Theory and Building Practice

Vol. 4, No. 2, 2022

https://doi.org/10.23939/jtbp2022.02.017

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THE USE OF AN ULTRASONIC FLOW METER IN THE ZONE OF INFLUENCE OF INDIRECT SECTIONS OF THE WATER PIPELINE

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The accuracy of water flow rate measurement with an ultrasonic flow meter (UFM) is affected by pipeline conditions. On water pipelines, there is often no the required length of direct section, required by the device passport or regulatory documents. Therefore, we conducted experiments using UFM to measure water flow rate in the zone of influence of non-direct sections of the water pipeline. The flow rate was measured in two planes of the pipeline with an offset of 90° and the average value was taken. Thus, it was expected to take into account the average water velocity for the asymmetric velocity profile. The results of water flow rate measuring with UFM on short direct sections of the water pipeline, limited by pipeline bends sudden constriction of the pipeline, are presented. The greatest influence on the UFM measurement error is the 90° pipeline bends.

Keywords: ultrasonic flow meter, water flow rate, water flow velocity, velocity profile, pipeline section, hydraulic resistance.

Introduction

In the practice of the ultrasonic method of measuring water flow rate, time-type of UFM are preferably used, in which the difference in the propagation time of a sound pulse from the pipe walls along the flow and against the flow is directly proportional to the water flow velocity. As for the installation of UFM on the water pipeline, their passports specify a requirement for the presence of a sufficiently long direct section of the pipeline.

In this paper, we investigate the possibility of using UFM devices on short direct sections of the water supply system to determine water flow rate with acceptable accuracy. With closely located bends, narrowings and other indirect parts of the water pipeline, the profile of water velocities in the pipeline becomes asymmetric. In such sections of the water supply, for measuring the water flow rate, a trial application of UFM in two perpendicular directions was carried out. It was found that in this way it is possible to reach the average flow velocity and, accordingly, the real water flow rate in the pipeline.

The technical documentation for ultrasonic water flow meters states that in order to obtain reliable results, the pipeline must have an existing direct section of a certain length. However, it often happens that it is necessary to measure the flow of water using an UFM in small enclosed spaces, where there is no direct section of the required length. At the same time, there is no information on the absolute or relative values of the decrease in the accuracy of water flow measurements in the case of placing the UFM in the zones of influence of indirect sections of the water pipeline. Therefore, the study of the degree of influence of indirect sections of the water pipeline on the accuracy of measuring water flow rate with UFM is an urgent task.

The main purpose of the study is to establish the possibility of using UFM, in the zones of influence of indirect sections of the water pipeline, by measuring the water flow rate in two planes. The main objectives of the work is to investigate changes in the accuracy of measuring the water flow rate with UFM, when it is installed in the zone of influence bends, narrowings and other indirect parts of the water pipeline.

Among the known modern methods of measuring water flow rate, ultrasonic is distinguished by reliable operation, convenient diagnostics, and a wide measurement range. According to the principle of operation, ultrasonic flow meters are divided into frequency, phase, single-channel and multi-channel (Bilynskyi et al., 2015). It is believed that ultrasonic flow meters are promising for commercial accounting of water consumption (Guiping & Xiaoming, 2019), since they have a fairly high accuracy, however, ultrasonic flow meters are still quite expensive. Paper (Ivanova et al., 2013) presents the results of studies of the accuracy of the ultrasonic flow meter when measuring water flow rate in the river. The difference in the flow rates obtained by the ultrasonic flow meter and the hydrometric current meter was no more than 5 %.

Ultrasonic flow meters provide sufficient accuracy of water flow rate measurement when it is installed on a straight section of the pipeline where the water velocity profile in the pipe cross section is symmetrical (ISO 4064-2:2005; Rafik, 2013; Korobko et al., 2016).

