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ANALYSIS OF THE METHODS AND MEANS FOR CONTROLLING LIQUID AND GASEOUS MEDIUMS CONSUMPTION AND THEIR CLASSIFICATION

The paper analyzes main methods and means for controlling consumption of liquid and gaseous mediums and elaborates their classification. This makes it possible to choose a flowmeter, which would correspond to specific requirements.

***Keywords**: flowmeter, consumption control, classification, dynamic range, reliability, measurement accuracy, movable parts.*

Introduction

Due to the constant growth of prices for various types of energy, it is an important current task to provide a maximally accurate control of liquid and gaseous mediums consumption.

In Ukraine and other CIS countries gas is a basic energy carrier and a source of other energy types – electric and heat energy. Besides, gas is a commercial product and, therefore, the object of commercial agreements between an extractive company, gas transportation companies and end users. In the delivery of gaseous and liquid mediums the main problem of commercial relations is imbalance that arises during physical registration performed on the way from a supplier to end users. General factors, which determine this imbalance, are errors in measuring the substance volume, absence of reliable registration due to insufficient accuracy and limited range of a meter as well as failures of metering units [1]. To prevent such imbalance, it is necessary to select a flowmeter having all characteristics required for ensuring precise flow rate measurements.

Control of liquid and gaseous mediums consumption is important for metallurgy, food industry, construction engineering, biochemistry, ore dressing and other industries.

The aim of the work is analysis of the methods and means for controlling liquid and gaseous mediums consumption and elaboration of their classification.

Main part

At present, there is a huge number of flowmeters used for commercial and technological control over liquid, gas and vapor flows. Proceeding from the conducted analysis of the methods for substance flow rate control [2–34] and already existing classifications [35], a new improved classification, based on the four main classification criteria, is proposed (Fig. 1): according to the measured flow rate values, by physical phenomena, operating principles, according to the effects, which form the basis of their operation, and design features.

Substance flow rate is the amount of substance (liquid or gas) that flows through the section of pipe line within a time unit. Volumetric flow rate Q_V, that is measured in the units of volume per time unit, and mass flow rate Q_M are distinguished:

$$Q_V = V / t; \quad (1)$$

$$Q_M = M / t, \quad (2)$$

where V is the volume of liquid or gas that passed through the section of pipe within time t; M – mass of the liquid or gas that passed through the pipe section within time t [2].

