Optimization of the differential pressure flowmeters by means of "Raskhod-RU" CAD

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Abstract

New methodology of designing of the differential pressure flowmeters, which are optimal as to the accuracy of flowrate measurement is developed in order to provide minimum uncertainty of flowrate measurement results. This methodology is implemented in "Raskhod-RU" CAD system for computer aided design and calculation of differential pressure flowmeters. "Raskhod-RU" CAD meets the requirements of the new Standards (DSTU GOST 8.586.1,2,3,4,5–2009 and GOST 8.586.1,2,3,4,5–2005) and provides accomplishment of the following tasks: verification of conditions (constraints) for the application of the differential pressure method according to the requirements of the new Standards; calculation of primary device parameters, pipe straight lengths and flowmeter in general according to the requirements of the new Standards; calculation of uncertainty of fluid flowrate and volume measurement results; design of an optimal flowmeter as to the accuracy of flowrate measurement.

Key Words: *differential pressure, flowmeter, measurement, optimization.*

Introduction

The world prices for the energy resources have been rising up till now, which was caused by the world market trends and by other factors. The Ukrainian situation is complicated due to the fact that major part of the most important energy carriers (natural gas and oil) need to be purchased abroad (from Russia, Kazakhstan, Turkmenistan etc). Such a state of things is putting forth a very important task – the task of energy carrier saving.

Efficient consumption and saving of energy is possible only if metering is carried out with high accuracy and on every step and branch of supply of energy carriers. The accuracy of such a metering is defined by technical base, normative base, metrological base and professional level of personnel.

The present situation on the US gas market (when there is a surplus of gas and its price is low) does not diminish the importance of accurate metering of fluid energy carriers (natural gas in particular) especially for countries in the other parts of the world.

Normative Base for Flowrate Measurement

In order to control consumption of fluid energy carriers (natural gas, hot water, overheated steam etc.) the differential pressure method is applied. This method is used for measurement of energy carrier flowrate and volume in pipes with internal diameter of 50 mm and more.

Metering of fluid energy carriers by means of differential pressure devices in Europe is carried out according to the requirements of ISO 5167.1,2,3,4–2003 [1]. In CIS countries the new Intergovernmental Standard GOST 8.586.1,2,3,4,5–2005 [2] is in force. The first four parts of this Intergovernmental Standard were developed as modified versions of ISO 5167.1,2,3,4–2003 and the fifth part of GOST 8.586.5–2005 covers the requirements of CIS laws on measurement of energy carrier flowrate and volume and normalizes the procedure for measurements.

The Intergovernmental Standard GOST 8.586.1,2,3,4,5–2005 was developed by the authors of this paper together with scientists and specialists from "Ukrmetrteststandard" National Standardization Body (Ukraine) and with experts from "Gazmetrologia" Field Metrology Centre of "Gazprom" Joint-Stock Company (Russia). This Standard was implemented in Russia in 2007 as a National Standard. In 2010 this Standard was implemented in Ukraine as DSTU GOST 8.586.1,2,3,4,5–2009.

The most important thing here is that on the basis of the analysis which have been carried out it can be said that implementation of the new Standard will improve the accuracy of energy carrier metering.

It should be mentioned that the new Standards in force (ISO 5167.1,2,3,4–2003 and GOST 8.586.1,2,3,4,5–2005) differ from the previous Standards considerably. The most significant distinctions are new limitations for differential pressure method application, new mathematical formulae for the main coefficients of flowrate equation, new requirements to pipe straight lengths and fittings, new requirements to the application of flow straighteners and flow conditioners and finally new methodology for the assessment of flowrate and volume measurement results

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uncertainty. The detailed comparative analysis of various normative documents on fluid flow-rate measurement by means of the differential pressure method is presented in [3].

An important distinction between GOST 8.586.1,2,3,4,5–2005 and ISO 5167.1,2,3,4–2003 is that the first one covers a wider area of the differential pressure method application (Fig. 1). In particular there is a possibility to take into account the roughness of pipe internal diameter by introducing the corresponding correction coefficient into the flowrate equation. Similarly other influencing factors can be taken into account. Additionally there is normalization of fluid volume measurement in differential pressure flowmeters as well as normalization of uncertainties of fluid flowrate and volume measurement in GOST 8.586.1,2,3,4,5–2005.

