. Therefore we will put the mean time between operator’s error equal not less, than the mean activation time of a threat, i.e. 5.7 months.

The analyzed structure of system for probabilistic modeling is presented on Figure 1.

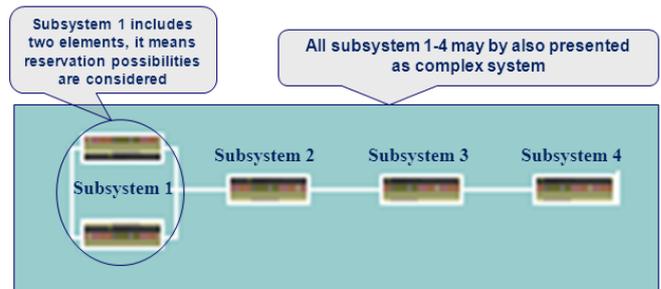


FIGURE 1. THE ANALYZED STRUCTURE OF SYSTEM

V. ANALYSIS OF MODELING RESULTS

The results of modeling are reflected by the Table 1.

TABLE I. RESULTS OF MODELING

| Subsystems, System | Prediction for 1 year | Prediction for 10 years |
|--|-----------------------|-------------------------|
| Subsystem 1 - Case 1) periodical system diagnostics (without monitoring) | 0.630 | 0.943 |
| - Case 2) periodical system diagnostics with continuous monitoring | 0.517 | 0.913 |
| Subsystem 2 - Case 1) | 0.571 | 0.929 |
| - Case 2) | 0.358 | 0.846 |
| Subsystem 2 - Case 1) | 0.659 | 0.950 |
| - Case 2) | 0.507 | 0.910 |
| Subsystem 2 - Case 1) | 0.273 | 0.787 |
| - Case 2) | 0.021 | 0.175 |
| System - Case 1) | 0.850 | 0.982 |
| - Case 2) | 0.734 | 0.965 |

Analysis of modeling results show the next.

Risk at least one failure on the main gas pipelines for a year makes 0.73-0.85. At the expense of monitoring, maintenance and adequate reaction in real time risk may be decreased to level 0.73. For a prognostic period till 10 years risks increase according to level 0.97- 0.98. These figures speak about practical inevitability of failures on the main gas pipelines. Subsystems 1-3 are "bottlenecks" in this system.

Typical distribution of risks on compound subsystems are the next: for subsystem 1 risk 0.52-0.63 for a year increases to 0.91-0.94 for 10 years; for subsystem 2 risk 0.36-0.57 for a year increases to 0.85-0.93 for 10 years; for subsystem 3 risk 0.51-0.66 for a year increases to 0.91-0.95 for 10 years; for subsystem 4 risk 0.02-0.27 for a year increases to 0.18-0.79 for 10 years. It means subsystems 1-3 owing to complexity of control and monitoring of conditions are the most vulnerable components of the main pipelines. In turn, the subsystem 4 supposing an effective control from personal, at the expense of the monthly control of integrity and continuous monitoring of a condition of critical equipment of a subsystem is today almost 10 times less vulnerable component of the main pipelines.

The important questions are: "Is it possible to decrease risks?" and, if "Yes" – "What measures are more essential?" and "What levels of risks are achievable?"

To answer these questions we will carry out search for subsystems 1-3 the ways of an effective use of means of the system control and continuous monitoring with measures of integrity recovery in real time. For a subsystem 1 implementation of monitoring is connected with a use of perspective intellectual pipelines monitored by sensor controls, for a subsystem 2 - with a use of satellite monitoring systems of a condition, for a subsystem 3 - with a use of means of modern automated systems for technological processes control. The proposed approach may be used during pipelines design and operation.

Let's assume, that from the point of view of possibilities of monitoring first three subsystems are improved at least to the level of 4th subsystem. It is really possible, technical characteristics can even be better in comparison with subsystem 4. For this case results of modeling system using general technology 2 of periodical system diagnostics with continuous monitoring and reaction in real time are reflected by Figures 2, 3 and Table 2.

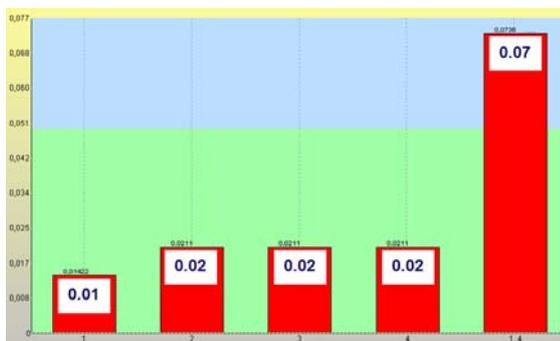


FIGURE 2. THE RESULTS OF PREDICTION ON A YEAR



FIGURE 3. THE RESULTS OF PREDICTION ON 10 YEARS

TABLE II. PREDICTED RISKS

| Subsystems, System | Prediction for 1 year | Prediction for 10 years |
|--|-----------------------|-------------------------|
| Subsystem 1 | 0.014 | 0.124 |
| Subsystems 2-4 | 0.021 | 0.175 |
| System (a frequency of failures on pipelines is about 5 times a year) | 0.074 | 0.439 |
| System (a frequency of failures on pipelines is about 10 times a year) | 0.126 | 0.587 |

The analysis of modeling of perspective main gas pipelines has shown the following.

The risk at least one failure within a year can be decreased from 0.88 to 0.07! The risk at least one failure within 10 years can be decreased from 0.97-0.99 to 0.44. It means, that the quantity of failures really can be reduced 10 times (i.e. to 3-6 in comparison with existing 50 failures for 10 years).

It is quite achievable at the expense of implementation of effective means and measures of monitoring, control and maintenance of system integrity, based on use:

- "smart" pipelines with intellectual sensors for controls;
- satellite systems of the continuous control of components conditions, allowing to monitor land and air elements;

Means of modern automated systems for technological processes control which are carrying out monitoring of operation of engineering stations, including compressors and connection knots, distributing stations, underground gas storehouses, stations of cooling, knots of reduction, measuring stations.

Thus for all means of monitoring the following technical requirements should be executed - the mean time before error (in analogy with MTBF) should be not less half a year.

Technical possibilities of recovery system integrity in due time on the base of background deviation analysis is required.

VI. INSTEAD OF CONCLUSION

The proposed approach to probabilistic prediction of pipelines safety has shown that effective means and measures of monitoring, control and maintenance of system integrity should allow quantitative rationale preventive measures of

control. The use of proposed approach is possible during pipelines design and operation.

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