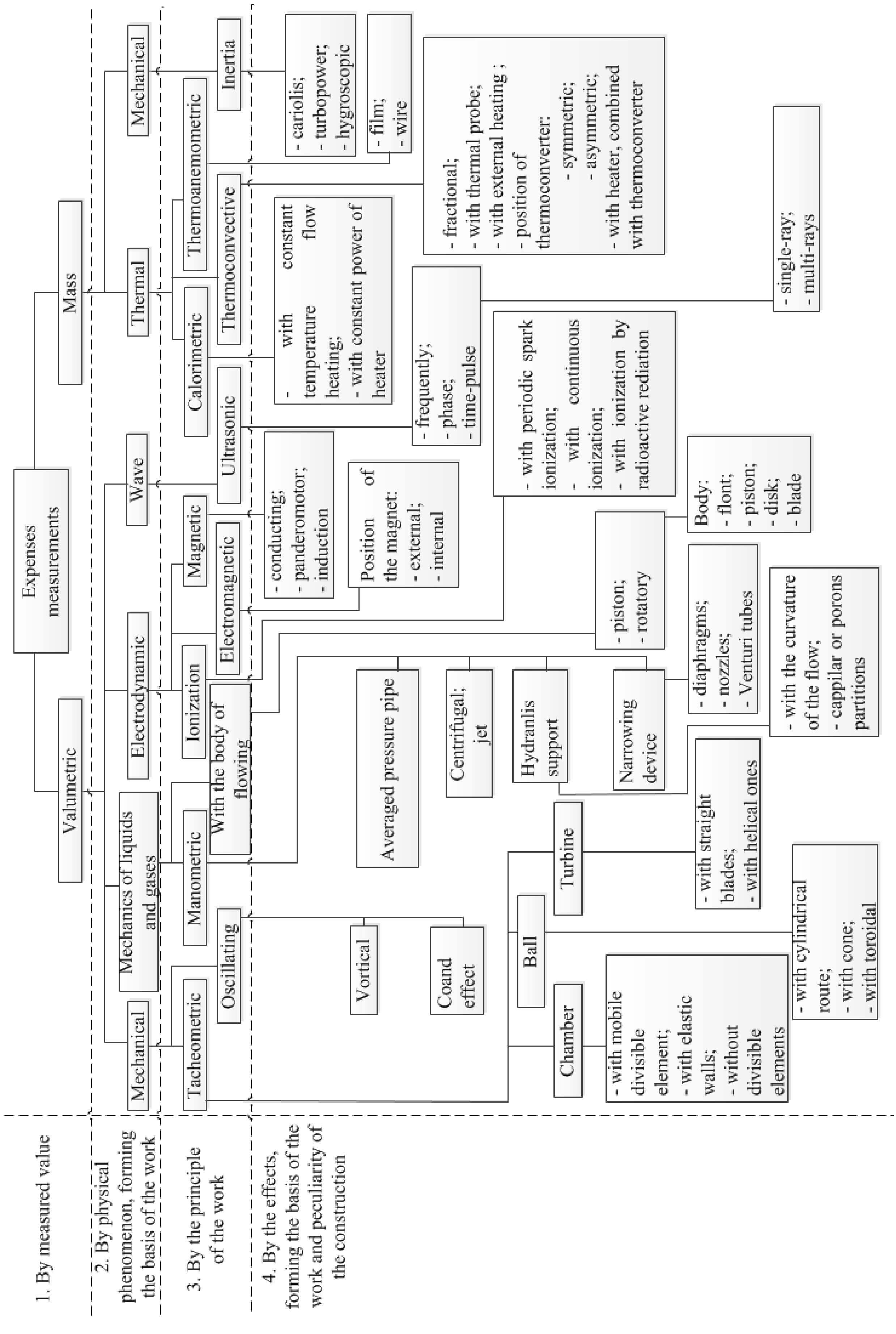

Fig. 1. Classification of methods and means for flow rate measurements

Thus, according to the quantity to be measured, volumetric and mass flowmeters are distinguished.

According to physical phenomena, which form the basis of their operation, volumetric flowmeters are divided into mechanical, fluid mechanics, electrodynamic and wave flowmeters; mass flowmeters are divided into thermal and mechanical metering devices.

According to the operating principle, tachometric and oscillating flowmeters belong to mechanical volumetric flowmeters and inertia flowmeters – to mass flowmeters.

According to the effects, used in tachometric flowmeters, three main groups can be distinguished: positive-displacement (they are also referred to as orifice or membrane flowmeters), turbine and ball-type flowmeters [3]. The first two types are the most common ones.

Positive-displacement flowmeters are intended for measuring flow rate of transparent liquids in closed pipelines [4]. Operating principle of such meters is based on pressure differential, which is the consequence of energy preservation law, in accordance with which restriction of the substance flow channel causes increase of the flow rate and, therefore, the increase of kinetic energy. This leads to the substance pressure drop in the narrow part of such channel since kinetic energy increases at the expense of pressure energy. In this case displacement of the movable partitions of measuring chambers under gas pressure occurs. Relationship between pressure drop and flow rate is given by

$$Q = K\sqrt{\Delta P}\,, \tag{3}$$

where Q – substance flow rate; K – constant for a given device; ΔP – pressure differential at the ends of the narrow part (this value depends on the diameter of the narrow channel) [5].

Positive-displacement flowmeters are characterized by the following advantages:

1. The possibility to be used at (in) large-diameter pipelines;
2. They do not require considerable expenses for installation;
3. They are time-proven, provide reliable operation for many years;
4. Economical type of registration for small flow rate variations;
5. Absence of movable parts;
6. Installation place, position and flow direction do not influence its operation [6].

Disadvantages of the above-described flowmeters include the following:

1. Dynamic range is limited by the value 4 : 1 or 5 : 1;
2. Possible blocking of the system due to the diaphragm bending caused by hydraulic shock;
3. Fitting length of the measuring system could have large value;
4. Geometry of the opening edges may change due to erosion, which reduces accuracy of the entire system [7].

Well-known international companies such as LLC «АППЭК» (compact flowmeter OriMaster, Russia), Mecon (flowmeter FON4, Germany), Siemens (Germany), PietroFiorentini (Italy) are producers of positive-displacement flowmeters.

Turbine flowmeters operate according to the principle of meters with Voldman's impeller, i.e. they register the volume, passing through the section, using average flow rate [8].