By increasing the number of pairs of sensors, it is possible to more accurately take into account the water velocity profile in the pipe cross section (Matiko et al., 2021). But it is not advisable to use more than four acoustic channels (Matiko et al., 2021) since the software processing of UFM information becomes more complicated and the measurement error decreases insignificantly (±0.1 %). The speed of sound signals between ultrasound sensors increases in the direction of water flow, and decreases in the opposite direction.

In the paper (Roman & Matiko, 2013), the distribution of gas velocity in seven cross-sections in the section of the pipeline bend was investigated. During the research, the sensors were installed at different angles relative to the pipeline cross-sections. It was determined that the error of single-beam UFM with diametral acoustic channels at an angle of 45° or 135° is less dependent on the impact of pipeline bend at an UFM distance of $30D$ to $100D$ after the 90° pipeline bend. This arrangement of the sensors allows for an error in measuring the flow rate that does not exceed 1 %. The authors claim that single-beam UFM do not provide reliable and accurate measurements in the conditions of a distorted flow velocity profile.

An assessment of the influence of the flow velocity profile on the UFM measurement errors was also performed in the paper (Bratslavskyi & Pysarets, 2019). The authors performed numerical modeling of UFM operation process for hydraulic resistance located at different distances from the flow meter, which allowed to determine the required length of the direct section before of the UFM location place.

The paper (Jagatheesaperumal et al., 2020) is devoted to research on reducing the measurement error of single-beam and multi-beam UFM by means of their improvement. The issue of increasing the accuracy of UFM measurements, which are equipped with a special module that records the difference of several pulses in one package, was separately investigated (Grzelak et al., 2014).

The operation characteristics of an UFM in non-ideal conditions (after the pipeline bend) on a pipeline with a radius of 300 mm were studied using laboratory experiments and numerical hydrodynamics models (Stoker et al., 2012). Comparing the velocity profiles with those for the ideal flow, a method and formula was applied to correct the measurement result. The measurement error, which was previously 16 %, has decreased to 2 %.

Some UFM researchers suggest reducing the amount of electronic calculations in them (Yazdanshenasshad & Safizadeh, 2019). As a result, its required power will decrease and additional errors that arise in such a modified approximate method are eliminated by mathematical procedures. Such UFM is most suitable for measuring the velocities and flow rates of gas flows.

For example, portable UFM are beneficial to use at water supply facilities where there are many individual water intake wells (Bosak et al., 2019), or industrial water users (Cherniuk et al., 2019). At such objects, as a rule, there are no ideal conditions for the direct section of the pipeline, so it may be useful to make a corresponding correction of the results of the UFM measurement.

In the analyzed publications, there is not enough research and information on the use of UFM in the zone of influence of indirect sections of the water pipelines. Therefore, we consider the topic we have chosen for research to be quite relevant from the point of view of the practical application of UFM.

Materials and methods

The research was carried out on the equipment of the laboratory of the department of hydraulic and water engineering of the Lviv Polytechnic National University.

A series of experiments were carried out to assess the influence of various types of indirect sections on the accuracy of measurements by the ultrasonic flow meter"Dnipro-7U": the influence the pipeline bend (90°); the influence of sudden constriction of the pipeline from the diameter $D_y = 100$ mm to $D_y = 75$ mm; the influence of the pipeline branch (90°).

Before starting the research, a parallel control of the accuracy of UFM measurements with the results of measurements of standardized 90° triangular sharp crested weir (Fig. 1) was carried out. Flow measurement with an UFM was carried out on a water pipe with a diameter of $D = 100$ mm in the water flow rate range of 0.94–4.70 dm^3/s.

