A NEW APPROACH TO NUMERICAL CALCULATION OF NON-STATIONARY PROCESSES IN COMPLEX MAIN GAS PIPELINES

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Abstract

The indicators of the main gas pipeline complexes are analyzed and studied, and a new approach to the numerical calculation of non-static processes in the system is proposed. Issues of unsteady movement liquid and gas in pipes are significant importance for both the design and operation pipelines. Based on the new approach, a method for calculating the characteristics of non-static processes in main gas pipeline complexes has been constructed. Based on the calculation methods, some important analytical expressions for assessing the performance of main gas pipeline complexes have been obtained.

Keywords: Complex magistral gazoprovodov, gas industry, design, non-static processes, operation pipelines.

I. Introduction

Currently, the gas industry is one of the leading branches of Azerbaijan's economy. Gas supply data show that trunk gas pipelines operate in a non-stationary pumping mode for a significant part of the time [1].

In this regard, in conditions of non-stationarity during operation of trunk gas pipelines, it is often necessary to deal with various malfunctions of their technical condition, leading to a violation of the operating mode, contributing to the creation of pre-emergency and emergency situations in the system and, thereby, disrupting the rhythm of the pipeline operation [2, 3].

Considering that in many regions of Azerbaijan, gas is the main type of fuel and chemical raw material, guaranteed uninterrupted supply of gas during that time has important importance.

Accidents occurring on main gas pipelines lead to significant losses caused by gas leakage and stoppage of pumping, which in turn leads to stoppage processes, disruption of gas supplies to consumers, contamination of the surrounding area and the threat of death of plants and animals.

Therefore, it is of great practical importance to study the gas-dynamic condition of main gas pipelines under various conditions of violation of their working modes, with the aim of reducing gas loss and choosing a rational control method under technological and emergency modes.

Thus, the creation of methods of calculation of non-stationary modes of operation of main gas pipelines will allow more effective implementation of their design and operation [4, 5].

However, the solution to the problem developing sufficiently accurate mathematical relationships and algorithms describing non-stationary processes in gas transport systems, taking into account real factors such as the influence of inertia and friction of the pumped gas, the distribution of parameters of the outlet sections, the influence of the characteristics of compressor stations, shut-off valves is still far from being implemented [6, 7].

In most of the studies, they were mainly carried out only for a particular case - the solution of the equations describing the non-stationary movement of gas along one section of the gas transport network, without considering the entire gas pipeline network, including compressor stations, taps, shut-off valves, gas consumers, in a single gas-dynamic mode, which Essentially narrows the circle of practical tasks [8, 9].

In this article, a simple universal numerical method is proposed, which allows to calculate non-stationary processes in complex main gas pipeline systems with a sufficiently high accuracy, taking into account the influence of inertial forces, friction, as well as the real characteristics of compressor stations, shut-off valves, taps when they are turned on and off, and arbitrary moments of time.

The proposed method is based on the use of a new approach in determining the values of the originals of the transfer functions by using a discrete analogue of the integral convolution equation, which allows you to move to the domain of discrete images of the desired functions.

In the domain of originals without finding the roots of the characteristic equation, while replacing the continuous integration operations by summation by the trapezoid formula, which significantly increases the accuracy of calculations, simplifies mathematical tabs and significantly expands the range of practical problems to be solved [1, 3, 6].

Examples of reasons causing non-stationary operating modes of gas pipeline systems may be:

- irregularity of gas reception from the field and gas supply from gas processing plants;
- stopping and starting compressor units, which may be planned or emergency due to failure of linear equipment, power outage, or activation of the automatic protection system;
- putting a gas pipeline into operation after construction, eliminating emergency situations or long-term shutdowns;
- turning on and off track discharges and gas injections along the pipeline route;
- changing the state of underground gas storage facilities:
- violation of the gas pipeline tightness, occurrence of leaks;
- stopping, switching from one mode of the gas pipeline system to another, which can be planned or emergency due to failure of equipment or a linear section.

In addition, the magnitude of the non-stationarity of the pumping process is influenced by a number of other factors: the process of filling and emptying the gas pipeline during pipe testing, the blowdown process, pipe ruptures and contamination with condensate, hydrate formation, corrosion processes, and finally, changes in the mode introduced by service personnel in the process of managing the long-distance gas transportation system.

In many cases, the occurrence of these reasons has a negative impact on the operation of the gas pipeline and creates the risk of emergency situations.

