Methods of modeling the performance of gas pipeline facilities

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Abstract. Control systems and parameter monitoring systems are currently being implemented in technical systems and, thereby, are improving them. As a result, in production, in the process of management, there is a need for special mathematical methods that allow making scientifically sound decisions. This is especially relevant in pipeline transport, and in particular in the gas industry, when solving the problems of mathematical modeling of processes and optimizing gas transportation modes. Simulation of equipment operation modes has already been put into practice and is an integral part of the operational control of the gas transportation system.

Technical systems are being improved at a rapid pace with the introduction of a management and parameter monitoring system. In this regard, the tasks of analyzing complex technological processes become more relevant.

Improving the management system helps to reduce failures due to errors that can be avoided by improving the management system. Improvement of control algorithms will make it possible to improve regulation of equipment operation modes.

Mathematical modeling makes it possible to recognize the parameters of the system without conducting experiments and industrial experiments. Mathematical modeling is the construction of a system of equations that describe a certain process. The mathematical model of the technical system is a collection of relations and concepts presented using mathematical symbols and symbols reflecting the most characteristic properties of the investigated processes [1-3].

In production, in the process of management, there is a need for special mathematical methods that allow making scientifically sound decisions.

Mathematical methods when conducting studies of technical systems can be effectively used when the parameters of the mathematical model meet the necessary conditions.

Methods are classified by branches of science, by applied mathematical apparatus, etc. But if you create a model to describe the process, the simulation goal is the first. Depending on the modeling objectives, you can select the following models:

- descriptive (descriptive);
- optimization;
- multicriterial;
- game;
- imitation.
In the case where a model is created to affect the process, optimization modeling takes place. In pipeline transport, and in particular in the gas industry, the problems of mathematical modeling of processes and optimization of gas transportation modes are especially relevant.

To date, modeling of equipment operation modes has already entered into practice and is an integral part of the operational control of the gas transportation system.

In gas pipelines, problems in some cases involve finding an optimal solution that could minimize costs with maximum efficiency. In mathematical modeling, such problems have the general name "operation study" [5-7].

Methods of process modeling in pipeline transport were considered in the works.

The approach to determining the allowable pressure of a gas pipeline with a colony of corrosion cracks, developed at Gazprom Transgaz Samara LLC, takes into account the concentration of stresses in the zone with a surface defect. An analytical model was obtained to calculate the allowable internal pressure of the damaged gas pipeline.

As time passes, the technical condition of the pipelines deteriorates, as a result of which the maximum allowable pressure in the pipe changes. In this case, when modeling the operation modes of gas pipelines and compressor stations, the reliability of information on the state of the gas pipeline and gas pumping units is an important component. Algorithms for solving the problem of choosing the optimal modes proposed in the work are based on a fuzzy-multiple representation of inaccurate data.

A number of technological tasks in pipeline transport allow you to solve the method of asymptotic coordinates.

Its essence is as follows. Suppose that a certain value F depends simultaneously on two parameters p and q. Then, by setting the values of the parameter q, you can determine the dependence F op. If the curves in plane (p, F) are similar to each other, it is possible to match the coordinates to describe a two-dimensional surface with simple curves. Then, at different values of q, the curves in the plane (p, F) will be compressed into one curve. These coordinates are called asymptotic.

When calculating operating modes of compressor stations, the specified characteristics of centrifugal superchargers, built according to the results of bench tests, are used. His method is also used for hydraulic characteristics of main oil pipelines taking into account changes in effective diameter.

Hydraulic efficiency factor is required to calculate pipelines. It is proposed to apply asymptotic coordinate method in modeling [8].

Using the asymptotic coordinate method, an improved model of the form KNe = f (t, T) was previously obtained. For example, for a gas turbine plant of type ГТК-10-4, the analytical model has the following form (1):

\[ K_{Ne} = (-0.0021t^2 + 0.0893t + 0.0096) + (0.876e^{-0.0016T} - 1.005e^{-0.0027T}) + 1.005e^{-0.0027T} \]

In the natural gas main transport, the pumping volumes are controlled by changing the schemes, number and speed of the shaft of the gas pumping units operating at the compressor stations, while pressure surges that affect the reliability of the pipeline are possible.

The occurrence of pressure surges is also possible when filling sections of gas pipelines during start-up after repair. Consider the effect of pressure surges on the operability of the main gas pipeline (IDLE).

Limit cycle of pipe loading corresponds to change of annular stresses in pipeline by value equal to 10% of yield strength.