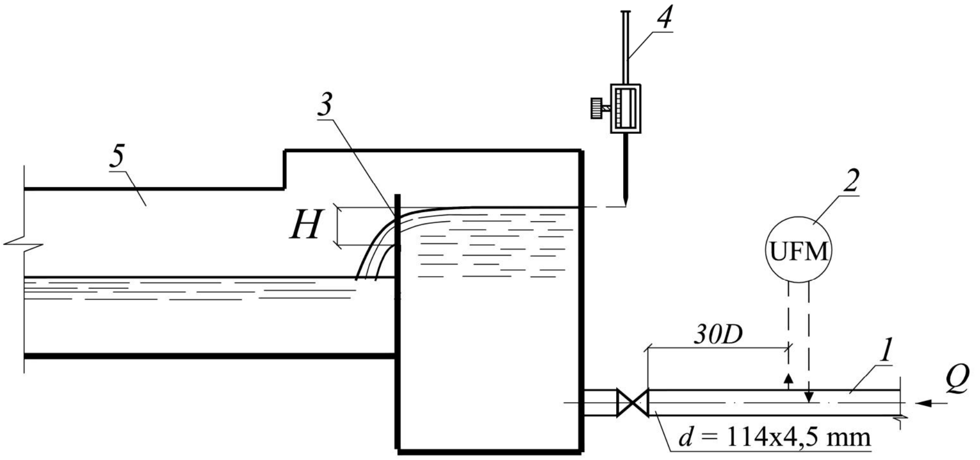


Fig. 1. Scheme of experimental parallel measurement of water flow rate in the pipeline using UFM"Dnipro-7U" and a standardized measuring spillway: 1 – water pipeline in which the water flow rate was measured by the UFM device; 2 – UFM"Dnipro-7U"; 3 – measuring 90° triangular sharp crested weir; 4 – level gauge; 5 – outlet flume

Water head, over the 90° triangular sharp crested weir, were measured with a level gauge with an accuracy of 0.5 mm. Water flow rate Q over the triangular weir was determined by the King's formula (Zhuk et al., 2020):

$$Q = 1.343 H^{2.47}, \tag{1}$$

where H – water head over the triangular sharp crested weir.

The method for measuring water flow rate in the water pipeline system was adopted in accordance with the instructions for using UFM"Dnipro-7U". In each experiment, after stabilization the water flow rate, 6–8 readings were recorded from the monitor of UFM, from which the average value of the water flow rate in the pipeline was taken.

The results of checking the accuracy of water flow rate measurement by the UFM"Dnipro-7U" are presented in graphic form (Fig. 2).

The deviations of the values of water flow rate measured by two methods are insignificant within 0–5.2 %, which in absolute terms amounted to 0.00–0.13 dm^3/s. It should also be taken into account that the accuracy of calculations when determining the water flow rate over a triangular weir is not absolute and is within 1–5 %. Therefore, the accuracy of measuring the water flow rate with the UFM"Dnipro-7U" is confirmed and corresponds to its passport parameters.

Results and discussion

The measurement of water flow rate with UFM“Dnipro-7U” was performed at a distance of 1.5D (Fig. 3) before the sudden constriction of the pipeline from the diameter D_y = 100 mm to D_y = 75 mm. Before the pipeline branch, the measurements were performed at a distance of 4.5D.

