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Research of the metrological model of optic-thermal method of natural gas flow measurement

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Abstract

The article substantiates the importance of research aimed at the development and study of contactless method of natural gas flow measurement.

On the basis of the developed mathematical model of contactless optic-thermal method of gas flow measurement and key provisions of the uncertainty theory the metrological model analysis is made. The component of the combined standard uncertainty due to the uncertainty of uncorrelated input parameters of the measurement equation is researched and evaluated. The dominant components and the ways of reducing their impact on the combined standard uncertainty are selected. The greatest contribution to combined standard uncertainty of the method makes the uncertainty of interference fringes number measurement, the uncertainty of the distance between the cross-sections of the pipeline measurement and uncertainty of the coefficient determination, which characterizes the velocity distribution of the gas flow.

The components of combined standard uncertainty (thermophysical parameters of the gas and the pipeline material, the geometric characteristics of the pipeline), which are correlated with each other due to the temperature dependence, are identified. The uncertainty budget of correlated measurements is compiled. Quantitative assessment showed that the correlation between certain input parameters does not have large impact on the combined standard uncertainty of the measurement.

Analysis of the metrological model of the contactless optic-thermal method of gas flow measurement allowed estimating the relative combined standard uncertainty of the method and substantiating the perspective applications of the method for measuring gas flow in large diameter pipelines.

Keywords: gas flow; optic-thermal method; standard uncertainty; metrological model; correlated parameters; uncorrelated parameters; uncertainty budget.

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Introduction

The oil and gas industry in Ukraine as a separate sector of fuel and energy industry of the country is one of the most promising and intellectual branches of national economy today. Ensuring the accurate accounting and economical use of natural gas is the most important scientific and practical tasks of science and technology of Ukraine at present.

Analysis of recent research and problem statement

The problem is that the technical and metrological support of oil and gas industry is at insufficient level in Ukraine. It is related primarily to the fact that the vast majority of the total gas volumes is measured by the systems based on the pressure differential method (DSTU GOST 8.586.5:2009) [1]. Also the turbine, vortex, ultrasonic, rotary, membrane and other flowmeters are used [2, 3]. The application of contact transducers leads to a significant component of the measurement uncertainty due to the influence of the sensor on the flow. The most widespread contactless flowmeters are ultrasonic flowmeters. However, they have several drawbacks that limit their use in practice [4]. Therefore, the development and research of contactless optic-thermal devices is a promising area in natural gas flow measurement [5].

Research aim and objectives

The aim of this research is the development and analysis of metrological model of optic-thermal method of natural gas flow measurement.

To achieve this goal, it is necessary to solve the following tasks:

- to analyze and assess the uncertainty of gas flow measurement caused by the inaccuracy of the set uncorrelated input parameters of the measurement equation on the basis of the developed mathematical model [5];

• to analyze and assess the dominant components of uncertainty from the point of view of their origin and ways of reducing their impact on the combined standard uncertainty;

• to analyze and assess the component of combined standard uncertainty, caused by the correlated input parameters of the measurement equation.

Analysis of the metrological model

The contactless optic-thermal method for measuring gas flow is developed on the basis of optical and thermal methods combination.

The physical essence of the optical method for measuring gas flow is as follows: if there is gas transfer through the pipeline, there will be a pressure drop at two separated sections, which leads to a difference in the gas refractive indices in these sections. As a result, the phase velocities of the optical rays passing through the studied sections will also differ. The resulting optical path difference is measured by a system consisting of an interferometer and a measuring signal-processing unit. By determining the optical difference in the path of the rays, we can conclude about the pressure difference, that is, about the speed or flow rate of gas in the pipeline.

Increasing in the sensitivity of the optical method is achieved because the optical difference in the path of the rays passing through separated sections of the pipeline increases due to the temperature difference in these sections.

