Experimental study and analysis of hydraulic characteristics of diaphragm (chamber) gas flow meter

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Abstract: In the conditions of life, the most common household gas flow meters are diaphragm (chamber) flow meters. From a technical point of view, hydraulic and durability characteristics are important. A basic requirement that must be met by measuring instruments used for industrial or domestic applications is to be as accurate as possible. The diaphragm flow meter type BK G2.5T was experimentally studied in the work. The hydraulic (resistance) characteristic \( \Delta p = f(Q) \) of this type of flow meters is obtained and it is derived the analytical dependence of this characteristic - square parabola and means pressure drop at a nominal flow rate – \( \Delta p_m = 0.4 \text{ mbar} \). The established pulsation character of the operation of the diaphragm flow meter is analyzed by the introduced one the characteristic of the pressure pulsations \( \delta p = p_{\text{max}} - p_{\text{min}} = f(Q) \), as for the specific flow meter the pulsations are \( \delta p = 0.1…0.2 \text{ mbar} \). The original results from obtained researches will be useful for constructors for optimization of the design of the gas systems.

1. Introduction

Natural gas is increasing its importance for meeting the energy needs in the various fields of industries and households. This is necessitated both by its wide distribution and by its ecological characteristics [1, 2, 3]. To measure the consumption of natural gas, various constructions of gas flow meters have been created. The extensive classification of gas flow meters based on the principle of operation includes diaphragm (membrane), rotary (volumetric), turbine, differential, Coriolis, vortex, ultrasonic and others [4, 5, 6, 7].

Practically the most common flow meters are diaphragm (membrane) due to their wide exploitation in the home [8, 9]. When installing diaphragm flow meters in domestic gas supply installations, it is necessary to take into account the hydraulic characteristics of these devices and the specifics of their work, specified in more detail in point 2. Designers of gas systems are faced with the lack of sufficient information about these characteristics - often set a generalized pressure drop for a group of flow meters, this drop is not associated with the specific flow rate [3, 6, 7].

The aim of the present work is to clarify some specific features of the hydraulic resistance characteristics and the principles of work of diaphragm flow meters.

2. Principle of operation and main characteristics of diaphragm flow meters

Diaphragm flow meters are used to measure gas consumption in a wide range - from 1.6… 160 m³/h, but in the practice are used mainly flow meters with small flow rate - 1.6 ... 10 m³/h. Structurally diaphragm flow meters consist of several assemblies [7] (figure 1). There is a huge variety of designs...
of diaphragm flow meters [5, 10, 11], many protected patents for various units - valves, actuators, and registering mechanisms, etc.

The diaphragm flow meter is a volumetric flow meter with a periodic filling and emptying of variable volume chambers, in which the movement for this filling and emptying is mechanically transmitted to a counter, and the flowing gas drives it. The main elements of the measuring device (figure 1) are:

- two flexible membranes or diaphragms 3, dividing together with the housing 1 and the cover 2 into the whole device into four chambers (measuring compartments);
- valves 5 for controlling and directing the gas flow when filling and emptying the chambers;
- a suitable connection and measuring mechanism 4 for maintaining the diaphragms, synchronizing the valves and recording the number of cycles.

![Figure 1. Diaphragm flow meter with sliding valves and built-in temperature corrector (a) device: 1 - housing; 2 - cover; 3 - membranes; 4 - measuring mechanism; 5 - gas distribution sliding valves; 6 - tightening hoop; 7 - gas inlet; 8 - gas outlet (b) principle of operation - left (l) and right (r) compartments, in which there are two chambers: diaphragm (d) and body (k).](image)

The movement of the membrane is regulated in such a way that the total displacement in the successive cycles, realizing the filling and emptying of the chambers, is the same.

The operation of the diaphragm flow meter is connected at any time with filling the one chamber, emptying the other chamber from the same compartment, and pausing for the other two chambers located in the adjacent compartment. For example, for the process shown in figure 1b, left position: the housing chamber (k) is filling and the diaphragm chamber (d) of the right compartment (r) is emptying. At the same time, the chambers (d-k) in the left compartment (l) are at rest [7]. The gas distribution valves move in synchrony and occupy one of the four possible positions.

The improvement of the constructions of the diaphragm flowmeters is in the direction [12], [13], [14]: achieving a minimum resistance to the gas flowing and at the same time driving the device; achieving maximum density and wear resistance of the valves; increasing the accuracy of measurement and installation of temperature correctors in the diaphragm flow meter.

The main characteristics of diaphragm flow meters relate to their accuracy - the dependence of the error of the measured amount of gas on the flow rate, pressure or temperature of the gas [13], [15], [2], [7] – figure 2a.

