tional standard. It can be seen that the uncertainty of the final strength measurement depends on all previous stages of the measurement, and this work aims to make recommendations on how these contributions can be estimated.
The purpose of this study is to analyze the components of the error of power plants of the multi-lever type, which are part of the state standard. The paper analyzes the method of reproduction, storage and transmission of the unit size, lever reinforcement installations, which can be used as reference metrological institutes and calibration laboratories. The basic principles of operation of the above reference installations are considered and the mathematical model of reproduction of the size of unit of force is created.
**Key words:** force; measurement; error; measurement uncertainty; lever installation; mathematical model.

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# ULTRASONIC MEASUREMENT TECHNOLOGY IN AUTOMATED CONTROL OF WATER RESOURCES

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*Control of water resources is becoming an important strategic issue. That is why authorities set the goal for water agencies to manage the availability of water and create regulations to its rational use. The main point in water control is measurement. There are three important aspects of measurements of water resources: at water extraction from nature, at the consumption and at custody transfer. Control of water consumption sometimes is based not on measurements, but on preliminary estimation, for example, by pumping.*

*Ultrasonic measurement technology as a key feature of automated control of resources has a potential role in this market. In contrast to mechanical (turbine) meters, ultrasonic meters have a priority because they also give a possibility to realize smart metering. In contrast to electromagnetic meters, which also measure with high accuracy and realize smart functions, ultrasonic meters much more suitable for rough water, wastewater and sewage. Such water resources are usually poorly controlled, which means that no one knows their exact cost.*

*Measurement is mandatory to control cost and for billing. Accuracy is important issue, especially when we say about measurements in large pipe diameters. There is practically no alternative to ultrasonic flow meters. Market of diverse meters concentrated on diameters under 400 mm. For larger diameters, only ultrasonic meters are in use. They have many chords, difficult algorithms for data processing. Thus, they are applicable over a very wide flow range.*

*In this paper, we discover transit-time ultrasonic flow meters to understand features of their measurement theory taking into account all factors affecting their work. This article describes errors inherent in these flowmeters during measurements.*

*As far as accuracy is significantly important in billing, the cost of 1% measurement error in consumption of water resources for small (DN50÷DN150 mm) and large (DN200÷DN1200 mm) pipe diameters has been evaluated and analyzed. The losses from the installation of low-quality metering devices are demonstrated and discussed.*

***Keywords:*** *water resources; ultrasonic flow meter; measurement accuracy; measurement error.*

**Introduction. Formulation of the problem**

The United Nations estimates that at least 780 million people in the World do not have access to clean drinking water; some 2.5 billion people lack access to safe sanitation systems [1]. That is why authorities set the goal for water agencies to manage the availability of water resources and create regulations to its rational use.

Providing an adequate water supply is a major challenge facing many public water utilities, especially in developing countries. A significant part of this challenge is non-revenue water, which is the difference between the volume of water put into a water distribution system and the volume that is billed to customers. It is estimated that water utilities in developing countries can lose 40-50% of the water they put into their systems and they are unable to bill their customers for this loss.

Control of water consumption sometimes is based not on measurements, but on preliminary estimation, for example, by pumping. In this regard, there is an increased need for high-precision flow measurement devices, especially for large-pipe diameters, which are widely used at treatment facilities of water utilities, pumping stations, water supply networks, etc. At the same time, it is necessary to take into account the fact that the market for flowmeters for measuring in pipes of large diameters is very limited. Only electromagnetic and ultrasonic ones are suitable in terms of their metrological parameters. Nevertheless, electromagnetic flow meters, as a rule, are not produced for diameters of more than 300-400 mm due to a significant complication of the design and an increase in the metal consumption of the device. It turns out that there is simply no alternative to ultrasound flow metering technology in this market segment.

That is why ultrasonic flow meters attract more and more attention in recent years, since they are widely used in many areas of the national economy. The global market for ultrasonic flowmeters is primarily driven by the re-investment of manufacturing majors in plant renovation, modernization, capacity expansions, and technology developments. Flowmeter manufacturers are focusing a great deal of attention on ultrasonic flowmeters.