Such flowmeters are used mainly at the enterprises with very high natural gas consumption as well as at the lines with relatively high pressure. Modern counting mechanism of the turbine flowmeter is a kind of a computer mini-system. It does not only count pulses, converting them into digital equivalent, but also controls proper operation of the meter, signals about a non-sanctioned interference into its operation. Lately, such mechanisms have been equipped with modems and due to them all data of the given direction are transmitted to the servers of support services [6].

At the turbine meters pressure differential variations should be periodically controlled. Permissible pressure differential value at the meter for specific operating conditions is calculated by the formula:

$$\Delta P = \Delta P_r\left(\frac{\rho_s \cdot P}{\rho_{av} \cdot P_r}\right)\cdot\left(\frac{Q}{Q_r}\right)^2, \tag{4}$$

where ΔP_r – pressure differential at the meter, which is regulated by technical documentation, Pa; P – gas pressure (absolute) under specific operating conditions, MPa; P_r – gas pressure value under standard conditions, for which pressure losses are regulated; ρ_s – gas density value under standard conditions; P_{av} – gas density value under standard conditions , for which pressure losses are specified; Q – gas flow rate under specific operating conditions, m^3/year; Q_r – gas flow rate, for which pressure losses are regulated, m^3/year [9].

As turbine flowmeter comprises several movable parts, the following factors should be taken into account:

1. lubrication properties of the medium;
2. change of the state and size of the vanes;
3. wear of bearings and friction;
4. temperature, pressure and viscosity of the measured medium;
5. pressure drops at the flow meter;
6. input rate profile and turbulence effects.

Due to these factors, calibration should be performed and turbine meters should be checked under operating conditions.

Main advantages of such flowmeters include:

1. high precision (± 0,5% of the actual value);
2. maximal dynamic range up to 10 : 1;
3. flowmeters with bypass channels are relatively cheap [7];
4. non-volatility;
5. low noise level [10].

Turbine flowmeters are sensitive to flow distortions at the input and output of the flowmeter, although current requirements to the lengths of straight parts in front of the device and behind it are minimal and amount respectively to 2 and 1 diameter of the flowmeter conditional passage. Another disadvantage is increased error in measuring pulsing gas flows.

It is recommended to choose flowmeters of the types where the temperature meter and pressure take-off opening are located in the body. It is not desirable to install meters in the areas where condensate accumulation is possible [11].

Among the producers of turbine flowmeters there are such well-known companies as «Elster Instromet» (Germany), «КОНВЕЛС Автоматизация» (Russia), «Advantek Engineering» (USA), «Cameron» (USA), «Actaris» (Russia).

Oscillating flowmeters are divided into vortex flowmeters and meters with the application of Coanda effect. The most common flowmeters of this class are vortex flowmeters used at the large-scale enterprises, where huge amounts of natural gas are consumed. Counting mechanism of the vortex flowmeter is a computer mini-system just like in turbine flowmeters. An important advantage of this system is its insensitivity to pneumatic shocks and the possibility of operation with the application of contaminated gases [6].

At the back part of the body of a special shape (a so called bluff body), which is exposed to fluid flow, turbulences are formed. These turbulences form the so called Karman's vortex street. Breakaway of turbulences from the bluff body could be revealed and calculated. In a certain range their quantity is proportional to the flow rate, which makes it possible to measure fluid motion speed. [12].

The frequency of turbulences formation and the fluid speed have almost linear dependence, which is given by:

$$f = S_t \cdot \left(v/d \right), \tag{5}$$

где f – frequency of turbulences formation; S_t – Strouhal number, which is determined experimentally; v – fluid flow speed; d – width of the bluff body [12].

The frequency of turbulences formation is not changed with fluid density changes [13].

Advantages of the vortex flowmeters include:

1. sufficiently wide dynamic range;
2. small flow resistance;
3. absence of movable parts;
4. linear output signal;
5. small pressure loss;
6. simplicity and reliability of maintenance since piezo sensors do not contact with the medium [12].

Vortex meters have the following drawbacks:

1. possible influence of vibration on precision of measurements;
2. significant role of proper installation;
3. maximal flow rates correspond to fluid flow speed of 80 or 100 m / s;
4. insufficient stability of the conversion factor in the required range, which does not allow to recommend devices of this type for commercial gas consumption registering without pre-calibration during operation process;
5. it is necessary to provide straight obstacle-free parts of the pipeline in front and behind the flowmeter [14].

A well-known producer is «Endress + Hauser» ProlineProwirl company [15]. Other producers of such flowmeters are «Сибнефтеавтоматика» engineering company (Russia), «Emerson» (flowmeters Rosemount, USA), Yokogawa Electric Corporation (flowmeters YEWFLO, Japan).