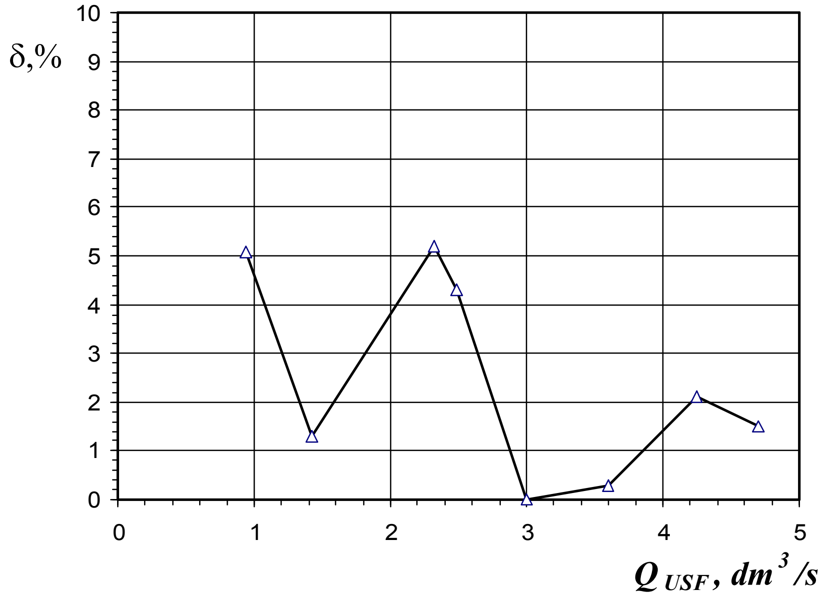


Fig. 2. Graph of UFM accuracy change within experimental water flow rates $\delta = f(Q_{UFM})$

The measurement of water flow rate with UFM “Dnipro-7U” was performed at a distance of 1.5D (Fig. 3) before the sudden constriction of the pipeline from the diameter D_y = 100 mm to D_y = 75 mm. Before the pipeline branch, the measurements were performed at a distance of 4.5D.

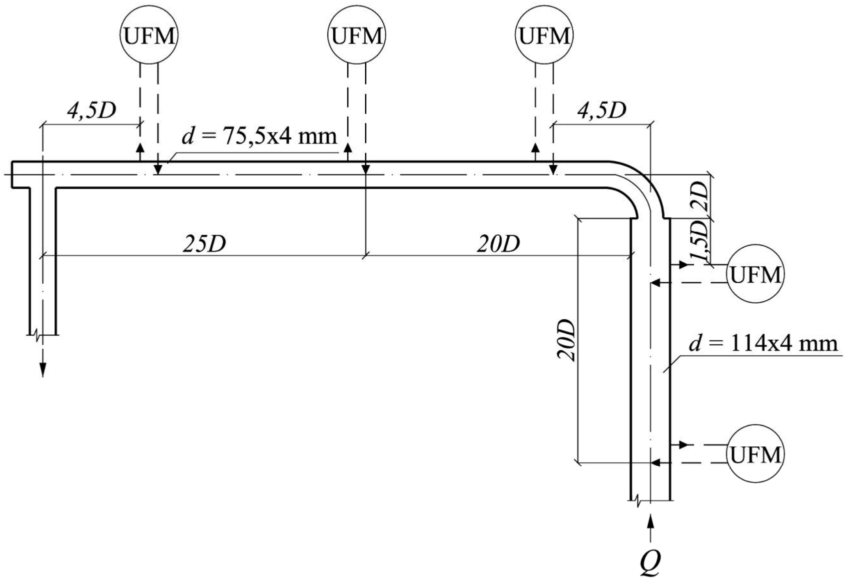


Fig. 3. Scheme of comparative ultrasound measurements on direct sections of the water pipeline and in the zone of influence of indirect sections (before the sudden constriction of the pipeline, before the pipeline branch; after the 90° bend)

The results of experimental measurements of water flow rate with UFM“Dnipro-7U” are given in Table 1.

In table 1: Q_1, Q_2 – water flow rates in the zone of influence in the horizontal section of water pipeline measured in vertical and horizontal planes, respectively; Q – water flow rate on the direct section of the water pipeline; Q_{av} – the average value of water flow rate; Q_y, Q_x – water flow rates in the zone of influence in the vertical section of water pipeline measured in two directions shifted by 90°.