Much of their research and development efforts are currently going into these meters, perhaps at the expense of other meters such as vortex and turbine. Engineers have made significant progress in enhancing the accuracy and reliability of ultrasonic flowmeters, mainly by increasing the number of paths, thereby increasing the number of measurement points, and by adding greater diagnostic capability. Because of growing indicators of world water infrastructure and construction market, ultrasonic flow meter market is showing almost 10% of growth each year [2]. Growth in this market is also driven by the use of ultrasonic flowmeters for custody transfer applications.

Inline ultrasonic meters account for two-thirds of revenues, with the remainder divided between clamp-on and insertion meters [3].

**Analysis of recent research and publications**

A well-designed ultrasonic flow meter requires understanding the physics of sound propagation, signal processing and of course hydrodynamic phenomenon inside metering cell.

Literature survey [4-6] with respect to mentioned subject matter shows that many researches focus their attention on the effect of turbulent fluctuations on the trajectories of sound paths of transit time ultrasonic flow meters and flow visualization near transducer housings. The results were discussed in terms of their consequences for the performance of certain ultrasonic meters. These studies indicate flow patterns and recirculation zones. The reason of such studies was in complex and unclear relationship between meter performance and the inlet flow profile. All researches had practically the same aim – the development of a high accuracy and low cost ultrasonic flow meters with minimal dependence on installation effects and variable flow conditions.

Some researchers [7] investigated numerically as well as experimentally certain ideas regarding reshaping of the duct to achieve optimum meter geometry in different temperature conditions for measured flow. Really, one more important tendency is impact of measured medium temperature on ultrasonic meter performance, because now these meters are often used to measure the flow rate of heat-conveying liquid in heat quantity measurements.

**The purpose of this work** is to consider and take into account the contribution of the most significant factors to the error of an ultrasonic flow meter and estimate the cost of this error.

**Features of ultrasonic measurement technology**

Ultrasonic technology is one of the few technologies that can measure any medium: liquids, gases and even steam. Measurement with virtually no pressure loss can save significant costs on pumping equipment, especially where high line pressures or long transport distances are required. However, there is no limit to perfection, and the tasks of further increasing the effectiveness of the ultrasonic method, in particular, accuracy, are relevant to this day. Especially when it comes to measuring energy resources that are very expensive today.

Prospects for improving the measurement accuracy mainly lie in the features of the measurement method and the production technology of devices implementing this method, therefore, we will consider the factors that have the greatest influence on the measurement process and evaluate the ways to eliminate the errors caused by them.

*The error caused by hydrodynamic correction factor*

The inaccuracy of determining this coefficient makes, perhaps, the largest share in the total error of the device. The hydrodynamic correction factor $k$ is defined by the ratio

$$k = \frac{V_{av}}{V_l}.$$

Where, $V_{av}$ is fluid velocity averaged for pipe cross-section, $V_l$ is fluid velocity averaged for length of sound propagation path.

Incorrect acceptance of the correction factor can give 5 % error and even more, especially in the lower part of the measurement range. To reduce this value, multi-chord flow sensing schemes are often used. When five chords are involved, the spread of readings errors is reduced to ±0.3%. If, nevertheless, we leave the traditional single-beam arrangement of piezoelectric sensors, it is necessary to clarify the value of the hydrodynamic correction factor experimentally.

Traditionally, this coefficient is calculated based on the power law of the velocity distribution according to the measurements carried out by Nikuradze [8]:

$$k = \frac{2n^2}{(1+2n)(1+n)},$$

where, $n = 11,269 - 3,019 \lg Re + 0,432 \lg^2 Re$, $Re$ is Reynolds number.