According to their operating principle, volumetric flowmeters, based on fluid mechanics, are divided into those with bluff body and manometers. Flowmeters with bluff body include piston-type and rotary flowmeters.

Rotary flowmeter is one of the first types of gas meters, which started to be used for gas consumption calculations. These flowmeters are mainly used at the enterprises where natural gas consumption does not exceed 200 m^3 / h [6]. Operating principle of such flowmeters is based on the rotation of two coaxially located rotors under the action of gas flow. Read-out device indicates the amount of gas (m^3), which passed through the meter with working pressure P and temperature T. Conversion into volumetric units V_H for the conditions according to standards of ГОСТ 299 is performed by the formula:

$$V_N = V_d \frac{P \cdot T_N}{T \cdot K \cdot P_N}, \tag{6}$$

where V_d – difference in the readings of the flowmeter within the measurement period, m^3; P – absolute gas pressure, MPa; T – absolute gas temperature, К; K – gas compression coefficient; $P_N = 0{,}101325$ MPa and $T_N = 293{,}15$ К – standard (normative) pressure and temperature respectively according to ГОСТ 2939 [16].

Such flowmeter has long operating life, big rated capacity in spite of small size and mass, it withstands overloading; automatic conversion of gas volume is performed by means of correctors (computing devices) [17].

In spite of the above advantages, a rotary flowmeter has a number of drawbacks, particularly, high cost. Besides, measuring system of the meter requires careful fitting of all parts and is unable to operate with contaminated gas [15].

Among the producers of rotary flowmeters are Belgian company «Instromet International», scientific-production company «Овен-Урал» and LLC «Сигнал» (Russia), enterprise «Actaris» and «Elster Instromet» (Germany).

Meters based on hydraulic resistances – flow restricting devices – belong to manometric flowmeters. Fluidic (jet) flowmeters, centrifugal flowmeters and averaged pressure tube also form a large group of manometric flowmeters.

Fluidic meters are widely used in heat power engineering, medicine, fuel and chemical industries. They are also used for commercial and technological control of liquid, gas and vapor flows.

Fluidic flowmeters make it possible to measure small gas volumes as they have low threshold sensitivity level [17]. Their operating principle is based on measuring switching frequency of a self-exciting oscillator (SEO), which is proportional to the gas consumption flow rate through the nozzle of SEO:

$$f = Sh \cdot \frac{q}{l \cdot b \cdot h}, \tag{7}$$

where Sh – Strouhal number; l, b, h – characteristic dimensions: chamber length, width and depth of the jet element nozzle respectively.

In accordance with the flow rate formula

$$q = \mu \cdot h \cdot b \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}, \tag{8}$$

we can make a conclusion that oscillation frequency of SEO is proportional to pressure drop at the jet element (to the flow rate through it) and to the medium density [19]:

$$f = Sh \cdot \frac{\mu}{l} \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}. \tag{9}$$

So, this method is similar to vortex method with bluff body since in both cases creation of an aerodynamic oscillator is provided.

Depending on the shape of jet and, therefore, on the operating principle, these flowmeters, in their turn, are further divided into three groups:

1. Flowmeters with oscillating jet (a type of vortex flowmeters). Like the vortex method, this method uses the principle of creation of an aerodynamic oscillator with frequency, proportional to gas flow rate [17, 19]. Along with other drawbacks, flowmeters of this group have a jet element of a very large size relative to the measured flow rate value and unstable conversion factor.
2. Jet-impact flow meters, which measure flow rate dependable pressure drop, emerging with the impact of liquid or gas jet. Such meters are used only for measuring small flow rates..
3. Flowmeters with outgoing jet deviation. The operating principle is based on the dependence of pressure drop, which emerges with deviation of the jet of the auxiliary gas or liquid, on the measured gas flow rate [19].

Russian companies «Газовик», LLC «Глобус», «Промприбор», «ТБН Энергосервис» are producers of fluidic flowmeters.

Orifices, nozzles and Venturi tubes are standard restricting devices. This method has the following advantages: the possibility to be used without application of complex microprocessor devices, flow rate measurement at low speeds of liquids and gases (0,1 ... 0,5 m / s) and high resistance to contaminated measured medium.

Disadvantages of such devices include:

1. Labor-consuming installation;
2. Low precision in narrow range of flow rate measurements (1: 3);
3. Considerable pressure losses at restricting devices, which in its turn, results in additional expenses for pump operation [20].