Nonstationary processes occurring in the main gas pipeline are described by partial differential equations of the parabolic type:

$$\begin{aligned} -\frac{\partial p}{\partial x} &= k_1 \omega \\ -\frac{\partial \omega}{\partial x} &= k_2 \frac{\partial p}{\partial t}, \end{aligned} \quad , 0 \le x \le l \tag{1}$$

where $p = p(\chi, t)$, $\omega = \omega(\chi, t)$ – respectively, excess values pressure and speed of gas movement; $k_1 = 2a\rho$, $k_2 = 1/\rho c^2, \rho -$ gas density; c - speed of sound in gas; $2\alpha = \lambda \omega_{cp} / 2D$ – coefficient linearized according to I.A.

Charny; λ - coefficient of hydraulic resistance; D – internal diameter of the pipe; ω_{cp} - average gas flow velocity over the cross section in steady state [1]:

$$\omega_{ъп} = \frac{2}{3}\left(\frac{\omega_1^2 + \omega_0\omega_1 - 2\omega_0^2}{\omega_1 - \omega_0}\right) \tag{2}$$

where ω0, ω_1 - steady-state values of average speed.

For this problem, the initial conditions are taken to be zero:

$$p(x,t)_{t=0} = 0, \quad \omega(x,t)_{t=0} = 0 \tag{3}$$

Boundary conditions may have different forms depending on the operating modes of the gas pipeline.

In the case under consideration, let us assume that the boundary conditions are as follows:

$$\omega(x,t)_{x=0} = \omega_H(t), \quad \mathrm{p}(x,t)_{x=1} = 0 \tag{4}$$

where $\omega_H(t)$ - arbitrary law of change in the speed of gas movement at the beginning of the pipe.

So, the gas pipeline length $l = 100$ km, the internal diameter of the gas pipeline (D) = 1 m, the coefficient hydraulic resistance $(\lambda_0) = 0{,}01$, the average gas pumping speed $(\omega_{cp}) = 10$ m/s operates in a steady state.

The case was considered when, at the beginning of the pipe at the moment of time $t \geq 0$, a pressure jump $\mathrm{P}(0,t) = \mathrm{P}_H(t) = 10^{-1}\, M\Pi a$, occurs, and at the end of the pipeline a constant flow rate is maintained, i.e. $G(l,t) = G_K(t) = 0$ (Fig. 1) - since in this example $\mathrm{P} = \mathrm{P}(x,t)$, $G = G(x,t)$ - implies disturbances of pressure and flow rate above their stationary values.

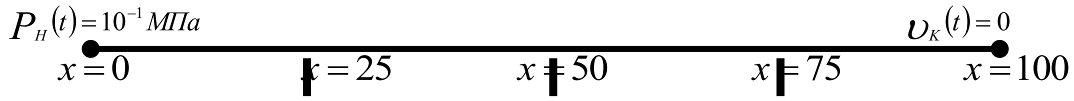

Figure 1: *Structure and description of the pipeline maintaining a constant flow rate*

The speed of sound in gas is 320 m/s.

The value of the reduced coefficient of linear friction is determined by the formula:

$$2\grave{a} = \frac{\lambda_0 \omega_{ñð}}{2D} = \frac{0{,}01 \cdot 10}{2 \cdot 1} = 0{,}05 \;\; 1/c$$

According to the conditions of the problem, the initial conditions are zero.

Calculations were carried out on a computer at $\lambda = 10$.

As experimental studies show, when compressor units are turned on or off, or valves at the beginning of a gas pipeline are opened or closed, the pressure and speed of gas movement at any point in the pipe change according to an arbitrary law.

In connection with the widespread introduction of computer technology into the practice of engineering calculations, the use of numerical methods for calculating non-stationary processes in main gas pipelines is currently becoming especially effective.

In this case, a numerical method is given for calculating non-stationary modes in main gas pipelines taking into account the friction forces and inertia of gas, with an arbitrary law of change in the speed of gas movement at the beginning and pressure at the end of the pipeline (Figure 1).

The essence of the proposed method is based on the use of a discrete analogue of the integral convolution equation.

The advantage of the proposed approach is that it allows, without going into the area of discrete images, to make the transition from Laplace images of the sought functions to the area originals, without finding the roots of the characteristic equation, to replace the operations continuous integration with summation using the trapezoid method, which significantly simplifies mathematical calculations and increases the accuracy of calculations.