Table 1

The results of UFM measuring the water flow rate before the sudden constriction of the pipeline with a diameter of D=100×75 mm and before the pipeline branch (90°)

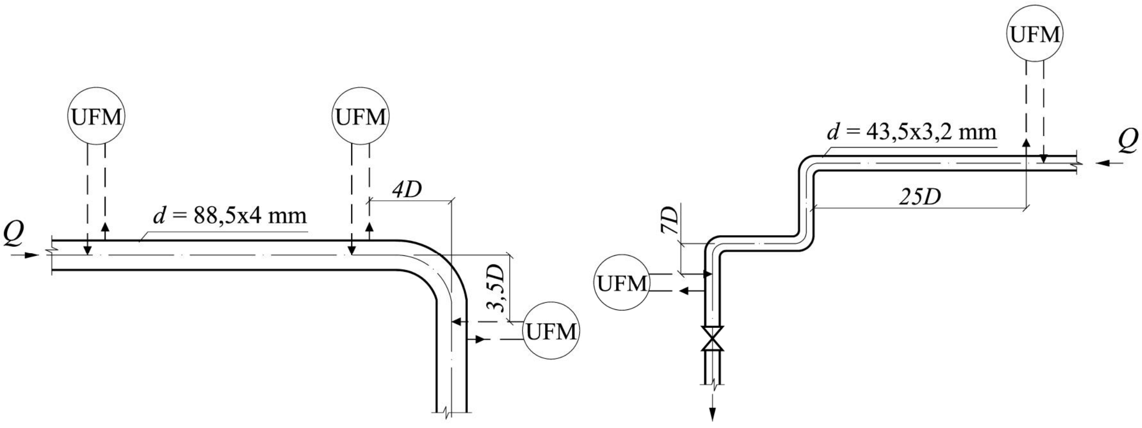
Pipeline diameter	Zone of measurement	Direct section Q_l, dm^3/s	The results of the UFM application in the zone of influence Q, dm^3/s			Error, %
			Q_1,	Q_2	Q_{av},	
D=75,5×4 mm	Before the pipeline branch (90°) (l = 4.5D)	1.60	1.54	1.65	1.60	0.0
		1.46	1.43	1.47	1.45	0.7
		1.35	1.33	1.39	1.36	0.8
		1.50	1.48	1.58	1.53	2.0
		1.12	1.17	1.19	1.18	5.5
D=114×5 mm	Before the sudden constriction of the pipeline 100×75mm (l = 1.5D)	Q_l	Q_y	Q_x	$Q_l - Q_y$	
		0.70	0.66	0.65	0.04	5.7
		1.08	1.07	1.07	0.01	0.93
		1.60	1.58	1.50	0.02	1.25
		1.71	1.64	1.45	0.07	4.1
		2.10	2.15	2.06	–0.05	2.38
		2.34	2.20	2.06	0.14	6.0
		2.52	2.49	2.44	0.03	1.2
		2.60–2.63	2.57–2.56	2.55–2.51	0.03– 0.07	1.2–2.7
		2.79	2.68	2.64	0.12	4.3

Measurement of water flow rate with UFM before the sudden constriction of the pipeline gives acceptable results with an error of 1.2–4.1 %. At low and maximum water flow rates in the pipeline, the error increases to 6 %. Mostly, the water flow rate measured with UFM in the zone of influence was lower than in the direct section. A concentric transition (narrowing or expansion) on the pipeline does not significantly change the velocity profile in the pressure water pipeline, according to the results of our experiment, even at a distance of 1.5D. Therefore, we can conclude that for practical application of UFM, it is sufficient to have a direct section of pipeline with a length of 5D–8D. In the experimental research scheme, there is a 90° bend of pipeline behind the concentric transition. This bend in a certain way influenced the accuracy of UFM readings, however, the sudden constriction of the pipeline before the bend significantly reduces this influence. Therefore, as we can see the presence of a concentric narrowing or expansion of the water pipeline (before the pipeline bend) is a stabilizer of the water flow velocity profile and ensures the accuracy of UFM measurements. Taking into account the velocity profiles in pressure pipelines, it can be predicted that the length of the indirect section of the influence on the accuracy of the flow rate measurements with UFM also depends on the pressure value in this water pipeline and decreases for pipes of larger diameter.

