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Selection rationale for leakage monitoring in gas pipeline*

A. D. Lebed[1], S. P. Glushko[2]**
[1,2] Kuban State Technological University, Krasnodar, Russian Federation

Обоснование выбора способов контроля утечек на газопроводе***

А. Д. Лебедь[1], С. П. Глушко[2]**
[1,2] Кубанский государственный технологический университет, г. Краснодар, Российская Федерация

Introduction. Efficient leak detection methods and gas flow metering are analyzed. The work objective is to select an automatic system of methods providing the improvement of the quality of leakage monitoring and gas flow metering in gas pipelines.
Materials and Methods. The following techniques for detecting gas leakage in the pipeline are considered: according to the pressure profile, volume balance method, acoustic emission method, variable-pressure drop method on the forcing device, ultrasonic method.
Research Results. The analysis shows that all techniques for monitoring leakage and gas flow are dependent on the environmental parameters. Therefore, an important task is to achieve independence of the measurement results from changes in the environmental parameters. In most flow meters, changes in density, pressure and temperature affect drastically the measurement results. An additional error that arises in this case can reach large values.

Keywords: main gas pipeline, control, leakage, control system, robot.

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Введение. Анализируются эффективные методы обнаружения утечек и учета расхода газа. Целью работы является выбор автоматической системы методов, позволяющей повысить качество контроля утечек и учета расхода газа на магистральных газопроводах.
Материалы и методы. Рассмотрены следующие методы обнаружения утечек газа в трубопроводе: по профилю давления, объемно-балансовый, метод акустической эмиссии, метод переменного перепада давления на вынуждающем устройстве, ультразвуковой метод.
Результаты исследования. Анализ показывает, что все методы контроля утечек и расхода газа зависят от параметров окружающей среды. Поэтому важной задачей является достижение независимости результатов измерений от изменения параметров среды. У большинства расходомеров изменение плотности, давления и температуры среды существенно сказывается на результатах измерения. Возникающая при этом дополнительная погрешность может достигать больших величин.

Ключевые слова: магистральный газопровод, контроль, утечки, система управления, робот.

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Introduction. Due to the high growth of the gas industry, the increase in the share of natural gas relative to other energy sources in the domestic Russian market and the increase in gas consumption in the world market, reducing gas losses and improving the safety of operation of gas pipelines is an urgent task [1]. Therefore, the most important problem is to maintain the working condition of the linear sections of the field and main gas pipelines (MGP). Underground gas pipelines operated under normal conditions can be maintained in working condition for several decades. The maintenance of the working condition of underground and aboveground MGP is facilitated through their condition monitoring and on-time scheduled maintenance.

Defects on the MG occur as a result of corrosion and, less commonly, due to mechanical damage. Detection of places of corrosion and damage is associated with time and material costs. Breaking a gas pipeline for direct visual inspection is economically unprofitable or impossible. Examination of only the outer surface of the pipe usually turns

* The research is done within the frame of the independent R&D.
**E-mail: anya-11-06@mail.ru, sputnik_s7@mail.ru
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sour. Therefore, it is relevant to monitor the status of underground and aboveground field MGP without breaking. The solution to this problem is complicated by considerable technical difficulties; however, modern methods and means of measuring equipment enable to overcome them. These means vary in the following properties and parameters:

- physical phenomena underlying the work;
- principle of action;
- sensitivity;
- area of application;
- diagnosis locality or globality.

In gas leak detection systems in the pipelines, organoleptic and instrumental methods are used. The easiest method is odor fixation. For visual control methods, a foaming soap emulsion is used to record the occurrence of ice or a snow coat, the appearance of yellow grass in summer or brown snow in winter. Undoubtedly, instrumental methods are more advanced and accurate.

They are based on the use of automatic and manual gas analyzers. As automatic gas analyzers, gas sensors are widely applied: these are high-precision measuring devices used in continuous automatic monitoring of the amount of gases contained in air. Gas detectors are used in industrial, domestic and communal facilities. Gas sensors are available in the form of separate devices that can be placed autonomously and respond to changes in the concentration of certain gases. They instantly respond to an increase in the concentration of gases emanating from the gas transmission system. Modern models of sensors are equipped with liquid crystal displays on which measured values are displayed. Built-in memory provides recording the data and storing all measurement results. The display also shows information on the durability of the device and existing troubles. This feature allows changing worn-out components in proper time.

