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INCREASING THE RELIABILITY OF IN-HOUSE GAS EQUIPMENT

Statement of the problem. Existing methods do not always allow one to estimate the reliability of in-house gas equipment, therefore the problem of the development of reliability criterion and its use for assessment of operation of repair divisions needs to be addressed.
Results. A mathematical description of condition of equipment based on the probability theory for Markov random processes has been obtained. A criterion for the estimation of equipment reliability representing the relation of an expectation value of the amount of elements in good order of groups of equipment to the total number of elements in a group has been proposed. Kolmogorov's differential equations for determining the criterion of reliability of equipment have been obtained based on a mean value method. The equations define the dependence of the criterion of reliability on the parameter of a failure flow that depends on the effective work of repair services. Solutions of equations for determining the criterion of reliability of equipment for constant and varying failure flow parameter have been obtained.
Conclusions. The use of the proposed approach for estimating the reliability of equipment allows to plan volumes of repair work and to estimate the requirements of repair divisions for resources. Operation of the equipment using the obtained criterion of reliability estimation allows to increase its reliability.

Keywords: intrahouse gas equipment, reliability increase, criterion of reliability, probability theory, Markov random processes.

Introduction

The existing methods for determining technological reliability of in-house gas equipment do not always allow the assessment of the efficiency of repair works undertaken by gas distribution services.

Up until recently no criteria for the assessment of equipment reliability has been in place. The criteria for the assessment of technological reliability of equipment and predicting the effect of repair works on equipment reliability will be set forth in this paper.

The description of the model of the state of equipment elements was based on the theory of Markov random processes with discrete conditions and continuous timing [2, 3]. Let us assume that the state of equipment elements S randomly changes in time in a way that cannot be predicted, i.e. there is a random process taking place in the system of elements. A random process in the system of the equipment elements S is Markov if it has the following property: for any moment t_0 the state of the system in the future ($t > t_0$) depends only on the current state ($t = t_0$), i.e. the state of the system does not depend on the previous conditions.

1. Statement of the problem

For a system of the elements of the equipment S a model as a number of sets of the states of the system S_1, S_2, , S_n is necessary that it can be in case the system fails. Let $\{S_k\}_{n=1}^{k} = 1$ be a set of possible states of the system of the elements of the equipment S that tend to change in time. The geometric interpretation of the state of the system is a graph of states where states are identified with the vortices connected by transitions from the i-th state in the j-th one.

A transition of states is likely to be a transition P_{ij}. A probability P_{ij} indicates a possibility of the i-th state being followed by a transition into the j-th state. Transitions are random but if there is enough data on how often they occur over a significant time of operation, this calculation probability will in time be almost similar to a transition probability.

Since all number of defects that cause the system to shift from the state S_i to the state S_j which are Poisson and independent ones, i.e. a process taking place in the system S is Markov. Let us look at how defects emerge in a system of the equipment elements on the condition that transitions of the system from one state to another occur at random times [1, 4].

2. Model of a state of the elements

Let p_i (t) be a probability of the equipment element being in a state S at the moment t S_i (i =1, , n). A transition of the system from a state S_i to S_j according to the graph of states is influenced by a Poisson flow of defects with a parameter $\lambda_{ij}(t)$, which enables one to determine a probability of states:

$$p_1(t), p_2(t), \ldots, p_n(t). \tag{1}$$

The theory of continuous Markov chains makes it possible to compose linear differential equations for probabilities of states that show how long systems of the equipment elements in each of these states for a specific flow of defects. Probabilities of states of the equipment elements comply with the system of Kolmogorov differential equations [2]:

$$\frac{dp_i(t)}{dt} = \sum_{j=1}^{n} p_j(t)\lambda_{ji}(t) - p_i(t)\sum_{j=1}^{n}\mu_{ij}(t) \quad (i=1, 2, – , n), \tag{2}$$

where $\mu_{ij}(t)$ is a parameter of a flow of the restoration of the equipment elements.

A similar approach provides a handy mathematical apparatus only when a number of possible states of a system is comparatively small and a system of the equipment elements consists of several dozens of elements. Even in this case a system (2) has to be solved for several hundreds of differential equations using numerical methods. In case there are quite many states, numerical power to solve a system of differential equations with numerical methods does not suffice and this is why this approach is hard to employ.

In order to get around those challenges, a mean value method was used [1, 5, 7]. Each equipment element can be in either of possible states: in order and out of order. In order to make determination of how fast flows of defects are, the equipment elements were divided into homogeneous groups: interior gas shut-off devices, home gas appliances, gas controls, gas consumption control and collective gas tanks.

A number of elements in each state corresponds to the current state of the *i*-th group of the equipment elements:

$$N_i = \sum_{k=1}^{2} N_i^k(t), \tag{3}$$

where $N_i^k(t)$ is a number of the equipment elements of the *i*-th group that are in a state *k* at a moment *t*; *N* is a number of the equipment elements.