The equation describing the optic-thermal method is [5]

$$Q=\frac{1}{2}\cdot\frac{\pi R^4}{\mu\cdot l\cdot K\cdot\left(\int\limits_0^{2R}\frac{dr}{T_1(r)}-\int\limits_0^{2R}\frac{dr}{T_2(r)}\right)}\cdot\left(1-\frac{3,75}{\xi}\right)\cdot\lambda_0\cdot m, \quad (1)$$

where Q – the gas flow; R – the inner radius of the pipeline; μ – the gas viscosity coefficient; l – distance between the researched cross-sections; K – the coefficient determined as

$$K=\frac{e^2/m}{\varepsilon_0\cdot k_0}\cdot\sum_{k=1}^{N_k}\frac{1}{\omega_{0k}^2-\omega^2}$$

from the publication [5]; T_1 and T_2 – the absolute temperatures in cross-sections of the pipeline; r – the current radius; ξ – the coefficient determined as Lambert function; m – the number of interference fringes; λ_0 – the wavelength in vacuum.

The metrological model of optic-thermal method of natural gas flow measurement was analyzed based on the developed mathematical model.

A preliminary assessment of the uncertainty components of the optic-thermal method was made in the research, because there are no multiple observations for the study of the systematic and random effects influences. Information for a preliminary assessment was received from the numerical simulation results, natural experiments, the physical properties of the determined values, the passport data of the used equipment and directories.

The uncertainty in the gas flow measurement caused by the inaccuracy of the set uncorrelated input parameters of the measurement equation (1) is determined as [6]:

$$U_1^2(Q)=\sum_{i=1}^{N_0}\left(\frac{\partial Q}{\partial x_i}\right)^2 U^2(x_i), \quad (2)$$

where x_i – the input parameters of the measurement equation (1); $U(x_i)$ – the measurement uncertainty of the i-th input parameter.

The estimation results of uncorrelated input parameters measurement uncertainty with the assumption of uniform distribution of scattering input values are presented in Table 1.

The uncertainty in the gas flow measurement caused by the inaccuracy of the set uncorrelated input parameters measurement equation (1) is

$$U_1(Q)=4.3356\times10^{-4}\ \text{m}^3/\text{s}.$$

The analysis of uncertainty shows that the dominant components are due to the inaccuracy of number of interference fringes measuring ($\left(\frac{\partial Q}{\partial m}\right)^2 S^2(m)$=6.0035×10^{-8} m^6/s^2), the inaccuracy in the cross-sections location ($\left(\frac{\partial Q}{\partial l}\right)^2 S^2(l)$=3.4789×10^{-8} m^6/s^2), the inaccuracy in the determination of the gas flow rate type of the distribution ($\left(\frac{\partial Q}{\partial \xi}\right)^2 S^2(\xi)$ = 1.1686× ×10^{-8} m^6/s^2). Other components in accordance with the criterion of negligible errors can be neglected.

To identify possible ways to improve the accuracy of optical-thermal method, it is necessary to analyze the dominant components of uncertainty from the point of view of their origin and ways of reducing their influence on the combined standard uncertainty.

1. Component of uncertainty due to inaccuracy of the number of interference fringes measuring.

The measurement uncertainty of the interference fringes number associated with the instrumental error of the used interferometer (type B uncertainty). To reduce this component of uncertainty is possible by the use of high-precision laser interferometers.