If non-stationary processes occur under the influence of a change in the gas velocity at the beginning of the gas pipeline, then as a result of this the pumping speed and gas pressure at any point of the gas pipeline also change.

This type of boundary conditions connects the gas velocity at the beginning of the gas pipeline in the time domain with the pressure at the end, which is most often used in the case of coordinating the productivity of gas pipeline sections.

The solution to the problem under consideration allows one to determine, for a given change in the velocity at the beginning and pressure at the end of the gas pipeline, the pressure and gas velocity in any section of the pipe.

From the point of view of operational management, it is of interest to obtain a dependence by which it would be possible to quantitatively assess the effect of a change in productivity at the beginning of a linear section on the pressure at its end.

In this case, the relationship between continuous time t and discrete time is as follows:

$$t = \frac{nT}{\lambda}$$

where $T = 2\tau$, $\tau = \frac{l}{c}$ - is the time of wave propagation to one end of the gas pipeline.

The results of calculations for this case, regarding the change in pressure in sections $x = 25км$, $x = 50км$, $x = 75км$ are shown in Figure 2 (curves $1 \div 3$), and regarding the change in flow rate – in figure 3 (curves $1^{/} \div 3^{/}$).

As can be seen from figure 2-3, when moving from one section to another during non-stationary processes, a delay and different rate of increase of the non-stationary process along the length of the main gas pipeline are clearly visible.

For example, as can be seen from Figure 2 (4.4) at t=6h the level of pressure increase in sections $x = 25км$, $x = 50км$, $x = 75км$ respectively is when, $P(25,t) = 8{,}7 МПa$, $P(50,t) = 7{,}48 МПa$, $P(75,t) = 6{,}25 МПa$.