Mathematical expectation of a number of elements of heating networks the tare in a state *k* at a moment *t* is:

$$m_i^k(t) = M\left(N_i^k(t)\right). \tag{4}$$

Kolmogorov differential equation for mathematical expectation of a number of the equipment elements in order of the i-th group takes the form [2, 3, 4]:

$$\frac{d\left(\frac{m_i^1(t)}{N_i}\right)}{dt} = -\lambda_i \cdot \frac{m_i^1(t)}{N_i} + \mu_i \cdot \left(1 - \frac{m_i^1(t)}{N_i}\right), \quad (5)$$

where $\frac{m_i^1(t)}{N_i}$ is mathematical expectation of a percentage of the equipment elements in order of the i-th group; λ_i is a parameter of a flow of defects of the i-th group of the equipment elements, 1/year; μ_i is a parameter of restoration flow of the i-th group of the equipment elements, 1/year.

Besides, according to (3) the condition is obeyed

$$\frac{m_i^1(t)}{N_i} + \frac{m_i^2(t)}{N_i} = 1, \quad (6)$$

where $m_i^2(t)/N_i$ is mathematical expectation of a percentage of the equipment elements out of order in the i-th equipment group.

The initial conditions to solve a differential equation (5) are mathematical expectations of a percentage of the equipment elements in order at the initial moment of time:

$$\frac{m_i^1(t_0)}{N_i} = \frac{m_{i0}^1}{N_i}. \quad (7)$$

3. Reliability criterion

We suggest using a ratio of mathematical expectation of a number of the equipment elements in order to the total of the elements in the group as a reliability criterion [16, 18, 20]:

$$K_i(t) = \frac{m_i^1(t_0)}{N_i}. \quad (8)$$

Then the differential equation is transformed to be

$$\frac{dK_i(t)}{dt} = -\lambda_i \cdot K_i(t) + \mu_i \cdot \left(1 - K_i(t)\right) \quad (9)$$

with the initial conditions

$$K_i(t_0) = K_{i0}\,. \tag{10}$$

4. Determining a reliability criterion

Solving a differential equation (9) for a constant λ_i under the initial condition (10), we get

$$K_i(t) = \frac{\mu_i}{\lambda_i + \mu_i} + e^{-(\lambda_i+\mu_i)(t-t_0)}\left(K_{i0} - \frac{\mu_i}{\lambda_i + \mu_i}\right). \tag{11}$$

An important property of the expression (11) is an asymptote:

at $t \to \infty$

$$K_i(t) = \frac{\mu_i}{\lambda_i + \mu_i}\,, \tag{12}$$

that describes the magnitude of a reliability criterion of the equipment of the *i*-th group over a significant service period.

The expression (11) consists of a constant part

$$\frac{\mu_i}{\lambda_i + \mu_i}\,,$$

which describes mathematical expectation of a percentage of elements in order of the *i*-th group over a long service period, and a variable part

$$e^{-(\lambda_i+\mu_i)(t-t_0)}\left(K_{i0} - \frac{\mu_i}{\lambda_i + \mu_i}\right),$$

which describes a shift of the criterion $K_i(t)$ to the stationary mode. Fig. 1 shows the comparison of change of a criterion $K_i(t)$ depending on the initial value.

Fig. 1 shows how at the same parameters of a flow of defects depending on the initial value K_{i0} of the criterion $K_i(t)$ in time tends to the same value

$$\frac{\mu_i}{\lambda_i + \mu_i}\,,$$

that describes the correlation of defects and restoration.

The comparison of change in the criterion $K_i(t)$ depending on a flow of defects and restoration is shown in Fig. 2.

a) b)