For this reason it was expedient to introduce a new “velocity-area” method with the application of the averaged pressure tube.

This facility creates a pressure drop, proportional to squared flow rate, in accordance with Bernoulli’s principle: the sum of energies at a certain point of the tube is a sum of static energy (pressure created by the substance in all directions), kinetic energy (substance speed) and potential energy (gravitational component). For such case Bernoulli’s principle is written as:

$$\frac{v_1}{2g}+\frac{p_1}{\rho}=\frac{v_2}{2g}+\frac{p_2}{\rho}, \qquad (10)$$

where v – flow velocity; g – gravitational constant; p –pressure; ρ – substance density [21].

Averaged pressure tube is used in more than a million of flow metering units and in large-diameter tubes. This is explained by stable and accurate operation with good repeatability of the results. Besides, the facility has significant advantages over the traditional restricting orifices due to simple installation and low pressure losses.

A disadvantage of flowmeters with a variable pressure drop is low precision when they are used for low flow rate measurements in small-diameter tubes (less than 50 mm) and pulsing flows [21].

Industrial production of averaged pressure tubes is provided by some foreign companies, e. g., USA company Hanejwell (Austrian branch) produces flow meters with the tubes of Annubar type.

Volumetric electrodynamic flowmeters are divided into ionization, magnetic and electromagnetic flowmeters.

Their operating principle is based on measuring the intensity of radiation directed transversally to the flow. To reduce the error, caused by instability (variability) of the radiation source, differential transducers with flow ionization (or ultrasound radiation) receivers are most often used [22].

Disadvantages of such flowmeters include influence of the gas parameters, temperature and pressure on the ionization value. Avoidance of these factor leads to significant complication of the design of pulsing and sensitive elements. Besides, ionization meters cannot be used for measuring flow rates of strongly ionized and incandescent gases [23].

LLC «Прамень» is a developer of ionization flow meters.

Operating principle of the magneto-inductive flowmeters is based on measuring EMF, proportional to the flow rate, which is induced in the flow of electricity-conductive substance under the action of external magnetic field (Faraday law) . According to this law, for any closed loop an induced EMF is proportional to the change rate of magnetic flux, passing through this loop.

Main advantage of such meters is as follows: initial converters do not have parts projecting inside the pipeline while isolation and anticorrosion coatings make it possible to measure flow rates of aggressive and abrasive mediums [24].

Polarization of sensitive elements, leading to changes of the converter resistance, is a disadvantage of this method. This causes additional errors. Besides, these flowmeters are sensitive to flow inhomogeneity, turbulence and non-uniform distribution of flow velocities in the channel section.

In spite of their drawbacks, magneto-inductive flowmeters are widely used in metallurgy, food industry, construction, biochemistry, ore dressing production, medicine since they have low inertia as compared with flowmeters of other types [25].

Producers of such flowmeters are «Krohne», «Siemens», «Honeywell» (USA).

The ultrasound method is one more flow rate measurement method that has become popular lately. It uses time dependence of the ultrasound vibrations propagation through gas flow in the pipeline with pre-defined diameter [26].

Time difference $\Delta\tau$ is directly proportional to flow velocity v:

$$\Delta\tau=\frac{2L}{c^2}v, \qquad (11)$$

where c – sound speed in the medium; L – distance, that is passed by ultrasound vibrations [27].

In the ultrasound meter pairs of primary transducers are located. Presence of several such pairs makes it possible to obtain more accurate flow rate values. Each of the sensors is capable of receiving and transmitting a signal. Measurements of the time, within which the signal passes between each of the pairs, occur simultaneously. The signal is generated by piezoelectric crystals, to which voltage is applied or, vice versa, when ultrasound wave strikes the crystal, voltage appears at the crystal. Increasing the number of the pairs of sensors, it is possible to determine accurately and to compensate mathematically distortions of the flow profile throughout the entire section of the tube. When there is no substance motion in the tube, signal transmission time is the same both upstream and downstream. As soon as the substance starts flowing in the measuring tube, the speed of sound signals increases in the direction of liquid flow and decreases in the opposite direction [29].

Ultrasound flowmeters, in their turn, are divided into:

1. Frequency flowmeters, where the difference in the frequencies of repetition of short pulses or packets of ultrasound vibrations is measured;
2. Phase flowmeters, which measure the difference of the phase shifts of ultrasound vibrations;
3. Time-pulse flowmeters, where the difference in time, within which short pulses pass, is measured directly [27];
4. Resonance flowmeters;
5. Single-channel (with two piezoelements);
6. Double-channel (with four piesoelements);
7. Multichannel [29].