Gas control sensors are divided into two main types: household and industrial. Household alarms provide a number of responses to exceeding the set gas concentration. The main tasks of an industrial sensor are measuring and displaying gas content indices. Industrial devices are used to solve more significant problems and as part of automated systems together with a control panel that displays data from gas sensors. By the type of gas being monitored, methane and propane alarms are distinguished, as well as alarms designed to measure the concentration of carbon monoxide or carbon monoxide. Along with this, there are combined (multi-component) signaling devices. Gas sensors can be stationary, line-powered ones, located close to the electrical source, or portable, battery-driven sensors.

A gas contamination sensor is a multifunctional device; it has functions of audio and light warning. For example, in the САКЗ-МК-1 (SAKZ-MK-1) system (Fig. 1), if the device responded to gas pollution, its indicator lights up and an audible alert is generated. Gas sensors have a relay output for connecting additional electrical devices: announcers, fans, mechanisms and devices of the fire and dispatcher panels.

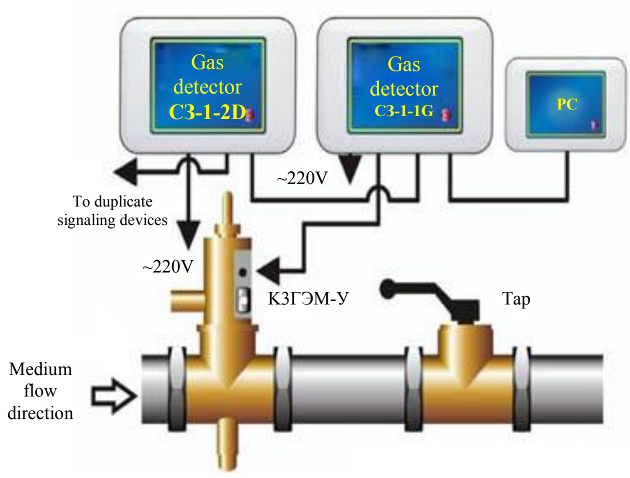

Fig. 1. Gas alarm system САКЗ-МК-1 (SAKZ-MK-1)

Gas pollution sensors according to STO (company standard) Gazprom 5.37-2011 are used in nodes of measuring the flow rate and amount of flammable natural gas supplied from field treatment facilities, underground storage facilities, gas processing plants, to the main gas pipelines and then transported to consumers in the Russian Federation, to neighboring countries where it is utilized and consumed on in-home process needs. Gas sensors are disadvantageous to use throughout the main pipelines. Besides, in hard-to-reach locations of trunk pipelines, it is difficult to use organoleptic and instrumental methods for detecting gas leakage.

Materials and Methods. In addition to the above methods for detecting gas leakage in pipelines, the following techniques are used [2]:

- pressure profile analysis;
- volume-balance method;
- acoustic emission analysis;
- variable pressure drop analysis;
- mechanical method using velocity flowmeters;
- ultrasonic flow rate metering method.

According to the leakage detection method for pressure profile analysis, a simulation of the pressure distribution along the pipeline and a statistical analysis of this distribution are performed. In case of gas leakage, the flow rate in the controlled section becomes greater than the initial flow rate in this section, and the flow rate in the section after the leakage point becomes smaller than the initial flow rate. As a result, the pressure drop in the area to the leakage point increases, and after the leakage decreases, which leads to the appearance of a break in the pressure profile. The leak detection method through analyzing the pressure profile works only in the stationary mode since many factors cause similar changes. A significant drawback of this method is low accuracy and presence of false responses. To reduce false responses, deviations should be recorded at least at two adjacent points. For the same purposes, an averaged pressure distribution profile is used, which is a quasistationary profile. This profile is obtained through filtering pressure at points in the pipeline. The averaged pressure profile is not constant. It changes, but more slowly than the actual pressure, which leads to an increase in the detection time of leaks.