The problem is that the proposed theory is suitable only for the case of an almost ideal pipe without changing its configuration, i.e. constrictions, expansions, without so-called "pockets" on the flow meter section near ultrasonic sensors, etc. In addition, the proposed formula does not take into account flow asymmetry, which leads to an uneven distribution of velocities, as a result of which the measured average velocity will not correspond to the real one. It turns out that in order to obtain the true values of the correction factor *k*, it is advisable to carry out a numerical experiment, and to assess its reliability, comparing obtained results with the results of a full-scale experiment. Subsequently, this way to solve the problem will give huge savings in time and material costs.

*Temperature error*

This error is determined by the influence of temperature on the distribution of the velocity profile over the pipe cross section, as well as on the nature of the passage of an ultrasonic signal in such a medium.

It has been established [7] that ultrasonic flow meters are influenced by thermal conditions, since the fluid's viscosity and density are functions of temperature. The temperature affects not only velocity profile, but also acoustic propagation.

By using an experimentally determined velocity profile, a commercial CFD-code and a theoretical measurement model for the ultrasonic flow meter, we have predicted the calibration factor curve for the meter at different temperature conditions.

The temperature will influence the error curve. In other words, the shift of the correction factor is dependent on different temperatures of measured flow. This influence can be dismissed putting necessary temperature correction in process of flow rate calculation.

*Time measurement error*

In ultrasonic flow measurement, the timing process is an integral part. The use of high-precision and stable electronics, high-quality quartz emitters, original methods for measuring short time intervals today makes it possible to reduce the time measurement error to almost zero. Thus, we can assume that the process of measuring the time delay of the passage of acoustic signals is completely worked out and does not introduce inaccuracies in the measurements.

*Errors determined by geometric parameters of flowmeter*

These errors can have different origins. Firstly, it is necessary to take into account the flow meter diameter tolerances put in the design documentation. It is because of them in some cases we get a step when connecting the flow meter section to the pipe. If we are talking about acoustic flow meters, where the rays are located near the walls of the pipeline, then this step can significantly affect the final measurement result.

According to research conducted by Instromet Inc. (Houston, USA) [9] a step of 5 % leads to an error of 0.1-0.15 % even for multipath flowmeters. In order to avoid the negative effect of steps, as well as to implement the possibility of connecting the flow meter to pipes with a diameter that differs within a given tolerance, it is advisable to use conical transitions. So, the boundary layer does not detach from the pipe walls, the velocity distribution is not distorted, and, accordingly, an error is not introduced into measuring process.

Secondly, when the flow meter is connected to the pipe, different roughness of the inner surfaces of the pipe and the flow meter can occur. According to the results of the studies [9], the error can reach up to 0.3 % when using pipes with a high degree of corrosion on the inner surface of the pipes.

In practice, it is often very difficult to separate corrosion from pollution or sedimentary deposits that are formed on the pipe walls, and very unevenly around the circumference, but both the first and the second substance lead to a decrease in the flow area of the meter, and therefore to the appearance of an additional component of the error. Regarding the irregularity of plaque: in pipelines of large diameters, glassy precipitation is often observed, as well as "stalagmite" formations several centimeters thick at the bottom of the pipe, and corrosion shells on the top due to the frequent passage of water-air "plugs".

As follows from the above, the influence of a number of factors destabilizing the operation of ultrasonic flow meters can be foreseen and prevented in advance, while saving a lot of money associated with inaccurate control. This is largely helped by the use of software based on modern data processing methods. In addition, the software makes it possible to most fully implement in the device the functions of automated control, accounting and analysis of emergency situations arising at the facilities of operation.

**What inaccurate measurements lead to**

Constantly increasing water price rates brings close attention to the problem of saving and effectively utilizing these resources, even more important than before.

However, how can we achieve these savings without an accurate and precise measurement control? It is interesting to see the financial loss due to 1 % measurement inaccuracy on water consumption caused by ordinary, cheap poor quality flow meters. As time goes, these imperfect meters produce measurement error not 1 %, but 10-15 % and greater. Due to this poor quality in accuracy, cheap meters are repeatedly taken to national metrological verifications, where they are calibrated and sent out back to their working sites.