The results of the experiment also showed that in the zone of influence of the pipeline branch, the accuracy of measurements of nominal and maximum water flow rates is quite high, with a deviation of no more than 1–2 %. At low water flow rates in the pipeline, the measurement error increases to 5 %. It should be noted that in the in the zone of influence of the pipeline branch, the UFM readings are usually slightly higher than the actual water flow rates. This may be the result of a change in the velocity profile – from rounded, characteristic of a stable turbulent flow, to an elongated in the zone of influence of the pipeline branch.

The possibility of using of UFM in the zone of influence of the 90° bend at the pipelines with diameters of 40–100 mm was also investigated. Measurement of the water flow rate in the pipeline with UFM was performed at a distance: 4*D*; 3.5*D*; 7*D* before and after the 90° bends (Fig. 3, Fig. 4).

In the first case (Fig. 4, *a*), the measurement of water flow rate with UFM was performed in the zone of influence of the pipeline 90° bend at a distance of 4*D* and 3.5*D*.



a *b*

Fig. 4. Scheme of comparative ultrasound measurements on direct sections of the water pipeline and in the zone of influence of indirect sections: a – before and after the 90° bend on the pipeline with the diameter of D = 88.5×4 mm; b – after the 90° bend on the pipeline with the diameter of D = 43.5×3.2 mm

Table 2

The results of UFM measuring the water flow rate in the zone of influence of the pipeline 90° bends

Pipeline diameter	Zone of measurement	Direct section Q_l, dm^3/s	The results of the UFM application in the zone of influence Q, dm^3/s				Error, %
			Q_1,	Q_2	Q_c,	$Q_c - Q$	
D=88,5×4mm	Horizontal section before the pipeline bend (*l* = 4*D*)	0.72	0.63	0.545	0.587	-0.133	-21.1
		0.84	0.67	0.59	0.63	-0.210	-25
		0.96	0.71	0.70	0.705	-0.255	-36
		0.79	0.97	1.10	1.035	0.245	25
		0.83	1.05	0.89	0.97	0.210	25
		0.83	1.05	0.90	0.975	0.145	17.5
		0.82	0.94	0.82	0.88	0.060	7.3
D=75,5×4mm	Horizontal section after the pipeline bend (*l* = 4.5*D*)	1.07	1.15	1.19	1.17	0.100	9.2
		1.25	1.17	1.10	1.135	-0.115	-9.2
		0.58	0.53	0.56	0.545	-0.035	-6.0
		1.36	1.30	1.30	1.30	-0.060	-4.4
		1.51	1.40	1.44	1.42	-0.090	-6.0
		1.53	1.44	1.48	1.46	-0.070	-4.6
D=88,5×4mm	Vertical section after the pipeline bend (*l* = 3.5*D*)	0.82	0.68	0.93	0.80	-0.020	-2.4
		0.85	0.65	0.95	0.80	-0.050	-5.9
		0.76	0.87	0.90	0.885	0.125	16.4
		0.64	0.73	0.73	0.73	0.110	17.2
D=42,3×2,8mm	Vertical section after the pipeline bend (*l* = 7*D*)	0.73	0.61	0.63	0.62	-0.110	-15.1
		1.15	1.02	1.06	1.04	-0.110	-9.6
		1.82	1.79	1.80	1.795	-0.025	-1.4
		3.11	2.42	2.80	2.61	-0.500	-16.0

The results of experimental measurements of water flow rate with UFM“Dnipro-7U” in the zone of influence of the pipeline 90° bend are given in Table 2.

The error of measuring the water flow rate with UFM“Dnipro-7U” after the bend of the pipeline with diameter *D*=88.5×4 mm at distance 4*D*, and the pipe with diameter *D*=42.3×2.8 mm at distance 7*D* was within 1.4–17.2 %. At average water flow rates, the measurement error was within 2.4–5.9 %. At low and maximum water flow rates, the accuracy of measurement after the pipeline bend is significantly reduced. Water flow rates measurements with UFM after the pipeline bend and on a direct section on the pipe with diameter *D*=42.3×2.8 mm showed close results in the range of average operational water flow rates. The measurement error at low water flow rates was 14 % or more.

