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INTELLECTUAL SENSOR FOR MEASURING WATER CONSUMPTION IN LARGE PIPES

Cho'lliyev Ya'qubjon Ergashovich- PhD, "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University"

Ko'charov Farrux Jabbor o'g'li – PhD student, "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University"

Begmatov Murodjon Turg'un o'g'li – PhD student, "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University"

Abstract

This article is about the method of capacitive measurement of water consumption in pipes, in which the sensors measuring flow parameters depending on the capacity, pressure and electromagnetic field of the two-phase medium in the pipe are analyzed. Also, in the article, the method of measuring the electric capacity parameter of two-phase current is analyzed in more detail.

Keywords: *large pipe, electrode, electric driving force big pipe, Multisim, modele, two phases, bubble.*

Introduction. The sudden increase in the demand for water and energy resources in the world at the present time makes the development and implementation of a new generation of measurement and control systems, which are an important technical tool for ensuring their economy, one of the urgent tasks.

Currently, the water shortage is increasing in our country. This means we need to support every drop of water. At the same time, in developed countries, water management systems are used to measure and control water flow and water meters of various designs. Existing measurement and control systems have some shortcomings in energy saving.

A number of scientific research works aimed at improving the technical means of measuring and controlling water consumption are being carried out all over the world. However, insufficient attention has been paid to the development of a system for direct measurement and control of water consumption in the suction pipes of pumping stations. In this regard, one of the most important tasks is the development and implementation of intelligent sensors with expanded functionality for measuring and controlling water consumption based on physical and technical effects in pump units.

Flow rate is an important parameter in multiphase flow detection. Accurate speed calculation is the basis for ensuring production efficiency, providing management decisions and implementing advanced control. Currently, some classical tomographic methods are used to calculate flow velocity, such as ultrasound, microwave, and X-ray detection [1].

Measurement of key parameters such as concentration, velocity, mass flow rate and flow pattern are essential for industrial optimization processes[2].

Many methods have been published to measure the above flow parameters.

Various sensors have been developed to measure and monitor water consumption in the pipeline. These sensors allow measurement and control of parameters such as consumption in the pipe, air gap in the flow and the resulting capacity.

There are direct and indirect methods of measuring flow in pipelines, and these methods have their own advantages and disadvantages.

Today, reliable methods and devices for measuring pumped water flow for large pipe diameters have not yet been developed. The flow rate is calculated using indirect methods based on the passport characteristics of the pumps, which may not correspond to the design parameters due to the wear and tear of the pumps and electric motors over the years of operation, corrosion and erosion of the pipes and water supply facilities, etc.

The most important indicator of energy efficiency of pumping stations is the comparative indicators of energy consumption. Different pumps and pumping stations consume different amounts of electricity when delivering a certain flow of water (for example, 1000 m3). It depends on such factors as the brand of the pump and the electric motor and their service life, geometric pressure, pipe diameter and service life, the number of parallel or serial pumps on one line of the pressure pipeline, and the composition of the pump.

However, although modern electronic electricity consumption meters are installed in each pumping station to determine the numerator of the value [kW/h/thousand m3], there are still no direct methods and devices for determining the denominator of this value in pumping stations. Therefore, today, evaluating the performance of pumps and pumping stations by comparing the actual norm with the specific norm of electricity consumption cannot be considered objective due to the unreliability of the actual norm.

Ziqiang Cui, Kai Gao, and others proposed a new method of electromagnetic flux measurement, according to which the distribution of conductivity in multiphase currents is not uniform and affects the induced potential distributions. Therefore, application of the electromagnetic flux model to non-uniform/asymmetric conductance distributions will inevitably lead to errors in velocity profile calculations. The proposed method was studied taking into account the permeability distribution. However, electromagnetic induction uses a metal electrode that penetrates the wall of the pipe being measured to obtain a current signal. When measuring sticky and mixed substances, the electrode is easily contaminated, which affects the measurement results and shortens the service life[3].