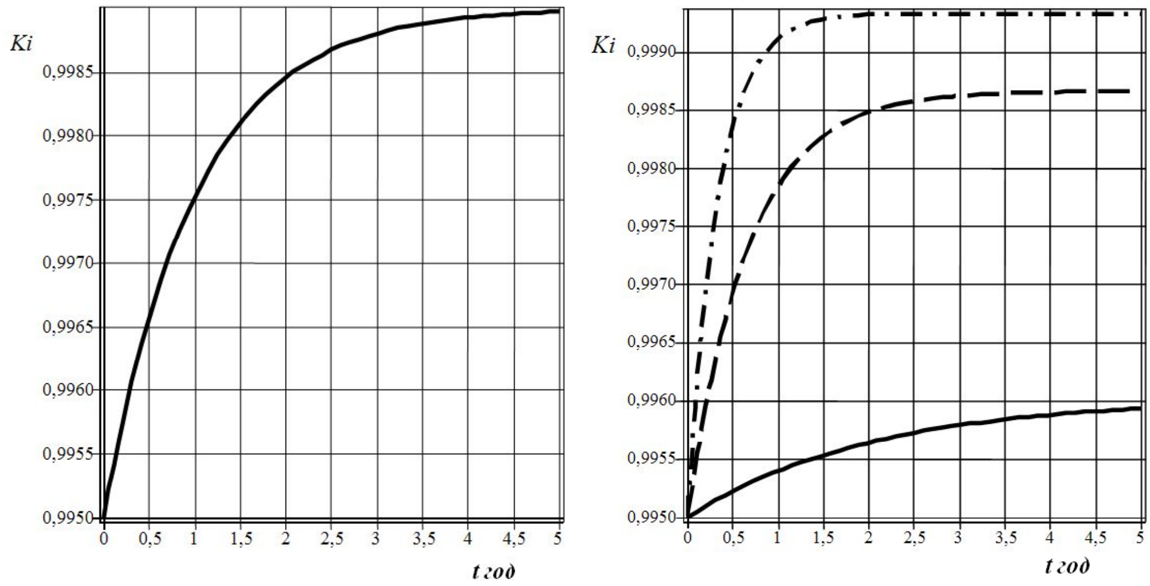

Fig. 1. Comparison of change in the criterion $K_i(t)$ depending on the initial value:

λ_i= 0.001 1/year; μ_i =1 1/year; a) $K_{i0} = 0{,}995\,0$; b) $K_{i0} = 0{,}9999$; год = year

The parameter of a flow of defects λ_i (t) of the i-th group of the equipment elements can change in time.

Solving a differential equation (9) for a variable λ_i (t) under the initial condition (10), we get the general solution:

$$K_i(t) = \left(\int_{t_0}^{t} \mu_i e^{-\int_{t_0}^{\tau}(-\lambda_i(\tau)-\mu_i)d\tau} d\tau + K_{i0} \right) e^{\int_{t_0}^{\tau}(-\lambda_i(\tau)-\mu_i)d\tau} . \qquad (13)$$

Change in the parameter of a flow of defects λ_i (t) of the i-th group of the equipment elements can be presented as a linear function:

$$\lambda_i(t) = \lambda_{i0} + b_i t . \qquad (14)$$

a) b)

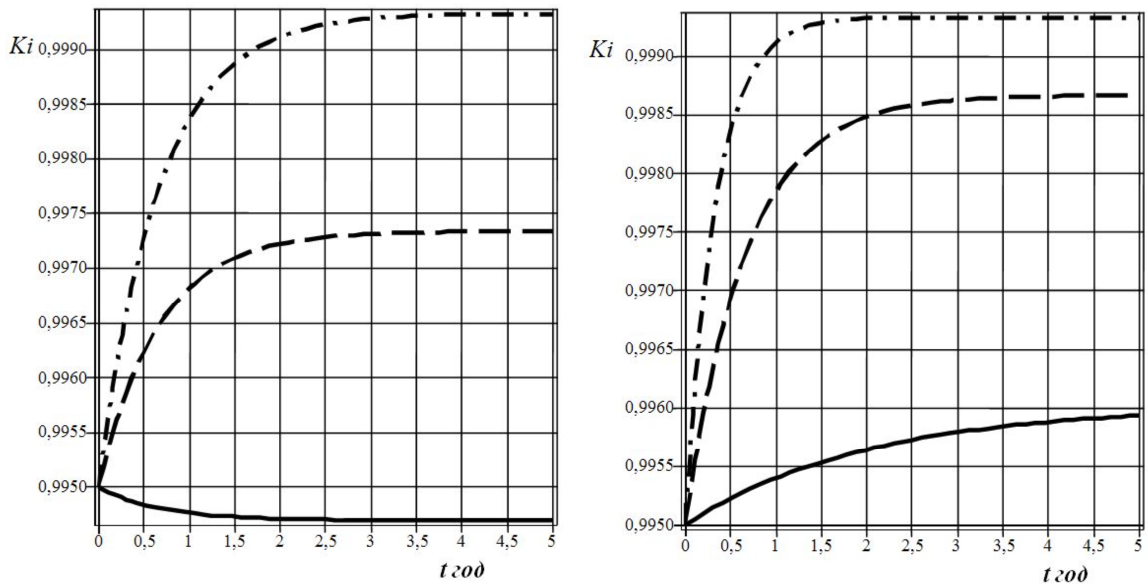

Fig. 2. Comparison of change in the criterion $K_i(t)$ depending on:

a) flow of defects:

μ_i = 1.5 1/year; $K_{i0} = 0{,}995$;

——— λ_i = 0.001 1/year; — — λ_i = 0.004 1/year; — · λ_i = 0.008 1/year;

b) flow of restoration:

λ_i = 0.002 1/year; $K_{i0} = 0{,}995$; ——— μ_i = 0.5 1/year;