Most of the materials from which the main gas pipelines are made are used for pipes that belong to the category of strength Х70, where the average ultimate strength is 630 MPa and the yield strength is 485 MPa.

According to the value of ring stresses from the normative (working) pressure is determined from the expression (2):

\[ \sigma_{eq} = \frac{p \cdot D_{min}}{2 \cdot \delta_n} \]
where \( p \) - operating (standard) pressure, MPa; 
\( D_{\text{пр}} \) - internal diameter of a pipe, cm; 
\( \delta_n \) - pipe wall thickness, mm.

Taking into account the presence of possible defects based on the results of the diagnostic examination, a correction coefficient of pipeline wall weakening \((3-4)\) is introduced into the formula:

\[
k_f = \frac{\delta_n - a}{\delta_n}
\]

\[
\Delta p_{DN} = \frac{2\sigma_\text{кц}\delta_n k_f}{D_{\text{пр}}}
\]

- for the new section of DN 1400 pipeline (or with service life less than 30 years) conditionally without defects \((k_f = 1.0)\);
- in the absence of information on the technical condition of the long-term operated section of the gas pipeline DN1400 (more than 30 years), the attenuation coefficient of the pipe wall is taken to be equal (the defect depth is 10%, which corresponds to the sensitivity threshold of the in-tube flaw detector);
- defective section of pipeline DN 1400 (for example, with a defect of 30% depth, \( k_f = 0.7 \)).

Table 1 shows the results of calculation of limit value of pressure change for MG of different diameter taking into account defect depth.

**Table 1.** Results of calculation of limit value of pressure change for main gas pipelines.

| h₀, % | 500 | 600 | 700 | 800 | 1000 | 1200 | 1400 |
|------|-----|-----|-----|-----|------|------|------|
| 0    | 31.8| 26.5| 23.0| 20.1| 16.0 | 13.3 | 11.7 |
| 10   | 28.6| 23.8| 20.7| 18.1| 14.4 | 12.0 | 10.6 |
| 20   | 25.4| 21.2| 18.4| 16.1| 12.8 | 10.6 | 9.4  |
| 30   | 22.3| 18.5| 16.1| 14.1| 11.2 | 9.3  | 8.2  |
| 40   | 19.1| 15.9| 13.8| 12.1| 9.6  | 8.0  | 7.0  |
| 50   | 15.9| 13.2| 11.5| 10.0| 8.0  | 6.6  | 5.9  |

The limit value of gas pressure change for pipelines of different diameter depending on defect depth can be determined according to the graph (figure 1).

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**Figure 1.** Limit value of gas pressure change for pipelines of different diameters depending on defect depth.
It is not very convenient to use a graphical relationship (figure 1), therefore, analytical modeling of characteristics to determine the limit value of gas pressure change is relevant ($\Delta P$) for pipelines of different diameter (DN) depending on defect depth ($h_d$). Method of asymptotic coordinates is proposed for development of analytical model [9].

Suppose that a certain value $F$ depends simultaneously on two parameters - $p$ and $q$. Then, by setting the values of parameter $q$, you can determine the dependence $F_{neg}$. If the curves in plane $(p, F)$ are similar to each other, it is possible to match the coordinates to describe a two-dimensional surface with simple curves.

Then, at different values of $q$, the curves in the plane $(p, F)$ will be compressed into one curve. Thus, these coordinates will be asymptotic.

For the characteristics shown in figure 2, an analytical constraint will be created.

In the plane $(\Delta P, \text{DN})$ is a series of lines at the interval $h_d=0\div30$.

![Figure 2. Dependence of limit value of pressure change ($\Delta P$) from outside pipe diameter (DN) at different values of defect depth ($h_d$).](image)

The first step is to build a function dependency $\Delta P$ on the second DN parameter for $-h_{d\min} \leq h_d \leq h_{d\max}$. Obtained functions $\phi(DN, h_{\min}), \psi(DN, h_{\max})$ (figure 2). Comparing the calculated and initial data, it was found that the mean square error of the calculation was not more than 1%.

The result is a mathematical model that allows, depending on the pipeline diameter (DN) and defect depth ($h_d$), to determine the limit value of pressure change in the gas pipeline ($\Delta P$).

Using asymptotic coordinates, a model was obtained for calculating atmospheric air pollution when dispersing gasoline vapors.

Thus, improving the management system is extremely relevant, as it reduces the number of failures that occur due to errors. And with the help of mathematical modeling, it also makes it possible to recognize the parameters of the system without conducting experiments and industrial experiments.

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