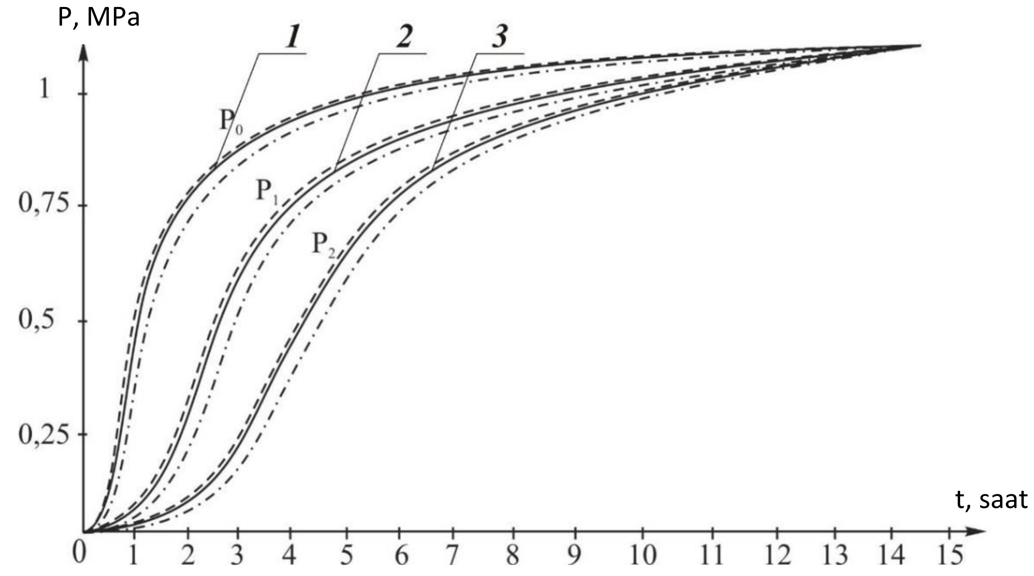

Figure 2: *Graphic dependence of pressure change in sections on time*

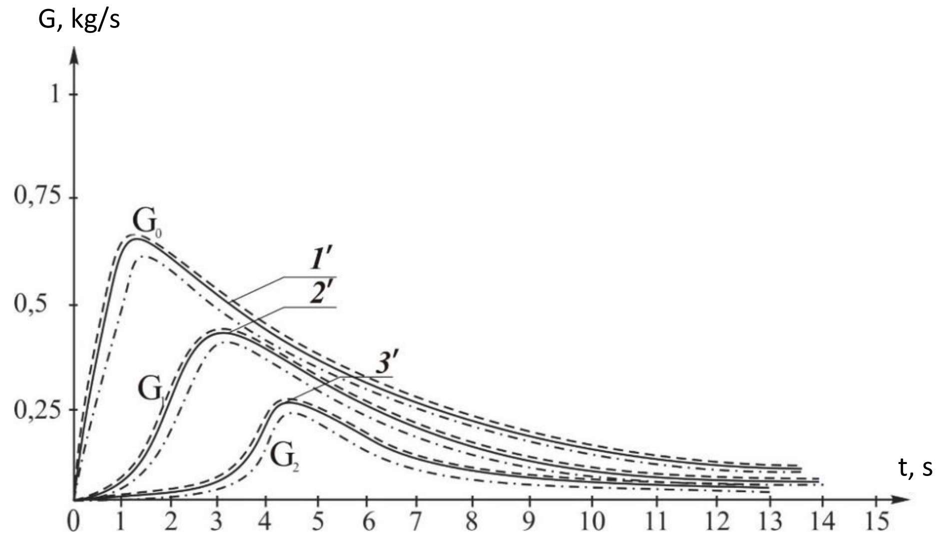

Figure 3: *Graphic dependence of non-stationary processes on time in a main gas pipeline*

In the case under consideration, when moving from one section to another, the pressure has a different rate of decrease, and the flow rate has a different rate of increase during non-stationary processes [8, 9].

From the analysis of the results shown in Figure 3, it follows that there is a different effect of delay of the non-stationary process relative to the pressure and flow rate from one section to another.

In addition, from the analysis of the obtained results (Figure 2-3) it follows that the nature of the change in pressure and flow rate during non-stationary processes occurring in main gas pipelines depends on the choice of the type of boundary conditions.

For comparison, Figure 2-3 also shows the results of this example obtained using the state variable method [4, 6] in the form of dotted lines. As can be seen from Figure 2-3, the calculation results obtained using both methods are completely identical. However, the method developed in this article significantly simplifies the mathematical calculations.

Since, in this case, to solve the problem, according to the method of state variables [4, 6]; the main gas pipeline is divided into four sections and for each section, in order to ensure the specified calculation accuracy [4, 6], six approximated ordinary differential equations of the first order are written.

Further, with the joint solutions of the indicated equations, both for pressure and flow rate, non-stationary processes occurring in the main gas pipeline are determined, which makes the mathematical calculations extremely complicated.

Thus, a general disadvantage of the state variable method is the great difficulty of determining the number of approximated ordinary differential equations of the first order to ensure a given accuracy of calculation of a non-stationary process depending on the length of the linear sections of the pipeline [4, 6, 8].

In Figure 2-3, in the form of dotted lines, the results of this example are also shown, obtained according to the numerical method based on the theory of pulse systems and the mathematical apparatus of the discrete Laplace transform [5, 7] (with this approach, the operation of continuous integration is replaced by summation according to the rectangle formula).

In this case, the error of the numerical method [5, 7] in comparison with the methodology developed in this work, for this case with respect to pressure is 6%, and with respect to flow rate – 8%. The proposed numerical method can be widely used in the design and operation of complex main gas pipelines.

Calculations according to the developed algorithms are reduced to simple recurrence relations that allow easy implementation on a computer.

Calculations based on the developed algorithms are reduced to simple recurrence relations that can be easily implemented on a computer.

The proposed method can be widely used by research and design organizations in the design and operation of main gas pipelines. The developed algorithms make it possible to solve a wide range of problems on non-stationary processes in complex gas transportation systems and allow:

- determine dangerous increases and decreases in pressure at the discharge and suction compressor stations; determine dangerous excess pressure at the valve, as well as at characteristic points of linear sections and branch sections, when switching on and off gas pumping units of compressor stations, valves, associated gas consumers, in order to prevent emergency phenomena;
- develop a set of measures for operational dispatch control of non-stationary operating modes complex systems main gas pipelines, such as determining the sequence of switching compressor units of compressor stations; determining the sequence of switching on branches when distributing gas supply volumes between associated consumers.

The practical use of the developed methods allows to increase the efficiency of dispatch services and the reliability operation main gas pipelines, leads to an increase in the throughput capacity of the gas pipeline, and a decrease in gas losses, as well as the costs electricity consumed by compressor stations.

II. Conclusions

1. As a result, the study proposed a new approach to creating methods for calculating the indicators of non-static processes in trunk gas pipeline complexes. Based on the calculation methods, some important analytical expressions were obtained for assessing the indicators of trunk gas pipeline complexes.

2. Based on numerical calculations, graphical dependencies of non-stationary processes on time were constructed for comparative analyses of system indicators.

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