Table 1

The estimation results of measurement uncertainty uncorrelated input quantities

$\frac{\partial Q}{\partial P}, \frac{m^3 \cdot s^2}{kg}$	$\frac{\partial Q}{\partial l}, \frac{m^2}{s}$	$\frac{\partial Q}{\partial R}, \frac{m^2}{s}$	$\frac{\partial Q}{\partial \delta}, \frac{m^2}{s}$	$\frac{\partial Q}{\partial \lambda_g}, \frac{m^2 \cdot s^2 \cdot K}{kg}$
1.8261×10^{-5}	-2.0167×10^{-2}	1.2975	-1.7912×10^{-1}	5.6263×10^{-3}
$U_P, \frac{kg}{s^3}$	U_l, m	U_R, m	U_δ, m	$U_{\lambda_g}, \frac{W}{m \cdot K}$
1.1561	9.2486×10^{-4}	2.3124×10^{-4}	5.7803×10^{-5}	3.1845×10^{-3}
$U^2(P), \frac{m^6}{s^2}$	$U^2(l), \frac{m^6}{s^2}$	$U^2(R), \frac{m^6}{s^2}$	$U^2(\delta), \frac{m^6}{s^2}$	$U^2(\lambda_g), \frac{m^6}{s^2}$
4.4562×10^{-10}	3.4789×10^{-8}	9.1815×10^{-10}	1.0720×10^{-10}	9.6115×10^{-10}
$\frac{\partial Q}{\partial \lambda_0}, \frac{m^2}{s}$	$\frac{\partial Q}{\partial K}, \frac{kg \cdot m^2}{K \cdot s^3}$	$\frac{\partial Q}{\partial \xi}, \frac{m^3}{s}$	$\frac{\partial Q}{\partial \mu_g}, \frac{m^4}{kg}$	$\frac{\partial Q}{\partial \lambda_m}, \frac{m^2 \cdot s^2 \cdot K}{kg}$
214.3595	-2.2631	2.3084×10^{-3}	-3.6514	-1.7361×10^{-5}
U_{λ_0}, m	$U_K, \frac{K \cdot m \cdot s^2}{kg}$	U_ξ	$U_{\mu_g}, \frac{kg}{m \cdot s}$	$U_{\lambda_g}, \frac{W}{m \cdot K}$
1.0947×10^{-13}	1.1718×10^{-6}	4.6810×10^{-2}	8.3815×10^{-7}	1.5607
$U^2(\lambda_0), \frac{m^6}{s^2}$	$U^2(K), \frac{m^6}{s^2}$	$U^2(\xi), \frac{m^6}{s^2}$	$U^2(P), \frac{m^6}{s^2}$	$U^2(\lambda_T), \frac{m^6}{s^2}$
5.5065×10^{-20}	6.9918×10^{-10}	1.1686×10^{-8}	9.3662×10^{-12}	7.3576×10^{-10}
$\frac{\partial Q}{\partial m}, m^3/s$	$\frac{\partial Q}{\partial c_g}, m \cdot s \cdot K$	$\frac{\partial Q}{\partial \rho_g}, \frac{m^6}{kg \cdot s}$	$\frac{\partial Q}{\partial c_m}, m \cdot s \cdot K$	$\frac{\partial Q}{\partial \rho_m}, \frac{m^6}{kg \cdot s}$
4.1182×10^{-3}	2.6484×10^{-7}	1.0951×10^{-3}	3.7153×10^{-4}	1.3147×10^{-4}
U_m	$U_{cg}, \frac{J}{kg \cdot K}$	$U_{\rho_g}, \frac{kg}{m^3}$	$U_{c_T}, \frac{J}{kg \cdot K}$	$U_{\rho_T}, \frac{kg}{m^3}$
5.9541×10^{-2}	85.9797	7.0953×10^{-2}	1.1560×10^{-2}	1.507×10^{-1}
$U^2(m), \frac{m^6}{s^2}$	$U^2(c_g), \frac{m^6}{s^2}$	$U^2(\rho_g), \frac{m^6}{s^2}$	$U^2(c_T), \frac{m^6}{s^2}$	$U^2(\rho_T), \frac{m^6}{s^2}$
6.0035×10^{-8}	5.1863×10^{-10}	6.0131×10^{-9}	1.8446×10^{-11}	3.9254×10^{-10}

To improve the accuracy of the interference fringes measuring number to 0.0005 λ_0 is possible by using a laser interferometer with the score bands based on frequency modulation [7].

2. Component of combined standard uncertainty due to the inaccuracy in the studied cross-sections location.

Component of combined standard uncertainty due to the inaccuracy in the studied cross-sections location has three components:

1) the type B uncertainty caused by the inaccuracy of the used measuring instrument. This component is primarily determined by the technical characteristics of the used radiation source (laser). Most suitable for optical measuring devices are gas lasers, since they provide a monochromatic and coherent radiation in a continuous mode in the visible and infrared regions of the spectrum. For preliminary estimation of the optical-thermal method accuracy, the calculations used the technical characteristics of the helium-neon laser LG-55 (λ_0 = 0.6328 μm, beam diameter using a single-mode regime 0.0015 m) [7]. The reducing of the uncertainty component is achieved by pre-adjusting and fine-tune the optical system;

2) the uncertainty caused by the expansion of the pipeline material due to changes in ambient temperature. This component can be reduced by introducing the relevant correction to the measurement result.

