Hardware error estimation model of signal reception in the task of monitoring the tightness of gas engineering systems

A A Malysheva¹, O A Gnezdilova¹, A A Pavlova¹ and A S Ovsienco¹,*

¹ Moscow state university of civil engineering, Moscow, Yaroslavskoye shosse, 26, Russia
Email: vealdes@inbox.ru

Abstract. We propose a solution of the task of improving the accuracy of estimates of gas flow in gas engineering systems. Performed an analytical review of works of leading scientists in the field of the theory of supply. It has been established that the question of control and to prevent gas leaks remains relevant now. It is proved, that for engineering systems use gas for domestic purposes, where low pressure set leaks quite difficult due to the large spread of points of vulnerability, also the greatest risk are low-intensity gas leaks, that hardly controlled by hardware due to accounting errors. The analysis of constructive solutions to the engineering supply systems of low pressure. Installed geometric variety. Accepted hypothesis about the impact of the quantity and type of butt joints leak gas pipeline systems engineering in General. An algorithm is presented for vulnerability assessment elements engineering gas supply systems for leaks. The mathematical model for the evaluation of measuring error of parametric parameter of gas flow in the system. The technique for monitoring the tightness of gas systems engineering with the rationale for selecting the method of evaluation of error results.

1. Introduction
The reliability of energy systems, which includes the gas supply system, is a complex indicator and is defined by a set of private indicators. In relation to natural gas distribution systems, the main of them is the accounting of energy consumption.

Gas engineering systems are a set of elements that supply gas to the source of consumption, functionally providing the required pressure, quality and safety of the system as a whole. Normative documents require gas distribution organizations (GDO) to conduct mandatory energy surveys in relation to the technical process: gas transportation through pipelines, maintenance and operation of gas distribution networks [1-2]. The practical objectives of the energy survey are to obtain reliable information on the use of fuel and energy resources and to develop measures for energy saving and energy efficiency. In order to implement the stated goal, a set of normative-technical and methodological documents reflecting the specifics of production activities in this area has been developed [3-5]:
• Regulations on conducting an energy survey of gas distribution organizations;
• The program of the energy survey of the gas distribution organization;
• Methodology for determining the consumption of natural gas for technological and own needs of the GDO, as well as the volume of technological losses during its transportation through gas distribution networks;
• Methodology for assessing the effectiveness of the introduction of energy-efficient technologies in the gas distribution sector;

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- Energy passport of the gas distribution organization;
- Instructions for filling the energy passport of the gas distribution organization;
- The methodology of calculating the energy efficiency indicators of the gas distribution organization.

For gas distribution organizations, target indicators for energy saving and energy efficiency have been set, which should be ensured during the implementation of energy saving and energy efficiency programs for GDO.

In the structure of the fuel and energy balance of GDO, natural gas consumption prevails (almost 90%). Its technological losses, in turn, according to the reported data are close to 80% of its total consumption. Evidently, in this situation, the determination of the actual gas losses and the search for ways to reduce them are the highest priority for improving the energy efficiency of the GDO which can be achieved by introducing telemetry systems for key target parameters. Given that the number of distribution points increases every year, out of 34700 gas control points, only 18% are equipped with a telemetry system. At the same time, it has been established, that the introduction of target indicators sets a relative decrease in specific gas losses during its transportation through distribution networks for various GDO ranging from 1–3 to 12–20% [3].

![Figure 1. Gas flow rate classificational scheme](image)

As an example, the resources of one of the companies serving gas distribution networks with a length of more than 300 000 km are considered. Their complex ensures the operation of about 300 000 gas reduction points.

2. Theoretical research. Methods and techniques

It is considered, that whatever the technical condition of the gas distribution networks, the value of gas losses is unchanged and depends on the geometric volume of networks, gas pressure and leakage coefficient. There is no normalized value for this indicator. The paper proposes taking into account the real technical condition of gas pipelines for calculating the target indicator.

The existing analysis scheme, which allows to estimate the load and resource supply of gas pipelines of each pressure category of the entire gas distribution network as a whole, is not suitable for efficiency increase, as we receive generalized indicators showing the presence or absence of problems in a particular network. The objective need to switch to a personalized analysis of the gas distribution network load has appeared, with objective detalization, to develop an algorithm for analyzing the load.
of networks, taking into account the property appurtenance for the formation of forecast investment programs.

The next step of analytical research was the assessment of the level of import substitution of equipment and components. A bottleneck has been identified, which is the equipment of gas reduction points, in particular, the gas pressure regulator in terms of its characteristics, manufacturing quality and reliability of operation, as well as the associated service frequency of domestic production are significantly inferior to Italian and German manufacturers.

Additionally, the issue of implementation of telecontrol system (TCS) is considered. The introduction of these systems allows to adjust the frequency of maintenance and reduce the frequency of scheduled operations which is not yet regulated.

Structurally, all elements of engineering systems have different types of connections. Their technical requirements provide for complete hermiticity throughout the period of operation. In practice, it often happens that the hermiticity is broken and gas is leaking into the surrounding space. Such leaks and related factors lead to dangerous situations, gas poisoning, fire and explosions.

Element components of gas distribution engineering systems, according to their quality and functional characteristics should have a high level of reliability throughout the whole operating period.

Information about the level of reliability and intensity of parametric change for the resource period for a significant part of the elements of engineering systems is not given in the technical characteristics provided by the manufacturer. The operational documentation contains instructional requirements for normal operating conditions and the frequency of service actions to maintain efficiency.