From a hydraulic point of view, however, the dependence of the pressure loss during different flow through the diaphragm flow meter is interesting - the characteristic $\Delta p = f (Q)$ – figure 2b [7]. When designing domestic gas systems, the allowable pressure drop in the whole system (without flow meter) is sometimes $[\Delta p] < 2$ mbar [16], [3], [6]. Although considered to be a small fraction of the gas pressure used to operate the flow meter, $\Delta p = 2$ mbar for flow meters up to G10 is set in samples of
prospectus characteristics for pressure losses in the flow meters. This shows: the flow meter is a large hydraulic resistance; it is not commented that the hydraulic losses in it depend on the flow rate (the characteristics $\Delta p = f(Q)$ are often absent); the flow meter can have a significant effect on lowering the pressure in front of the specific fuel consumer.

![Figure 2](image.png)

**Figure 2.** Characteristics of diaphragm flow meter: dependence of the error (accuracy) with an admissible limit of the measured amount of gas from the flow rate - for flow meter BK - G2,5 - $\delta = f(Q)$; b) pressure drop in flow meters type BK-G4 - $\Delta p = f(Q; d)$.

The hydraulic characteristic is also interesting due to the fact that the diaphragm flow meter is a volumetric type of flow meter. As described above, its working principle is based on discretion or portion work. When switching the sliding valves, which achieves the sequential filling and emptying of the chambers, moments of stopping and starting of the respective flows should be expected. The interruption at the time of switching can be expected to result in pressure and flow fluctuations. This problem is not commented in the commercial - production characteristics of different companies and in the study of diaphragm type flow meters.

### 3. Installation and methodology for investigation of the hydraulic characteristics of a diaphragm flow meter

In connection with the implementation of the planned study of the hydraulic characteristics of a diaphragm gas flow meter $\Delta p = f(Q)$ a laboratory installation was built – figure 3.

The supply of the installation is with a reciprocating compressor $1$. It should be specified that the working gas is air, which requires recalculation of the obtained hydraulic characteristic of the flow meter for another working gas (for example, natural gas $d = \rho_{ng} / \rho_a = 0.62$).

The tested diaphragm flow meter $10$ is type BK - G2,5 T, for which the nominal flow rate is 2,5 m$^3$/h. The flow control during the test is performed by means of a valve $14$ in the nominal range of the flow meter - from $Q_{MIN}$ to $Q_{MAX}$ (i.e. from 0.3 to 4 m$^3$/h). Preliminary control of the current volume flow is carried out with a flow meter - rotameter $13$.

With the pressure reducing valve $7$ the required working pressure in the system for the tested diaphragm flow meter $10$ is adjusted, controlled by the two-pipe liquid manometer $9$. Tests were performed at two values of the inlet pressure – $p_{i1} = 27.8$ mbar and $p_{i2} = 38.9$ mbar.

During the study, the two important hydrodynamic parameters were measured and calculated: the volumetric air flow rate $Q$ (measured by the volumetric method: by the volume $W$ measured with the tested diaphragm flow meter $10$ and the time $\tau$ for its flow, measured with a stopwatch $17$) and the pressure drop $\Delta p$ (losses of pressure) in the diaphragm flow meter measured with a differential pressure gauge $11$. 
The air flow required for the recalculation - atmospheric pressure ($p_{\text{atm}}$) and ambient air temperature ($t_{a}$) are measured with a barometer - aneroid 15 and a thermometer - hygrometer 16.

During the study, at a constant flow of air flowing through the flow meter 10, the sequential filling and switching of the volumes (chambers) caused pressure pulsations, the pressure changes from $p_{\text{min}}$ through $p_{m}$ to $p_{\text{max}}$, and vice versa. The measurement of these pulsations required a creative assessment in the reporting. The obtained results prove good correspondence and tendency of the characteristics, regardless of the subjective nature of part of the assessment. The frequency of the pulsations is directly related to the flow volume.

The obtained results gave grounds for introduction of additional hydraulic characteristic of the diaphragm flow meter - besides the classical dependence - the resistance characteristic $\Delta p_{m} = f (Q)$, a dynamic characteristic estimating the pressure pulsations depending on the flow which we introduced. This characteristic is defined as:

$$\delta_{p} = \Delta p_{\text{max}} - \Delta p_{\text{min}} = f (Q),$$

where $\Delta p_{\text{max}}$ and $\Delta p_{\text{min}}$ - maximum and minimum pressure drop in the volume flow meter at a constant flow rate $Q$.

Another characteristic is defined - relative deviation of the pressure pulsations, which determines what part of the pressure pulsations make up the measured average pressure drop:

$$\Delta = \left(\frac{\delta_{p}^2}{\Delta p_{m}}\right) \cdot 100$$

4. Results of the research and analysis of the obtained hydraulic and pulsation characteristics

The results of the study of diaphragm flow meter type BK-G2.5 T at two different inlet pressures are shown in figure 4. The graphs of both studies show three characteristics - these are the dependences of the maximum, average and minimum pressure drops in the flow meter during different flow $Q - \Delta p_{\text{max}}, \Delta p_{m}, \Delta p_{\text{min}} = f(Q)$.