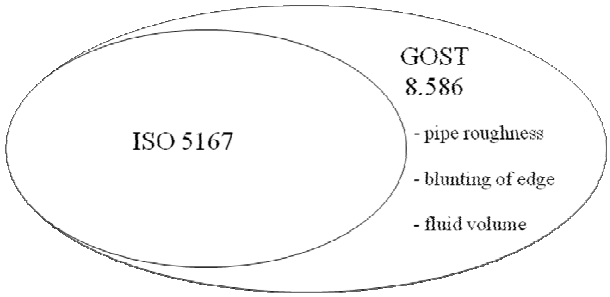


Figure 1 – Distinction between GOST 8.586.1,2,3,4,5–2005 and ISO 5167.1,2,3,4–2003

Peculiarities of the New Standards Implementation

Naturally such significant distinctions between the new Standards and the previous ones cause considerable difficulties during implementation of the first. In particular, for every flowmeter at least the following tasks have to be accomplished:

verification of conditions (constraints) for application of the differential pressure method according to the requirements of the new Standards;

verification of pipe straight lengths according to the requirements of the new Standards;

calculation of parameters of primary device, pipe straight lengths and flowmeter in general according to the requirements of the new Standards;

calculation of uncertainty of results of fluid flowrate and volume measurement according to the requirements of the new Standards.

For the accomplishment of these tasks it is very important to carry out the design of a flowmeter (and of the whole metering system) which is optimal in terms of measuring accuracy i.e. flowmeter providing minimum uncertainty of fluid flowrate and volume measurement.

The methodology of the mentioned above verifications, calculations and design of differential pressure flowmeters was not formalized even for the previous Standards. Such methodology is being developed according to the new Standards.

"Raskhod-RU" CAD Description

In order to simplify the accomplishment of the above mentioned tasks and implementation of the new Standards (GOST 8.586.1,2,3,4,5–2005) it's proposed to accomplish the developed calculations methodology and flowmeters design by means of a specialized computer program: system for computer aided calculation and design of differential pressure flowmeters.

Such a system, called "Raskhod-RU" CAD [4] was developed at the Institute of Energy Audit and Energy Carrier Accounting (www.ieoe.com.ua). By means of this computer program all the above mentioned tasks of verifications, calculations and design of flowmeters can be accomplished. "Raskhod-RU" CAD meets the requirements of the new Standards and is certified in Ukraine and in Russia.

"Raskhod-RU" CAD is intended for the design of flowmeters for 48 fluids including the following: natural gas, humid oil gas, overheated steam, dry saturated steam, water, air, nitrogen, argon, oxygen etc. All valid procedures for calculation of expansibility factor for natural gas (NX19 mod.; GERG-91 mod.; AGA8-92DC mod.; VNIC SMV; SD 7–2005) are implemented in the program.

At present "Raskhod-RU" CAD is available in Ukrainian, Russian, Kazakh and English.

The following four different types of flowmeter parameters calculation can be accomplished by means of "Raskhod-RU" CAD:

calculation of flowmeter parameters for the given upper limit of differential pressure measurement;

calculation of flowmeter parameters for the given allowable pressure loss at a primary device;

calculation of flowmeter parameters to secure minimum uncertainty of flowrate measurement;

calculation of flowmeter parameters for the given specifications of primary device and pipe (it is so called inverse calculation of flowmeter).

The first three types of calculation are applied at the initial design of a differential pressure flowmeter. Here in the second and third types of calculation an optimization problem is solved to minimize pressure losses at aprimary device or to minimize the uncertainty of flowrate measurement respectively. And the fourth type of calculation is applied to define the parameters of an existing flowmeter and the conditions of its application according to the requirements of the new Standards (GOST 8.586.1,2,3,4,5–2005).

In the course of flowmeter design the "Raskhod-RU" CAD gives the possibility to choose one of the three possible flowmeter configurations: with separate measurement of flow parameters; with the flowrate and volume calculator; with the measuring complex.

Thus, the program provides the possibility to specify the parameters of up to four measuring transducers (installed in series) in each channel of a flow parameter measurement (fluid pressure, temperature and differential pressure across the primary device). In order to provide a wider range of flowrate measure-ment the parameters of additional measuring transducers (installed in parallel) in the channels of

differential pressure measurement and fluid pressure measurement can be specified.

After choosing the type of the problem to be solved (type of calculation) the following input data should be entered:

parameters and characteristics of the fluid;

parameters and characteristics of the primary device;

parameters and characteristics of the pipe;

parameters and characteristics of the pipe straight lengths and fittings;

parameters and characteristics of the measuring and calculating instruments;

parameters and characteristics of the flowmeter unit.