The volume-balance control technique rests on the fact that when a leak is formed, the inlet flow rate becomes greater than the outlet flow rate. In addition, this method considers the amount of gas in the pipe itself, which decreases when a leak occurs. To implement this technique, it is necessary to measure the flow rate at the boundaries of the controlled area using high-precision tools.

The control parameter in the volume-balance method is not the gas pressure, but its normalized flow rate. The control of the pipeline section is performed through determining the difference between the normalized volumes of gas entering and leaving the section between two local flowmeters. This method provides the diagnosis of both rapidly developing breaks in the pipe, and slowly developing leaks, as well as leaks in very large sections of the pipeline between the flowmeters. The minimum value of the diagnosed leak is determined, first of all, by the error in measuring the flow rate and, with current means of measuring the flow rate, is at the level of 0.5–1.0%. Accuracy of leakage monitoring depends on the precision of the flowmeters. It is impossible to detect a leak whose flow rate is less than the measurement error. In this case, it is not the absolute error that matters, but only a meter to meter error.

The volume-balance method does not determine the leakage coordinate – this is its major drawback. Besides, the volume-balance flow in the sections provides the determination of the point of leakage in the gas pipeline only to an accuracy of the estimation of this parameter to a specific section. This, in turn, leads to additional time and gas losses from the moment of leakage to the moment of its elimination.

The acoustic emission analysis method takes the lead in the industry of the automatic detection of gas leaks in pipelines [3]. This method is based on the registration and analysis of acoustic waves that occur during plastic deformation and microlysis of the pipeline material, as well as when gas flows through the open-end holes in the pipe. Piezoelectric transducers and high-speed pressure meters are used to receive acoustic emission signals.

The advantages of this method are as follows:

- high sensitivity to developing defects;
- short detection time;
- high accuracy of determining the leakage coordinates.

The disadvantage of this method is difficulty of the acoustic emission signal extraction against the background of noise and interference. To increase noise immunity and reduce the number of false alarms, adhoc techniques of processing the received signals are applied.

When developing a system for detecting gas leakage at gas pipelines and gas metering units at the production facilities, the following tasks should be addressed:

- obtaining independence of measurement results from changes in environmental parameters due to gas pressure control;
- improving the accuracy of monitoring leakage and gas flow.

Gas flow measurement is an important task in the gas industry since a gas metering system is infeasible without flow measurement tools. At the gas industry facilities, tachometers and counters are used to measure gas flow and its quantity. Recently, the state-of-the-art-type ultrasonic flowmeters are also actively introduced into the gas pipeline control industry [4]. However, nowadays, a method of variable pressure drop on a constriction device (CD) is most widely used for measuring gas flow rate. The principle of method is to measure the pressure drop before and after the CD installed in the gas stream. Gas volumetric flow rate Q for special CD is determined from the formula:

$$Q = CE\varepsilon F_0 \sqrt{\frac{\Delta p}{\rho}},$$

where C is the discharge coefficient which is the ratio of the actual flow rate to the theoretical one; E is the input velocity coefficient; ε is the expansion coefficient considering an increase in the specific gas volume; F_0 is the area of CD, m^2; Δp is the drop created by the CD, Pa; ρ is the gas density, kg/m^3.

Advantages of the variable pressure drop method are as follows:

1. Versatility. This method is used to measure the flow rate of almost any medium: liquid, gas, steam. For viscous liquids, CDs of special form are used.
2. Low initial cost. The cost of a flowmeter based on the method of variable differential pressure comprises the cost of the CD, impulse lines and differential pressure sensor.
3. A simple verification technique. For periodic calibration of flowmeters, it is necessary to measure the geometric dimensions of the CD and to check the differential pressure sensor.
4. Zero moving parts.
5. Possibility to measure flow under high pressure conditions. Pressure in the pipeline can reach 40 MPa.
6. Possibility to measure flow over a wide temperature range of the medium being measured – from minus 200 to plus 1000° C.
7. A wide range of sizes. The considered method is used on pipelines in the range of nominal diameters from 15 to 2000 mm.