The calculation of the input correction in system “pipeline – gas medium” for temperature conditions in accordance with regulatory documentation [8] from –70 to +60 °C for the pipeline with a diameter of 1420 mm is shown below.

$$\Delta m = \frac{\partial m}{\partial \theta_g} \cdot \frac{\partial \theta_g}{\partial z} \cdot \Delta z. \quad (3)$$

According to the research results [5]:

$\frac{\partial m}{\partial \theta_g}$ = 6.6552 1/°C, $\frac{\partial \theta_g}{\partial z}$ = 65.8941 °C/m.

The uncertainty in the gas flow measurement caused by the availability of uncertainty Δz with the other fixed parameters is

$$\Delta Q = \frac{\partial Q}{\partial m} \cdot \frac{\partial m}{\partial \theta_g} \cdot \frac{\partial \theta_g}{\partial z} \cdot \Delta z, \quad (4)$$

it equals

$$\Delta Q = 0.004118 \cdot 6.6552 \cdot 65.8941 \cdot \Delta z = 1.8059 \cdot \Delta z.$$

The change of the distance between the measuring cross-sections depends on temperature in a known way [9]:

$$l = l_0 \cdot (1 + \alpha_m \cdot \theta_c), \quad (5)$$

where l_0 – the distance between the measuring cross-sections at T_c; α_m – coefficient of thermal expansion of the pipe material, for steel α_m = 0.9×10^{-5} K^{-1}; θ_c – the ambient temperature changing (–70...+60 °C).

For l = 2 m, correction will be

$$\Delta Q = 2.1129 \times 10^{-3} \text{ m}^3/\text{s}.$$

3. Component of uncertainty due to inaccuracy in the determination of the gas flow rate type of the distribution.

In accordance with regulatory documentation the volumetric flow rate is defined as [10]

$$Q = K_p \cdot \upsilon \cdot S, \quad (6)$$

where K_p – the ratio of the average flow rate in the cross-section to the flow rate at the measuring point; υ – local flow rate; S – the area of the pipeline cross-section.

At the described method, the local flow rate equals the flow velocity at the pipe axis [10]. The coefficient K_p depends on the hydraulic characteristics of pipelines (roughness, Reynolds number) and it must be pre-defined for each measuring cross-section. When a known value of hydraulic friction coefficient, the coefficient K_p is allowed to take in accordance with regulatory documentation [10] from 0.713 to 0.875.

The coefficient K_p uncertainty calculation is:

K_p is the ratio of the average flow velocity in the section υ_a to the flow velocity at the measurement point υ, that is $K_p = \frac{\upsilon_a}{\upsilon}$. Accordingly, its uncertainty is

$$u(K_p) = \sqrt{\left(\frac{1}{\upsilon}\right)^2 u^2(\upsilon_a) + \left(-\frac{\upsilon_a}{\upsilon^2}\right)^2 u^2(\upsilon)}.$$

Relative uncertainty is

$$\frac{u(K_p)}{K_p} = \frac{1}{K_p}\sqrt{\left(\frac{1}{\upsilon}\right)^2 u^2(\upsilon_a) + \left(-\frac{\upsilon_a}{\upsilon^2}\right)^2 u^2(\upsilon)} =$$
$$= \frac{\upsilon}{\upsilon_a}\sqrt{\left(\frac{1}{\upsilon}\right)^2 u^2(\upsilon_a) + \left(-\frac{\upsilon_a}{\upsilon^2}\right)^2 u^2(\upsilon)} =$$
$$= \sqrt{\left(\frac{u(\upsilon_a)}{\upsilon_a}\right)^2 + \left(\frac{u(\upsilon)}{\upsilon}\right)^2}.$$

In accordance with [10], the admissible error for measuring the flow velocity by the primary transducer should not exceed ± 3%, therefore, the relative type B uncertainty of velocity measurement, taking into account the 95 percent confidence level with which the error limit was obtained, will be

$$\frac{u(\upsilon_a)}{\upsilon_a} = \frac{u(\upsilon)}{\upsilon} = \frac{0.03}{2} = 0.015.$$