Despite the type of calculation, chosen by the user the calculation results are returned in the following way. After all the input data were entered, "Design" should be selected in the top menu of the program. The main calculation results will be displayed in the same dialog box. After selecting "Protocol" in the top menu of the program the calculation protocol with all the input parameters and characteristics together with calculation results and with drawings will be displayed in a separate window. After selecting "Figure" the curve of relative expanded uncertainty of fluid flowrate measurement versus flowrate (or versus diameter ratio of the primary device in case of making the design of a flowmeter optimal as to the accuracy of flowrate measurement) will be displayed in the same dialog box. The calculation results can be printed out.

Advantages of "Raskhod-RU" CAD

The following advantages of "Raskhod-RU" CAD should be specified:

user friendly interface of the program providing quick and easy learning of possibilities of the program and maximum use of these possibilities which is achieved by logical and understandable distribution of input data among the dialogue boxes; the interface of the program is made in such a way that the dialog boxes are being changed during input data entering (the fields for the unnecessary parameters and characteristics can be taken away if needed);

interactive shell for data input which is especially important for pipe straight lengths, in particular there is a possibility to use flow straighteners and flow conditioners in the pipe as well as various options for thermometer mounting;

automatic control of dialogue boxes during input data entering by the user which helps to avoid unforeseen mistakes;

input data files can be saved while there is no possibility to save the calculation protocol (in order to make distortions in the protocol impossible);

user cannot carry out calculation, design and get a calculation protocol for a flowmeter which does not meet the requirements of the new Standards;

display of warnings about additional component errors of measurement and possible ways to eliminate these errors according to the requirements of the new Standards;

high quality visualization of calculation results which simplifies the analysis and application of the results, in particular there are curves of flowrate measurement uncertainty versus flowrate or other parameters; there are also drawings of primary devices, pipe straight lengths and fittings etc.;

reliable protection against unauthorized use of the program.

Optimization of the Differential Pressure Flowmeters

A particularly important advantage of "Raskhod-RU" CAD is the possibility to carry out design of a flowmeter optimal as to the accuracy of flowrate measurement.

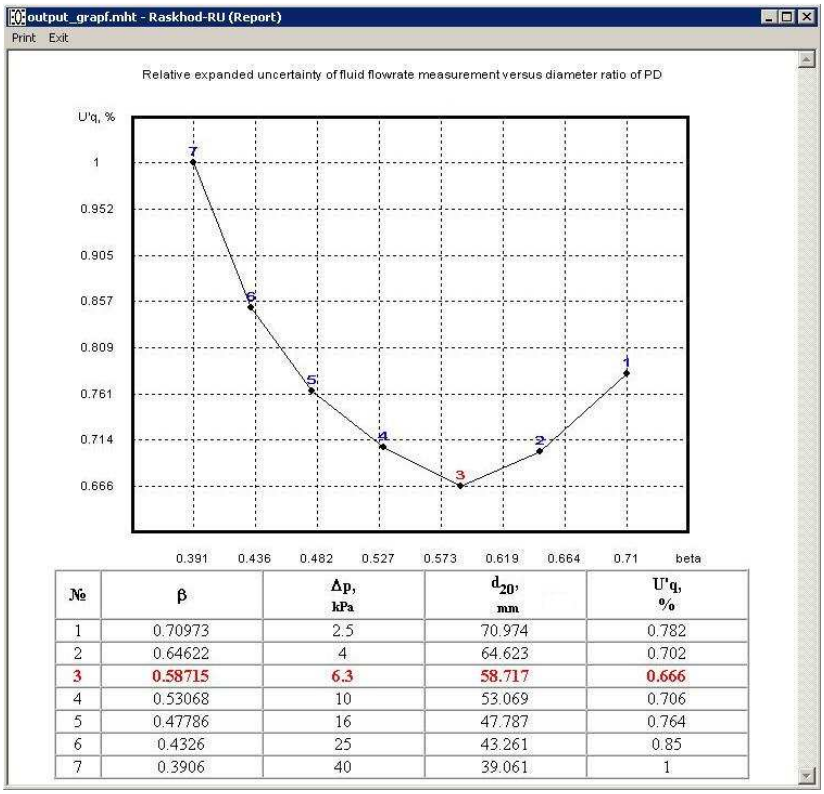
The methodology of designing the optimal flowmeter consists of the following:

correct choice of the measuring transducers of flow parameters (differential pressure, pressure and temperature). The accuracy class of the transducers should be not worth than 0.1 (a better choice is 0.075). The transducers should have the digital output signal to avoid distortions during transmitting the information to the flowrate and volume calculator. It is desirable that the differential pressure transducer has an option of readjustment of the measurement ranges which provides the possibility to make a wider range of flowrate measurement. At present there are differential pressure transducers with the possibility to readjust the ranges of measurement up to 100:1 and for the accuracy class of 0.75 up to 10:1. It is also possible to apply more than one differential pressure transducer in parallel to provide a wider range of flowrate measurement;

correct choice of the flowrate and volume calculator. The calculator should have the digital input from the measuring transducers and the function of readjustment of the ranges of differential pressure measurement or switching between the differential pressure transducers. The calculation of fluid flowrate in the calculator should be carried out according to the model in [2]. Any other algorithms lead to methodical error of flowrate measurement and it is a systematical error which should be avoided. There should be a correct calculation of fluid volume in the calculator according to [2];

correct choice of the primary device and its geometrical parameters. According to the results of our study it was defined that for each differential pressure flowmeter with a definite pipe diameter and a maximum flowrate, there is only one possible value of diameter ratio of the primary device for which the accuracy is the highest and the uncertainty of fluid flowrate and volume measurement is minimum. The results of designing an optimal primary device by means of "Raskhod-RU" CAD are shown in Fig. 2;

correct choice of the geometrical specifications of the pipe which should be carried out at initial design of the flowmeter. Types of fittings, pipe straight lengths, possibility to apply a flow straightener as well as the influence of the hydrodynamic effects should be taken into account;



№	β	Δp, kPa	d_{20}, mm	U'q, %
1	0.70973	2.5	70.974	0.782
2	0.64622	4	64.623	0.702
3	0.58715	6.3	58.717	0.666
4	0.53068	10	53.069	0.706
5	0.47786	16	47.787	0.764
6	0.4326	25	43.261	0.85
7	0.3906	40	39.061	1

Figure 2 – Curve of relative expanded uncertainty of fluid flowrate measurement versus diameter ratio of the primary device

to undertake measures to avoid the possible distortions of the results of differential pressure and pressure measurement at flowmeters by application of manifolds of a special design of "Techprylad" Company. There are five-valve "non-valve" manifolds for connecting the differential pressure transducers and three-valve "non-valve" manifolds for connecting the pressure transducers.

As an example the curve of relative expanded uncertainty of fluid flowrate measurement versus diameter ratio of primary device is shown in Fig. 2. There is a table under the curve with these values together with upper limits of differential pressure measurement and with diameter of the primary device opening. The presented curve and table demonstrate the possibility of obtaining of maximum accuracy of flowrate measurement when designing a differential pressure flowmeter. In the given example the highest accuracy is obtained for the flowmeter number three.

Conclusions

The methodology for calculation and design of the differential pressure flowmeters optimal as to the accuracy of flowrate measurement is developed according to the requirements of the new Standards (DSTU GOST 8.586.1,2,3,4,5–2009 and GOST 8.586.1,2,3,4,5–2005). This methodology is implemented in "Raskhod-RU" CAD which enables computer aided calculation and design of differential pressure flowmeters. At the same time verification of conditions (constraints) for application of the differential pressure method according to the requirements of the new Standards can be carried out by this computer program which simplifies the process of implementation and application of the new Standards significantly. Application of flowmeters optimal as to the accuracy of flowrate measurement, proposed by "Raskhod-RU" CAD, will provide improvement of fluid energy carrier metering accuracy.

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Оптимізація витратомірів перепаду тиску за допомогою «Raskhod-RU» CAD

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Розроблено нову методологію проектування витратомірів змінного перепаду тиску, оптимальних за точністю вимірювання витрати, яка забезпечує мінімальну невизначеність результатів вимірювання витрати. Ця методологія реалізована у системі автоматизованого проектування та розрахунку витратомірів змінного перепаду тиску САПР “Расход-РУ”, яка відповідає вимогам нових стандартів (ДСТУ ГОСТ 8.586.1,2,3,4,5–2009 і ГОСТ 8.586.1,2,3,4,5–2005) та забезпечує виконання таких завдань: перевірка умов (обмежень) для застосування методу змінного перепаду тиску відповідно до вимог нових стандартів; розрахунок параметрів звужувального пристрою, довжин прямолінійних ділянок і витратоміра в цілому відповідно до вимог нових стандартів; розрахунок невизначеності результатів вимірювання витрати і кількості рідин і газів; проектування оптимальних за точністю вимірювання витратомірів змінного перепаду тиску.

Ключові слова: *вимірювання, витратомір, диференціальний тиск, оптимізація.*