To eliminate the identified defects, according to standard methods, an assessment of reliability indicators is carried out, according to which the correlation field of changes in the reliability of the system elements from the period of their operating time [5-6].

3. Research results

In the theory of risk, calculation formulas for assessing the level of danger are proposed, by compiling scenarios of possible events, which in turn allows us to create a list of measures to prevent dangerous situations.

For domestic purpose gas engineering systems, where the flow pressure is low, it is rather difficult to establish leaks due to the high dispersion of points of vulnerability, also the most dangerous are sluggish gas leaks, which are difficult to fix by hardware due to metering errors.

It is established, that in engineering systems, there are points of vulnerability in terms of gas leakage. It is generally accepted that the cross-sectional area through which the gas is leaked does not exceed 1% of the cross-sectional area of the pipeline.

It is proposed to carry out a ranking to determine the level of danger and the probability of a gas leak, introducing the coefficient of vulnerability and the uncertainty value of the point by the magnitude of the error, using data from manufacturers of engineering gas supply and transmission equipment.

The question of choosing a rational method for solving the problem of static evaluation of the functioning of engineering gas systems and the maximum similarity of the model remains open.

Since this problem is relevant, many scientists and manufacturers are trying to solve the problem, offering different options and techniques.

In particular, the mathematical model of calculation of leakages in a separate gas supply system is proposed \( S(t) \) in the work of Sazonova S. A. [7]. The problem is formalized to detect the natural coordinate leakage and it is proposed to use the engineering technique for water networks, which after adaptation to gas supply systems is transformed into an expression

\[
S(t) = \mu \omega \sqrt{P - P_{bar}} \omega
\]

where \( \mu \) – flow coefficient, is taken 0.6;

\( \omega \) – cross section hole area;
Given the mathematical uncertainty of this indicator, it can be considered through the function of uncorrelated Gaussian noise $\xi(t)$ with dispersion $\sigma^2$ due to the error of the hardware signal reception.

It is logical to conclude that the level of uncertainty can be reduced by developing or improving software systems, based on the refinement of algorithms for solving the problem of monitoring the hermiticity of engineering gas systems.

To apply the method of monitoring the hermiticity of engineering gas systems, it is necessary to provide a justification for the choice of a method for estimating the error of the results [7].

Theoretically, this problem is solved by the matrix method, which establishes the relationship between the errors in the components of the column of free terms $\|A\|\|A^{-1}\|$ and the solution error $\xi_{Y,\beta}$, i.e. estimated values:

$$
\|\xi_1\| \leq \|A\|\|A^{-1}\|\|\xi_1\|
$$

In turn, the matrix has $\lambda$ a maximum and a minimum of eigenvalues expressed:

$$
\|A\|\|A^{-1}\| = \frac{\lambda_{\text{max}}}{\lambda_{\text{min}}}
$$

Using the basic models for solving matrices by additional transformations, we obtain an expression allowing us to estimate the errors of the results by the quality of the original data.

Representing a given matrix $\|A\|\|A^{-1}\|$ by the ratio $\det(A) = \prod_{i=1}^{n} \lambda_i$ we get the desired expression:

$$
\det(A) \leq \lambda_{\text{max}}^{n} \left( \frac{\lambda_{\text{max}}}{\lambda_{\text{min}}} \right) \leq n \frac{\lambda_{\text{min}}^{\text{max}}}{\lambda_{\text{max}}^{\text{min}}} \det(A) = \prod_{i=1}^{n} \lambda_i
$$

When developing an algorithm for monitoring the hermiticity of engineering gas systems, it is necessary to define the characteristics of the receiving device in order to ensure optimal signal conversion $X_n$. For this purpose, it is assumed that in each situation the probability density of the observed signals $P_i(X_n | \alpha_i)$, is determined, with an accuracy of the environmental parameters represented by the vector $\alpha_i$. The values $P_i(X_n | \alpha_i)$ represent a set of minimally sufficient statistics for derived loss coefficients and accepted probabilities.

As an example, the nature of probabilistic changes calculated by the distribution law with a variable value of the Weibull coefficient is given.

The graph presents the results of statistical data processing including the hourly characteristics of the operating time of the elements of the gas distribution system, in the time period-15 years (131400h continuous operation) and probabilistic reliability indicators for different values of the Weibull coefficient to establish the residual life and advanced accounting of risk-failure in the system [8].
4. Discussion

It should be noted that a two-variant, non-alternative hypothesis representing extreme events is considered: the engineering gas system is hermetic and there is a leak. The justification for this is the factor danger of the event – there is a leak and the further task of eliminating the negative consequences, starting with unpleasant sensations in the form of foreign smell, ending with an explosion with catastrophic consequences for humans, structures and the environment [9-11].

5. Conclusion

The analytical review of works of the leading scientists in the field of the theory of gas supply is completed.

It is established, that the issue of control and prevention of gas leaks remains relevant at the present time.

It is proved that for engineering systems of domestic gas usage, where the flow pressure is low, it is difficult to establish leaks due to the large dispersion of vulnerability points, also the most dangerous are sluggish gas leaks, the presence of which is difficult to be controlled by hardware due to the presence of accounting errors.

An algorithm for assessing the vulnerability of elements of the engineering system of gas supply by the leakage parameter is presented.

A mathematical model for estimating the parametric error of the gas flow parameter in the system is developed.

The method of monitoring the tightness of engineering gas systems with the justification of the choice of the method of evaluation of the error of the results is proposed.

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