Then the coefficient K_p measurement relative uncertainty is

$$\frac{u(K_p)}{K_p} = \sqrt{\left(\frac{u(\upsilon_a)}{\upsilon_a}\right)^2 + \left(\frac{u(\upsilon)}{\upsilon}\right)^2} =$$
$$= \frac{u(\upsilon)}{\upsilon}\sqrt{2} = 0.015\sqrt{2} = 0.0212 = 2.12\%.$$

Reducing of the combined standard uncertainty component, caused by the inaccuracy of the K_p setting [10], is achieved by prior calibration of the measuring instrument and plotting of gas flow rate for the certain diameter of the pipeline in accordance with the system of equations given in the research [5]. The influence of this component of the combined standard uncertainty is reduced by imposition the correction that calculated for the certain diameter of the pipeline.

The measurement equation (1) contains the parameters that are correlated with each other due to its dependence on the ambient temperature. These include the thermophysical parameters of the gas and the pipeline material, the geometric characteristics of the pipeline.

To estimate the degree of correlation, pairwise estimates of correlation moments are calculated [6]:

$$U\left(x_i, x_j\right) = \sum_{k=1}^{k} \frac{\partial x_i}{\partial q_k} \cdot \frac{\partial x_j}{\partial q_k} \cdot U^2\left(q_k\right), \quad (7)$$

where x – correlated parameters of equation; q_k, $k = 1,2,...k$ – independent from each other variables that are dependent on input variables.

For equation (1) $q = T$. The value $U^2(T)$ was determined in accordance with the taken uncertainty of temperature setting ±1.0 °C for the uniform distribution of the temperature values.

When determining the sensitivity coefficients $\frac{\partial x}{\partial q}$, it is necessary to have information about the dependence of each correlated parameter x from the influencing quantity $q = T$.

These dependencies have the following form:

1) The dependence of the distance between the measuring cross-sections l, the radius of the pipeline R and the thickness of the pipe on the temperature T is determined by the pipeline material, and has the form [9]

$$l = l_0 \cdot (1+\alpha_m \cdot (T-T_0)); \quad (8)$$

$$R=R_0 \cdot (1+\alpha_m \cdot (T-T_0)); \quad (9)$$

$$\delta=\delta_0 \cdot (1+\alpha_m \cdot (T-T_0)). \quad (10)$$

2) The dependence of gas viscosity μ_g on temperature T depends on the molecular composition of the gas and is determined as [9]

$$\mu_g = \frac{\sqrt{m_g \cdot T}}{\sqrt{6} \cdot \sigma_g}, \quad (11)$$

where μ_g – the mass of the gas molecules;

σ_g – the effective sectional area of the gas molecules.

3) Dependence of gas thermal conductivity λ_g on temperature T has the form [9]

$$\lambda_g = \frac{i}{2\sqrt{6} \cdot \sigma_g} \cdot \sqrt{\frac{T}{m_g}}, \quad (12)$$

where i – the degrees of freedom of gas molecules.

4) The gas density ρ_g depends on temperature T as [9]

$$\rho_g = \frac{p}{k_0 T} \cdot m_g. \quad (13)$$

5) Thermal conductivity of pipe material λ_m is defined as [9]

$$\lambda_m = \lambda_{0m} \cdot \left(1+\alpha_\lambda \left(T-T_0\right)\right), \quad (14)$$

where λ_{0m} – the thermal conductivity of the pipe material at T_0; α_λ – constant coefficient for a certain material.

6) The density of the pipe material ρ_m is defined as [9]

$$\rho_m = \rho_{0m} \cdot \left(1+\alpha_\rho \left(T-T_0\right)\right), \quad (15)$$

where ρ_{0m} – the density of the pipe material at T_0; α_ρ– constant coefficient for a certain material.

Based on dependencies (8–13) the measurement uncertainty budget of correlated input parameters of equation (1) was obtained (Table 2).