Ultrasound flowmeters are the most prospective for commercial accounting as they have a number of advantages:

1. Absence of movable parts or parts projecting into the flow;
2. They do not create additional pressure losses;
3. They can operate from an integrated autonomous power source for a long time;
4. Accuracy to <0,1% could be calibrated;
5. Measurements are relatively accurate even in the case of sensor failure [30].

In other initial measuring device, such as turbine flowmeters, it is difficult to understand if they still provide accurate information after a certain period of operation. Such factor as contamination caused by oil in the pipeline can influence the accuracy of any sensor. Sometimes, in order to check proper operation of a measuring device, visual examination is required. For ultrasound meters electronic diagnostics is proposed, which helps in checking their proper operating condition and prevents from extra internal interference which is often required for other measuring devices. Internal diagnostics can also be used for checking other indicators of a measuring facility such as temperature [28].

In spite of the evident advantages of ultrasound meters, the method has the following drawbacks:

1. Restrictions concerning minimal flow rates;
2. Complexity and high cost of the devices, which is by 3 – 4 times higher than that of tachometric and electromagnetic flowmeters, all other conditions being equal;
3. Influence of air bulbs in the flow on the flowmeter indications;
4. The necessity for long linear sections in front and behind the transducer [31].

Today, there is a huge number of companies engaged in the development if ultrasound flowmeters: «Krohne» (series UFM, GFM, Altosonic), «Emerson» (Senior Sonic, Junior Sonic), «Sick Mahack» (Northern America).

Mass flowmeters, among which heat and mechanical flowmeters are distinguished, belong to another class of gas flow rate measuring devices. Heat flowmeters include calorimetric and thermoanemometric devices. Mechanical flowmeters include inertia meters.

Carioles flowmeters together with turbo-power and hygroscopic devices are related to inertia meters. Inside each Carioles flowmeter a tube is located (e. g., Yokogawa company proposes a solution with two tubes) [32]. A so called exciter forces the tube to vibrate with a definite clock rate. If there is no motion of the measured medium in the tube, it vibrates with a uniform frequency.

Sensors, located at the input and output of the tube, register these uniform vibrations. As soon as the measured medium starts to move in the tube, additional longitudinal vibrations appear. Under the influence of Carioles force input and output parts of the tube deflect in different directions, i.e. a phase shift is observed [33]. Highly sensitive transducers are responsive to these vibrations. Therefore, phase shift is a measure of the substance flow rate. The higher the flow rate, the more vibration periods are included into the measured section [34].

This group of flowmeters has high accuracy and reliability, flow direction does not influence operation of the device; Carioles flowmeters, if installed properly, are not sensitive to vibrations and temperature drops.

Such flowmeters are suitable only for small-diameter pipelines and their indications are dependable on the slag deposits in the tubes.

Among the producers of Carioles flowmeters there are such companies as «Emerson» and «Endress + Hauser» (Switzerland).

Conclusions

Ensuring maximally accurate control over consumption of gaseous and liquid mediums is one of the most important current power engineering problems. At present there exist a lot of flow rate measurement methods. Each of the meters has its advantages and drawbacks, depending on which it finds application in industry. Taking the above-mentioned into account, the paper analyzes the existing flow rate measuring methods and proposes their classification. It has been determined that the ultrasound method is the most prospective one due to its wide dynamic range, reliable operation, high precision and convenient diagnostics. In spite of its evident advantages, ultrasound flowmeters are rather expensive and their increased number of channels leads to much more complicated information processing software realization.