The actual characteristic $\Delta (Q)$ is the mean curve and actually expresses the mean pressure drop $\Delta p_{m}$ in the flow meter at the respective flow rate $Q$. The other two graphical dependencies show the upper and lower ranges of the change in pressure drop as a function of flow. Regardless of the
complexity of the studies, the characteristics $\Delta p_{\text{max}}$ and $\Delta p_{\text{min}} = f(Q)$ are symmetrically located with respect to the mean resistance characteristic and have a clearly defined quadratic dependence.

The main characteristics have a pronounced parabolic (quadratic) character - proved by those describing the correlation curves and the high value of the correlation coefficient $R^2 > 0.99$ in both studies (at different inlet pressures).

Describing the correlation curves are very close, which is confirmed by the combined graphs $\Delta p(Q)$ for the two inlet pressures given in figure 5. This shows that the inlet (operating) pressure in the gas system does not affect from the performance of the flow meter and allows to write a generalized equation for the hydraulic characteristics of the studied diaphragm flow meter BK-G2,5T:

$$\Delta p = 2.3Q^2 + 6.1Q + 12.5$$  \hspace{1cm} (3)

As a generalized practical assessment required in the design of gas systems, it can be said that the pressure loss in this type of flowmeter is in the range of $\Delta p = 15÷ 80$ Pa $= 0.15÷ 0.8$ hPa $= 0.15÷0.8$ mbar, as the minimum static resistance of the flow meter (at $Q = 0$) is about $\Delta p_0 = 12$ Pa.

Another important conclusion of the study concerns the pressure pulsations $\delta p$ determined depending on (1). The experimental results of this study are presented in figure 6 as a dependence of $\delta p = f(Q)$ - i.e. give the change of the pressure pulsations with the increase of the flowing volume flow of the gas.

The dependence analysis shows the indisputable linear increase of the pressure pulsations with the increase of the flow rate. In addition, with an increase in the working pressure, there is a slight increase in these pulsations - as evidenced by the correlations describing the process (increasing coefficient of linear dependence).
pressures $p_{i2} = 38.9$ mbar and $p_{i1} = 27.8$ mbar. 

In absolute terms, the pressure pulsations at a nominal flow rate of $Q = 2.5$ m$^3$/h reach $\delta_p = 22\div25$ Pa, at an average pressure drop of $\Delta p_m = 42\div44$ Pa. The estimate for the share of the pulsations in the total pressure drop, given by the relative deviation of the pressure pulsations $\Delta$ (determined by (2)), shows that in the specific case it varies in the range $\Delta = 25\div30\%$.

Pressure pulsations are a significant part of the total losses and should be reported. For example, the pressure drop in the diaphragm flow meter in this case (at nominal flow rate) should be defined as:

$$\Delta p = \Delta p_m \pm (\delta_p / 2) = 43 \pm (24/2) = 43 \pm 12 \text{ Pa}$$  

The question of the influence of pressure pulsations $\delta_p$ on the overall operation of the gas system is interesting. Despite the relatively high relative share of pulsations in relation to the total pressure drop ($\Delta = 25\div30\%$), they constitute in absolute terms $\delta_p = 0.1\div0.2$ mbar, which relative to the operating pressure in gas systems $p_i = 20\div50$ mbar is relatively small. Given the volume of gas located from the flow meter to the consumer, which volume is a kind of accumulator and damper of these ripples, a reasonable assumption can be made - the impact of pressure ripples is insignificant. This conclusion - the influence of pressure pulsations on the operation of the entire gas system and possible recommendations for the location of the diaphragm flow meter should be checked experimentally.

Nevertheless, the proven conclusion about the pressure drop $\Delta p$ ($Q$) and the pressure pulsations $\delta_p = f(Q)$ should be taken into account when evaluating and analyzing the operation of the gas systems.

5. Conclusions
Experiment results of the hydraulic characteristic $\Delta p$ ($Q$) of a common diaphragm flow meter design have been obtained from our own studies. A correlation dependence (3) describing this characteristic with a high value of the derived correlation coefficient, which has a quadratic character. At nominal flow, the pressure losses in this type of flow meter are $\Delta p_m = 0.4$ mbar.

The pulsation character of the pressure change in the diaphragm flow meter has been established. This pulsation is evaluated by the introduced characteristic "pressure pulsations" - $\delta_p$. A linear proportionality of the pressure pulsations $\delta_p$ depending on the flow rate $Q$ has been established. In relative and absolute form, the pressure pulsations are respectively - $\Delta = 25\div30 \%$ and $\delta_p = 0.1\div0.2$ mbar. The results of the research can be used in the design, analysis and evaluation of the operation of gas systems.

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