— — μ_i = 1.5 1/year; — · μ_i = 3 1/year (год = year)

Then a differential equation (9) can be transformed to be

$$\frac{dK_i(t)}{dt} = -(\lambda_{i0} + b_i t)\cdot K_i(t) + \mu_i \cdot (1 - K_i(t)). \quad (15)$$

Solving a differential equation (15) under the initial condition (10), we get

$$K_i(t) = \begin{pmatrix} -\frac{1}{\sqrt{-2b_i}}\left(\mu_i\sqrt{\pi}e^{-\frac{1}{2}\frac{(\lambda_{i0}+\mu_i)^2}{b_i}} erf\left(-\frac{1}{2}\sqrt{-2b_i}\,(t-t_0)+\frac{\lambda_{i0}+\mu_i}{\sqrt{-2b_i}}\right)\right)+ \\ +K_{i0}+\frac{\mu_i\sqrt{\pi}e^{-\frac{1}{2}\frac{(\lambda_{i0}+\mu_i)^2}{b_i}erf\left(\frac{\lambda_{i0}+\mu_i}{\sqrt{-2b_i}}\right)}}{\sqrt{-2b_i}} \end{pmatrix} e^{-\frac{1}{2}(t-t_0)(b_i(t-t_0)+2\lambda_{i0}+2\mu_i)}. \quad (16)$$

Fig. 3 indicates the influence of a variably intensive flow of defects on change in the criterion $K_i(t)$.

a) b)

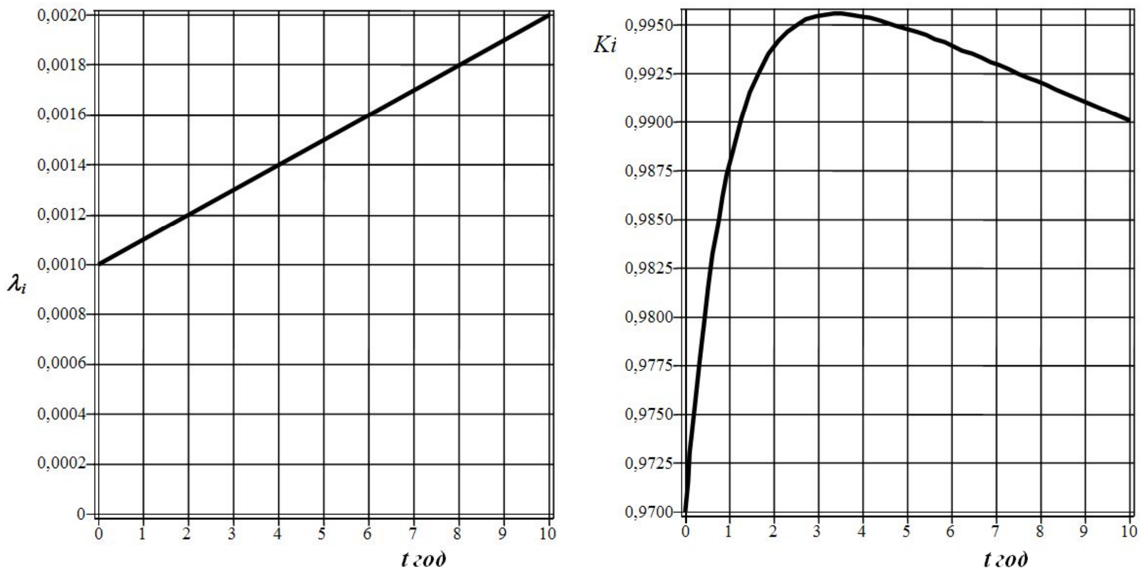

Fig. 3. Change in the criterion $K_i(t)$ at a variably intense flow of defects:

a) linear function of a flow of defects; b) criterion $K_i(t)$: λ_{i0}=0.001; b_i=0.001; μ_i = 1 1/year;

$K_{i0} = 0,97$

Therefore, the resulting solutions based on a reliability criterion $K_i(t)$ for a constant and variable parameter of a flow of defects allows one to predict how the work of maintenance services affect the state of the equipment elements.

Conclusions

1. Mathematical description of the state of equipment based on the probability theory for Markov random processes.

The criterion of reliability of equipment which is the ratio of mathematical expectation of elements in order to the total of the elements in the group.

2. Based on the mean value method Kolmogorov differential equations were obtained to determine a criterion of equipment reliability. The equations define how a criterion of reliability

depends on a parameter of a flow of defects and parameter of a flow of restoration that depends on the performance of maintenance services.

3. The solutions of the equations to determine a criterion of reliability for the constant and variable parameter of a flow of defects. The solutions allow one to estimate the effect of the performance of maintenance services on a criterion of reliability.

4. The use of the suggested method to assess the reliability of equipment enables planning of repair works and keeps track of the demand for maintenance services.

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