REFERENCES

1. Ряховский С. В. Основные принципы создания единой системы учета газа в региональной компании поставщика газа / С. В. Ряховский, Л. Г. Паскаль // Энергосбережение. – 2005. – № 10. – С. 54 – 58.
2. Тюленев Л. Н. Методы и средства измерений, испытаний и контроля / Л. Н. Тюленев, В. В. Шушерин, А. Ю. Кузнецов; под ред. С. В. Кортов. – Екатеринбург: ГОУ ВПО УГТУ УПИ, 2005. – 76 с.
3. ЭлектроТехИнфо: информационная торговая система [Електронний ресурс]: Тахометрические счетчики и расходомеры. Устройство, принцип действия, типы и виды тахометрических счетчиков и расходомеров. – Режим доступу: http://www.eti.su/articles/izmeritelnaya-tehnika/izmeritelnaya-tehnika_527.html. – Назва з екрану.
4. MESKOTEX MESS- UND KONTROLLTECHNIK [Електронний ресурс]: Диафрагменные расходомеры. – Режим доступу: http://www.meskotex.com/diaphragm.htm. – Назва з екрану.
5. DS/OM–RU Редакция 2 [Електронний ресурс]: Компактный диафрагменный расходомер OriMaster. Техническое описание. – Режим доступу: http://www05.abb.com/global/scot/scot203.nsf/veritydisplay/0b3b45a281a88c9bc12575a80037b487/$file/ds_om-ru_2.pdf. – Назва з екрану.
6. To build [Електронний ресурс]: Виды газовых счётчиков: мембранные, ротационные, турбинные счётчики. Вихревой расходомер. – Режим доступу: http://gas.to-build.ru/content/view/56/44/. – Назва з екрану.
7. LICON [Електронний ресурс]: Типы расходомеров. – Режим доступу: http://eclicon.ru/?page_id=1450. – Назва з екрану.
8. MESKOTEX MESS- UND KONTROLLTECHNIK [Електронний ресурс]: Турбинные расходомеры. – Режим доступу: http://www.meskotex.com/hm.htm. – Назва з екрану.
9. Правила метрологии ПР 50.2.019-2006 «Методика выполнения измерений при помощи турбинных, ротационных и вихревых счетчиков» / ред. В. Н. Копысов. – М. : ФГУП «Стандартинформ», 2007. – 33 с.
10. Журнал «Энергетика и ТЭК» [Електронний ресурс]: Расходомеры: принципы работы и опыт эксплуатации. – Режим доступу: http://www.energetika.by/arch/~page__m21=6~news__m21=140 . – Назва з екрану
11. Газовик [Електронний ресурс]: Турбинные счетчики газа. – Режим доступу: http://gazovik-gaz.ru/spravochnik/consum/turbinnyie-schetchiki-gaza.html. – Назва з екрану.
12. YOKOGAWA [Електронний ресурс]: Вихревой расходомер, вихревой расходомер – принцип действия. – Режим доступу: http://www.yokogawa.ru/measurementcharge?prod=443. – Назва з екрану.
13. Технический паспорт D184S035U03 Rev. 12 [Електронний ресурс]: 2-проводное компактное устройство. Измерительный преобразователь на базе цифрового сигнального процессора. – Режим доступу: http://www05.abb.com/global/scot/scot211.nsf/veritydisplay/53187d45f8a21695c1257950003daaec/$file/D184S035U03-RU-12-11_2011.pdf. – Назва з екрану.
14. Руководство по эксплуатации 00809-0107-4860 [Електронний ресурс]: Расходомеры вихревые Rosemount 8600D. – Режим доступу: http://www2.emersonprocess.com/siteadmincenter/PM%20Rosemount%20Documents/00809-0107-4860.pdf. – Назва з екрану.
15. Научно-производственна фирма "Раско" [Електронний ресурс]:О применимости различных методов измерения расхода для коммерческого учета газа . – Режим доступу:http://www.packo.ru/node/1763 . – Назва з екрану.
16. Руководство по эксплуатации 2.784.000 РЭ [Електронний ресурс]: СЧЁТЧИК ГАЗА РОТАЦИОННЫЙ