Many factors such as water content, which is heavily polluted, rust on inner pipes, and many others cause this decrease in accuracy measurements.

The size of the internal meter measuring channel diameter is proportional to the value of measuring inaccuracy, hence the bigger the internal meter measuring channel diameter the greater the measuring inaccuracy. Let us analyze the financial loss for large and small water pipe diameters caused by inaccurate measurements.

### Results and discussion

The calculations shown in Fig. 1 and Fig. 2 have been conducted to evaluate 1 % measurement error with the following parameters: nominal value of flow rate; 365 working days in a year; $1/m$^3$ price rate for water.

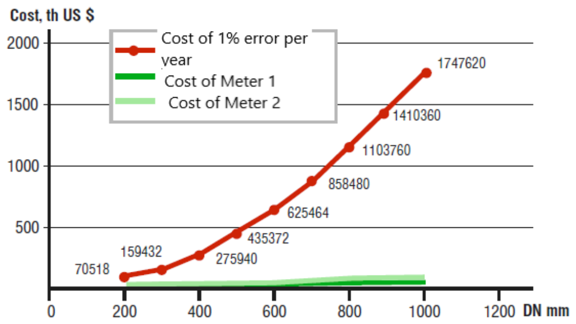


Fig. 1. Cost of 1 % error of water volume measurement in large pipes (DN200÷DN1200) *per year comparing to costs of ultrasonic water meters*

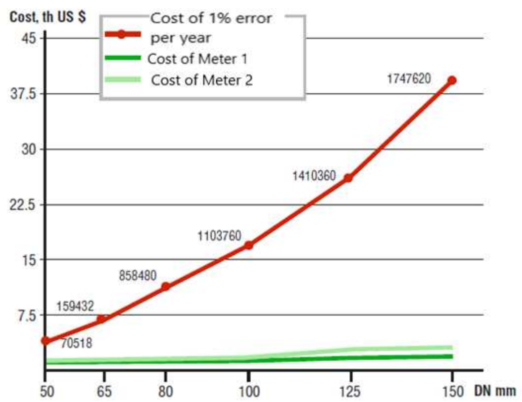


Fig. 2. Cost of 1 % error of water volume measurement in small pipes (DN50÷DN150) *per year comparing to costs of ultrasonic water meters*

Analyzing these figures we can conclude that the measurement inaccuracy problem can affect water suppliers as well as water consumers, depending towards which side the device is mismeasuring. However, not to take the risk towards either side of mismeasurements it is better to install several high quality meters that are going to give accurate measurements and work for a long time period. In other words, "you get what you pay for".

Especially that the savings the consumer receives upon the purchase of a cheap and inaccurate meter quickly overshadowed by thousands of dollars losses that the meter causes due to inaccurate measurements. Unfortunately, as time goes these losses accumulate to enormous amounts that the consumer does not expect. The first step to effectively save on water consumption is to buy a high precision meter.

As we see from Fig. 1 and Fig. 2 just for one year, the financial loss due to 1 % measurement error on large and small water pipe diameters exceeds the cost for different ultrasonic meters.

From the mentioned above findings we can conclude that buying a cheap and low quality flow meters you are not conserving water you are simply throwing your money out the window.

### Conclusion

Summarizing the above, we can say that the future of ultrasonic flow metering is seen in the further development and improvement of smart metering devices capable for diagnosing and preventing any unwanted factors from influencing the measuring process. Taking this into account, as well as the numerous obvious advantages of ultrasonic measurement technology including the high quality production, it is possible to predict the leading positions of these flow meters in any areas where accurate, stable and reliable measurements will save huge money and lead to real saving of water resources.