The accuracy of the water flow rate measuring after the bend on a horizontal section of the pipeline with a diameter of *D*=75.5×4 mm by the method of two mutually perpendicular planes was satisfactory and the error was within 4.6–9.2 %. The higher accuracy of water flow rate measurements on the horizontal section of the pipeline is probably due to the shape of the velocity profile in this direction.

Conclusions

1. The disadvantage of the ultrasonic flow meter is that they are not able to accurately measure the water flow rate of in case of an asymmetric profile of flow velocities. Therefore, to accurately measure the water flow rate, it is necessary to have a pipeline direct section of a certain length, which is often absent in the real operating conditions of water supply systems.
2. The presence of a narrowing or expansion of the water pipeline (before the pipeline bend) is a stabilizer of the water velocity profile and increases the accuracy of the UFM measurements. Therefore, for the possibility of using a UFM before the section with a change of pipeline diameter, a direct section of 5–7*D* length is enough, or shorter with a slight decrease in the accuracy of measurements.
3. In the zone of influence of the pipeline branch to measure the water flow rate it is permissible to use a UFM using the method of measuring the average value of flow rate in two mutually perpendicular planes of the pipeline. At medium and maximum water flow rates the measurement error was 1–2 %, and at low water flow rates – about 5 %.
4. The use of UFM in the zone of influence of the pipeline 90° bend by the method of measuring the average value of flow rate in two mutually perpendicular planes of the pipeline is permissible only for low and medium water flow rates. At large and maximum water flow rates the measurement error increases up to 20 %.

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ЗАСТОСУВАННЯ УЛЬТРАЗВУКОВОГО ВИТРАТОМІРА НА ДІЛЯНКАХ ВПЛИВУ НЕПРЯМИХ ЧАСТИН ВОДОПРОВОДУ

Ультразвукові витратоміри (УЗВ) використовуються для вимірювання витрат в трубопроводах діаметром більше 40–100 мм. Перевага даного метода вимірювання витрати води в зручності застосування, без додаткових монтажних операцій на трубопроводі, порівняно з вимірювальними діафрагмами. Ультразвукове вимірювання витрати води не є безпосереднім а частково розрахунковим, зокрема щодо визначення при цьому середньої швидкості води в трубопроводі. Для вимірювання УЗВ на водопроводах часто відсутня, необхідна довжина прямої ділянки труби, яка вимагається паспортом приладу або нормативними документами. В цьому аспекті також недостатньо інформації про абсолютні похибки точності вимірювання витрати води в водопроводі в зоні впливу непрямих ділянок На таких ділянках водопроводу епюра швидкостей води, як правило несиметрична, що впливає на точність показів УЗВ. Тому нами проведені дослідні використання УЗВ для вимірювання витрати води на ділянках впливу, – як середньої з двох напрямків зі зміщенням на 90°. Таким способом очікувалось врахувати саме середню швидкість води для несиметричної епюри швидкостей. В разі прийнятних результатів можна збільшити діапазон використання УЗВ на об’єктах водопостачання.

Представлено результати дослідного використання ультразвукового витратоміра “Дніпро-7У” на коротких прямих ділянках водопроводу, обмежених поворотами, звуженням тощо. Найбільше впливають на похибку вимірювань УЗВ колінчасті повороти трубопроводу. На таких ділянках, УЗВ показує витрату води, як правило, нижчу фактичної. Програмні ресурси УЗВ“Дніпро-7У”, а також аналогічних УЗВ, не надають можливості визначення середньої швидкості води у випадках несиметричних епюр. Наявність концентричного звуження або розширення водопроводу перед поворотом труби є стабілізатором епюри швидкостей води і забезпеченням точності вимірювань УЗВ.

Ключові слова: ультразвуковий витратомір, витрата води, швидкість потоку, епюра швидкостей, ділянка трубопроводу, гідравлічний опір.