РГ-К-Ex. – Режим доступу: http://www.ppx.ru/product/re_rgk.pdf. – Назва з екрану.
17. ПРАМЕНЬ [Електронний ресурс]: Струйные расходомеры. – Режим доступу: http://npopramen.ru/information/other-flowmeters/specific-methods/3-jet-flowmeters. – Назва з екрану.
18. Научно-производственна фирма "Раско" [Електронний ресурс]: О применении струйного автогенераторного метода измерения в бытовых счетчиках газа и поверочных установках . – Режим доступу:http://www.packo.ru/node/2151 . – Назва з екрану.
19. Чаплыгин Э. И. Математическая модель струйного расходомера. / Э. И. Чаплыгин, Ю. В. Земсков, В. В. Корзин // Журнал технической физики. – 2004. – т. 74. – № 4. – С. 16 – 19.
20. Измерение расхода с использованием осредняющих напорных трубок [Електронний ресурс] / В. Н. Жук // Энергетика и ТЭК. – 2010. – № 2. http://www.energetika.by/arch/~year__m21=2010~month__m21=2~page__m21=1~news__m21=568.
21. ETS [Електронний ресурс]: Основные принципы измерения расхода газа с помощью осредняющей напорной трубки. - Режим доступу: http://www.ets.inf.ua/PDF/Intra/%D0%9E%D1%81%D0%BD%D0%BE%D0%B2%D0%BD%D1%8B%D0%B5%20%D0%BF%D1%80%D0%B8%D0%BD%D1%86%D0%B8%D0%BF%D1%8B%20%D0%B8%D0%B7%D0%BC%D0%B5%D1%80%D0%B5%D0%BD%D0%B8%D1%8F%20%D1%80%D0%B0%D1%81%D1%85%D0%BE%D0%B4%D0%B0%20ITABAR-%D0%B7%D0%BE%D0%BD%D0%B4.pdf. – Назва з екрану.
22. Автоматизация производственных процессов [Електронний ресурс]: Ионизационные расходомеры. – Режим доступу: http://ru-auto.info/post/101488904990008/. – Назва з екрану.
23. Мегапаскаль – инфопортал [Електронний ресурс]: Ионизационные расходомеры. – Режим доступу http://megapaskal.ru/pribory/rashod-pribor/228-i-snova-rashodomery-rashodomery-ionizacionnye.html. – Назва з екрану.
24. Прамень [Електронний ресурс]: Электромагнитные расходомеры. – Режим доступу: http://npopramen.ru/information/other-flowmeters/physycal-phenomena/12-electromagnetic-flowmeters. – Назва з екрану.
25. Расходомер.ру. [Електронний ресурс]: Что такое электромагнитный расходомер?!. – Режим доступу: http://www.td-rashodomer.ru/info/articles/elektromagnitnii_rashodomer.htm. – Назва з екрану.
26. Новый способ измерения расхода природного газа ультразвуковым методом [Електронний ресурс] / А. М. Деревягин, А. С. Фомин, В. В. Козлов // Газпром Россия. – 2008. – Режим доступу: http://npovympel.ru/files/pdf/hyperflow-us.pdf.
27. Андріїшин М. П. Вимірювання витрати та кількості газу: Довідник / М. П. Андріїшин. – Івано-Франківськ: ПП “Сімик”, 2004. – 160 с.
28. American school of gas measurment technology [Електронний ресурс]: Fundamentals of multipath ulrasonic flow meters for gas measurement. – Режим доступу:http://asgmt.com/wp-content/uploads/pdf-docs/2011/1/F05.pdf . – Назва з екрану.
29. Взлет.ру. [Електронний ресурс]: От однолучевых ультразвуковых расходомеров к многолучевым: критерий выбора. – Режим доступу: http://www.vzljot.ru/files/publications/odnoluch-ultrasonic.pdf. – Назва з екрану.
30. Chattopadhyay P. Flowmeters & Flow Measurement Ч. 2. / P. Chattopadhyay. – New Delhi, 2006. – 76 c.
31. Электротехинфо. [Електронний ресурс]: Ультразвуковые расходомеры. Устройство, принцип действия, типы и виды ультразвуковых расходомеров. – Режим доступу: http://www.eti.su/articles/izmeritelnaya-tehnika/izmeritelnaya-tehnika_529.html. – Назва з екрану.
32. YOKOGAWA. [Електронний ресурс]: Измерения расхода с помощью кориолисовых расходомеров в случае двухфазного потока. – Режим доступу: http://www.yokogawa.ru/default.aspx?mode=binary&id=502. – Назва з екрану.
33. Естествознание и математика. [Електронний ресурс]: Сила кориолиса в общем курсе физики. – Режим доступу: http://www.pskgu.ru/projects/pgu/storage/wt/wt141/wt141_02.pdf. – Назва з екрану.
34. Autoworks. [Електронний ресурс]: Измерение массового расхода. Кориолисовый расходомер. – Режим доступу: http://autoworks.com.ua/teoreticheskie-svedeniya/izmerenie-massovogo-rasxoda-koriolisovyj-rasxodomer/. – Назва з екрану.
35. Организация учета природного газа. Основные принципы, методы и средства обеспечения метрологической надежности узлов коммерческого учета газа [Електронний ресурс] / С. А. Золотаревский, О. Г. Гущин // Ежегодный сборник научно-технических статей, выпускаемый ООО “ЭЛЬСТЕР Газэлектроника”. – 2012. – Режим доступу: http://www.packo.ru/node/2150.

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