Table 2

Measurement uncertainty budget of correlated input parameters

$\frac{\partial Q}{\partial x_i} \cdot \frac{\partial Q}{\partial x_j} S(x_i, x_j)$	$S(l)$	$S(R)$	$S(\delta)$	$S(\mu_g)$
$S(l)$	1.3589×10⁻⁸	-3.5322×10⁻⁹	1.2069×10⁻⁹	3.5676×10⁻¹⁰
$S(R)$	-3.5322×10⁻⁹	9.1815×10⁻¹⁰	3.1373×10⁻¹⁰	-9.2734×10⁻¹¹
$S(\delta)$	1.2069×10⁻⁹	3.1373×10⁻¹⁰	1.0720×10⁻¹⁰	3.1686×10⁻¹¹
$S(\mu_g)$	3.5676×10⁻¹⁰	-9.2734×10⁻¹¹	3.1686×10⁻¹¹	9.3662×10⁻¹²
$S(\lambda_g)$	-3.6140×10⁻⁹	9.3940×10⁻¹⁰	-3.2099×10⁻¹⁰	-9.4880×10⁻¹¹
$S(\rho_g)$	-9.0393×10⁻⁹	2.3496×10⁻⁹	-8.0286×10⁻¹⁰	-2.3732×10⁻¹⁰
$S(\lambda_m)$	3.1620×10⁻⁹	-8.2191×10⁻¹⁰	2.8084×10⁻¹⁰	8.3014×10⁻¹¹
$S(\rho_m)$	2.3096×10⁻⁹	-6.0034×10⁻¹⁰	2.0513×10⁻¹⁰	6.0635×10⁻¹¹
$\frac{\partial Q}{\partial x_i} \cdot \frac{\partial Q}{\partial x_j} S(x_i, x_j)$	$S(\lambda_m)$	$S(\rho_m)$	$S(\lambda_g)$	$S(\rho_g)$
$S(l)$	3.1620×10⁻⁹	2.3096×10⁻⁹	-3.6140×10⁻⁹	-9.0393×10⁻⁹
$S(R)$	-8.2191×10⁻¹⁰	-6.0034×10⁻¹⁰	9.3940×10⁻¹⁰	2.3496×10⁻⁹
$S(\delta)$	2.8084×10⁻¹⁰	2.0513×10⁻¹⁰	-3.2099×10⁻¹⁰	-8.0286×10⁻¹⁰
$S(\mu_g)$	8.3014×10⁻¹¹	6.0635×10⁻¹¹	-9.4880×10⁻¹¹	-2.3732×10⁻¹⁰
$S(\lambda_g)$	-8.4094×10⁻¹⁰	-6.1424×10⁻¹⁰	9.6115×10⁻¹⁰	2.4040×10⁻⁹
$S(\rho_g)$	-2.1034×10⁻¹⁰	-1.5363×10⁻⁹	2.4040×10⁻⁹	6.01312×10⁻⁹
$S(\lambda_m)$	7.3576×10⁻¹⁰	5.3742×10⁻¹¹	-8.4094×10⁻¹⁰	-2.1034×10⁻¹⁰
$S(\rho_m)$	5.3742×10⁻¹¹	3.9254×10⁻¹⁰	-6.1424×10⁻¹⁰	-1.5363×10⁻⁹

Component of combined standard uncertainty, caused by the correlated input parameters, equals to [6]

$$S_2(Q) = 2\sum_{i=1}^{k-1}\sum_{j=i+1}^{k}\frac{\partial Q}{\partial x_i}\cdot\frac{\partial Q}{\partial x_j}S\left(x_i, x_j\right). \qquad (16)$$

$$S_2(Q) = -1.6683\times10^{-8}\ \text{m}^6/\text{s}^2.$$

The combined standard uncertainty of optic-thermal method of natural gas flow measurement is

$$S(Q) = \sqrt{\sum_{i=1}^{l}\left(\frac{\partial Q}{\partial x_i}\cdot S(x_i)\right)^2 + 2\sum_{i=1}^{k-1}\sum_{j=i+1}^{k}\frac{\partial Q}{\partial x_i}\cdot\frac{\partial Q}{\partial x_j}\cdot S\left(x_i, x_j\right)} = \sqrt{16.6774\times10^{-8} - 1.6683\times10^{-8}} = 3.8741\times10^{-4}\ \text{m}^3/\text{s}.$$

Due to the large number of input parameters of the measurement equation, we can make a reasonable assumption about the normal distribution. The obtained value of the combined standard uncertainty of gas flow management is $\pm7.7482\times10^{-4}$ m^3/s for normal distribution.