Disadvantages of measuring gas flow by the method of variable pressure drop analysis on the CD are the following:

1. Narrow dynamic range. The standard dynamic range of the CD is approximately 1: 3. This limitation is associated, first of all, with a quadratic dependence between the flow rate and the pressure drop on the CD. The dynamic range can be increased by the use of high-precision differential pressure (DP) indicators.
2. High operation cost. CD-based flowmeters require periodic maintenance, which includes measuring the geometrical dimensions of the constriction device, cleaning the impulse lines, heating the impulse lines, and zero setting on the DP indicator.
3. Low accuracy of measurements. The measurement error is usually 3.0-3.5%.

The principle of operation of tachometric flowmeters is based on the dependence of the speed of the transducer, installed in the pipeline, on the gas flow. In the flowmeters of the “counter” type, the flow transducer shaft is connected to a counting mechanism through the gearbox, which provides measuring the amount of transmitted gas. The advantages of such devices are speed and a wide range of measurements.

The error of the counters is 0.5–1.5%. The application of tachometric transducers can reduce the error in converting the flow rate to the converter speed up to 0.3%. The major disadvantages of tachometric flowmeters are wear of supports and the presence of moving elements. The disadvantage in relation to flowmeters with CD is the need for calibration facilities.

The principle of operation of ultrasonic flowmeters is based on the phenomenon of displacement of sound vibrations by a moving medium. This method has the following disadvantages:

• dependence of the intrinsic ultrasonic velocity on the physicochemical properties of the medium being measured;
• flow velocity is averaged along the ultrasonic beam, and not over the cross section of the pipe.

Averaging the flow rate brings the developers to supply the design with additional sensors or reflectors, which makes the flow meter more complicated. This increases the chances of an error in case of the system sensors breakdown.

Advantages of this method are:

• zero pressure drop;
• high speed;
• zero moving elements.

Research Results. The analysis shows that the task of detecting and localization (accurate positioning) of gas leakage cannot be solved using one of the considered methods. Given the advantages and disadvantages of the methods discussed in this paper, it is proposed to solve the problem using three methods and stepwise:

• determine the section with gas leakage between stations using the volume-balance method;

• establish a local section of pipeline damage and gas leakage by the method of acoustic emission analysis;
• using ultrasonic flaw detection, determine the leakage coordinates within the specified local damage section.

To control horizontal and straight length sections of the gas pipeline and to accurately fix the leakage points using an ultrasound scanner, various robots can be applied [5–7], for example, video crawlers which are mobile and universal means of pipeline inspection. They are suitable for various applications due to the modular design and the ability to inspect the pipes with diameters from 150 to 900 mm from inside. Fig. 2 shows one of these robots, Rovver 600 video crawler. The remote control of the robot provides checking focus and lighting, as well as heading the motion in the area of obstructions or branches.

Fig. 2 Rovver 600 video crawler

Discussion and Conclusions. The authors propose to increase the reliability of detection and localization of gas leakage using a combined three-stage technique, which includes a sequential application of the volume-balance method, acoustic emission analysis, and ultrasonic flow rate metering. In certain situations, the use of task-specified robots is recommended. The authors hold that robots should be equipped with a 90-degree bend detection sensor mounted on the head link, as well as with speed and distance sensors for accurate positioning. This will reduce the time of diagnosing gas pipelines of various types and cut down the cost of monitoring their condition.

Analysis of information on accidents in the gas complex is of great importance, first of all, for evaluating risk factors and the reliability of the gas transmission system. The analysis results are required to validate design solutions of gas supply system facilities, and they are applied when planning measures to increase their reliability and safety under operation.

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Authors:

Lebed, Anna D.,
student of the Control Systems and Technological Complexes Department, Kuban State Technological University (2, Moskovskaya St., Krasnodar, 350072, RF),
ORCID: https://orcid.org/0000-0003-4263-8806
anya-11-06@mail.ru

Glushko, Sergey P.,
associate professor of the Control Systems and Technological Complexes Department, Kuban State Technological University (2, Moskovskaya St., Krasnodar, 350072, RF), Cand.Sci. (Eng.), associate professor,
ORCID: https://orcid.org/0000-0002-7087-6572
sputnik_s7@mail.ru