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УЛЬТРАЗВУКОВА ВИМІРЮВАЛЬНА ТЕХНОЛОГІЯ В АВТОМАТИЗОВАНОМУ КОНТРОЛІ ВОДНИХ РЕСУРСІВ

Контроль над водними ресурсами стає важливим стратегічним завданням. Тому державні органи ставлять перед агенціями, що займаються водними ресурсами, мету керувати запасами води та створювати правила її раціонального використання. Основним моментом контролю води є вимірювання. Існують три важливі аспекти вимірювань водних ресурсів: при видобутку води з природних надр, при споживанні та при передачі на зберігання. Контроль споживання води іноді базується не на вимірюваннях, а на попередній оцінці, наприклад, за допомогою відкачування.

Технологія ультразвукового вимірювання, як основа автоматизованого контролю ресурсів, має потенційну роль на цьому ринку. На відміну від механічних (турбінних) лічильників ультразвукові мають пріоритет, оскільки вони дають можливість реалізувати розумне вимірювання. На відміну від електромагнітних лічильників, які також вимірюють з високою точністю і реалізують розумні функції, ультразвукові лічильники набагато більше підходять для неочищеної води і стічних вод. Такі водні ресурси зазвичай погано контролюються, а це означає, що ніхто не знає їх точної ціни.

Вимірювання є обов'язковим для контролю вартості та для виставлення рахунків. Точність є важливим питанням, особливо коли ми говоримо про вимірювання в трубах великих діаметрів. Альтернативи ультразвуковим витратомірам практично немає. Ринок різноманітних приладів обліку рідин зосереджений на діаметрах до 400 мм. Для більших діаметрів використовуються тільки ультразвукові вимірювачі. У них багато каналів зондування потоку, складні алгоритми обробки даних. Таким чином, вони застосовні в дуже широкому діапазоні вимірювання.

У цій статті ми розглядаємо ультразвукові витратоміри час-імпульсного типу, щоб зрозуміти особливості їхньої теорії вимірювання з урахуванням усіх факторів, що впливають на їхню роботу. В статті описані похибки, властиві цим витратомірам під час вимірювань.

Оскільки точність має велике значення при розрахунках, оцінено та проаналізовано вартість 1 % похибки вимірювання споживання водних ресурсів для труб малих (DN50÷DN150 мм) і великих (DN200÷DN1200 мм) діаметрів. Показано та обговорено втрати від встановлення неякісних приладів обліку.

**Ключові слова:** водні ресурси; ультразвуковий витратомір; точність вимірювання; похибка.

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УЛЬТРАЗВУКОВАЯ ИЗМЕРИТЕЛЬНАЯ ТЕХНОЛОГИЯ В АВТОМАТИЗИРОВАННОМ КОНТРОЛЕ ВОДНЫХ РЕСУРСОВ

Контроль над водными ресурсами - важный стратегический вопрос. Основным моментом в контроле воды является измерение. Ультразвуковая измерительная технология может сыграть важную роль в рациональном потреблении воды. В отличие от механических счетчиков, ультразвуковые счетчики имеют приоритет, потому что они также дают возможность реализовать интеллектуальный автоматизированный учет. В отличие от электромагнитных счетчиков, которые также измеряют с высокой точностью и реализуют интеллектуальные функции, ультразвуковые счетчики гораздо больше подходят для неочищенной воды и сточных вод. Такие водные ресурсы обычно плохо контролируются, а это означает, что никто не знает их точной стоимости.

Измерение обязательно для контроля затрат и выставления счетов. Точность - важная проблема, особенно когда мы говорим об измерениях на трубах большого диаметра. Альтернативы ультразвуковым расходомерам в этом сегменте практически нет. Рынок разнообразных счетчиков сконцентрирован на диаметрах до 400 мм. Для больших диаметров используются только ультразвуковые расходомеры. Таким образом, они применимы в очень широком диапазоне расхода. Поскольку точность очень важна при биллинге, была оценена и проанализирована стоимость 1 % погрешности измерения потребления водных ресурсов для труб различного диаметра. Оценены также потери от установки некачественных приборов учета.

**Ключевые слова:** водные ресурсы; ультразвуковой расходомер; точность измерения; погрешность измерения.

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