Thus, the analysis of the metrological model allows to conclude that the combined standard uncertainty of determining the gas flow by optic-thermal method can be up to ±0.2% for the gas flows more than 0.35 m^3/s and reduces with increasing gas flow and pipe diameter.

Conclusion

Analysis the uncertainty of optic-thermal method of natural gas flow measurement justifies the possibility and prospect of its practical application for large diameter pipelines.

Further development and research in this area should be focused on increasing the accuracy of the method by correcting for changes in the composition of the gas; studying the influence on the result of the presence of mechanical impurities and condensate in the gas, vibrations; increasing the possibilities of using the method for measurement of rapidly changing and pulsating flows.

Дослідження метрологічної моделі оптико-теплового методу вимірювання витрати природного газу

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Анотація

У статті обґрунтовано важливість проведення досліджень, спрямованих на розробку та вивчення безконтактних методів вимірювання витрати природного газу.

На базі розробленої математичної моделі безконтактного оптико-теплового методу вимірювання витрати газу та основних положень теорії невизначеності здійснено аналіз метрологічної моделі методу. Досліджено та оцінено складову сумарної стандартної невизначеності, яка обумовлена невизначеністю некорельованих вхідних параметрів рівняння вимірювання. Виокремлено домінуючі складові та проаналізовано шляхи зменшення їх впливу на сумарну стандартну невизначеність. Найбільший вклад у сумарну стандартну невизначеність методу вносять невизначеність вимірювання кількості інтерференційних смуг, невизначеність вимірювання відстані між досліджуваними перетинами трубопроводу та невизначеність завдання коефіцієнта, який характеризує розподіл швидкостей газового потоку.

Виявлено складові сумарної стандартної невизначеності (теплофізичні параметри газового середовища і матеріалу трубопроводу, геометричні характеристики трубопроводу), які корельовані одна з одною через залежність від температури середовища. Складено бюджет невизначеностей корельованих вимірювань. Кількісна оцінка показала, що наявність кореляції між визначеними вхідними параметрами не впливає значною мірою на сумарну стандартну невизначеність вимірювання.

Аналіз метрологічної моделі безконтактного оптико-теплового методу вимірювання витрати природного газу дозволив оцінити відносну сумарну стандартну невизначеність методу та обґрунтувати перспективність застосування методу для вимірювання витрати газу в трубопроводах великих діаметрів.

Ключові слова: витрата газу; оптико-тепловий метод; стандартна невизначеність; метрологічна модель; корельовані параметри; некорельовані параметри; бюджет невизначеностей.

Исследование метрологической модели оптико-теплового метода измерения расхода природного газа

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Аннотация

На базе разработанной математической модели бесконтактного оптико-теплового метода измерения расхода газа и основных положений теории неопределенности проведен анализ метрологической модели метода. Исследована и оценена составляющая суммарной стандартной неопределенности, обусловленная неопределенностью некоррелированных входных параметров уравнения измерения. Выделены доминирующие составляющие и проанализированы пути уменьшения их влияния на суммарную стандартную неопределенность.

Выявлены составляющие суммарной стандартной неопределенности, которые коррелированы друг с другом вследствие зависимости от температуры среды. Составлен бюджет неопределенности коррелированных измерений.

Анализ метрологической модели бесконтактного оптико-теплового метода измерения расхода природного газа позволил оценить относительную суммарную стандартную неопределенность метода и обосновать перспективность применения метода для измерения расхода газа в трубопроводах больших диаметров.

Ключевые слова: расход газа; оптико-тепловой метод; стандартная неопределенность; метрологическая модель; коррелированные параметры; некоррелированные параметры; бюджет неопределенностей.

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