Also, in many other sources, work was carried out on the method of measuring electromagnetic current. According to their research, in order to increase the accuracy of measurement and reduce disturbances, it was proposed to increase the number of induction signal receiving electrodes. This makes exploitation more complicated, as we mentioned above [4].

Electromagnetic tomography is based on Faraday's law of electromagnetic induction. In this method, the image field is stimulated by a changing magnetic field. When conducting or conducting materials are present in the imaging domain, the changing magnetic field creates eddy currents in the conducting materials and produces secondary fields or magnetic field fluctuations in the conducting materials due to the polarization of the magnetic dipoles[5].

Although contact methods can measure the detailed structure of two-phase flow, the effect on flow structure and parameters is large.

The electromagnetic flowmeter method is related to the measurement of the total resistance of the liquid and the monitoring of empty pipes with the electromagnetic flowmeter. In an electromagnetic flow meter, a pulsating magnetic current is generated in the measuring tube in a direction substantially perpendicular to the direction of the liquid flow.

This magnetic flux creates a potential difference (voltage) in the fluid that varies as a function of fluid flow. The potential difference is determined using two electrodes located in the pipe (Fig. 1). It is convenient to determine the total resistance of the liquid flowing through the measuring tube with a flow meter. This information can be used to determine the empty state of the pipe.

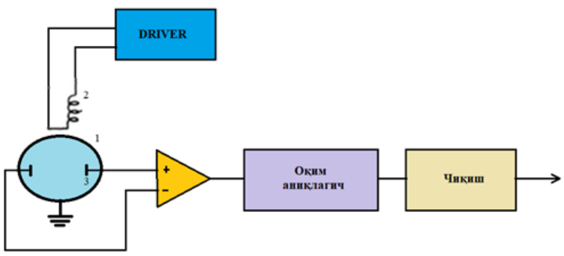


Figure 1. Electromagnetic flow meter. 1st pipe; 2nd crucible; 3-electrodes.

This detection method uses direct current flowing between the electrodes and soil and an additional empty tube detection circuit, but this method causes unwanted deposits on the electrodes, resulting in the need to replace them.

Mi Wang, Jiegui Liu et al. proposed a differential pressure sensor for obtaining combined ultrasound and flow data based on the fact that separation of each individual phase without precise flow measurement is important for academic research and industrial production in two-phase flow in a pipe. A combined multimodal ultrasonic and differential pressure sensor is proposed for simultaneous acquisition of flow data without separation. Liquid film fraction is measured with an ultrasonic thickness sensor, gas velocity is measured with an ultrasonic velocity sensor, and a new two-fluid model is established using multimodal ultrasound and differential pressure sensors.

The proposed dual measurement system requires the use of two types of sensors. This makes the system more expensive and more complicated to use[6].

All of the above methods are directly in contact with the liquids flowing in the pipeline, which complicates the operation, and also there is a demand to develop the design of the primary transducer for the water consumption measurement and control system, which does not have additional hydraulic resistance in the pipeline.

To meet these requirements, the method of capacitive measurement of two-phase liquid flow was used.

Research and analysis have shown that the determination of liquid flow in a pipe by capacitance is developed only for small diameter pipes.

Among mature scientists, Andrzej Krupa, Marcin Lackowski, and others have conducted many studies on the sensor for measuring the void fraction in two-phase flows. According to it, the current sensor is formed by two electrodes installed on the outer walls of a dielectric tube, through which a two-phase medium flows.

Materials and analysis. The capacity of the sensor depends on the geometric arrangement of the electrodes and the distribution of the electric field, which depends on the electrical conductivity of the medium around the electrodes and inside the pipe. For two-phase gas-liquid flow, the effective conductivity of the dielectric between the electrodes changes due to the change in the proportion of gas and liquid in the pipe (Fig. 2). In this paper, the change in sensor capacitance is numerically determined for a loop circuit. Capacitances were calculated by integration of the electric field distribution around two symmetrical electrodes in the form of cylinder sections using Gauss's law.

This form of electrodes was chosen because the sensitivity of this type of sensors is the highest and it is the most widely used in practice.

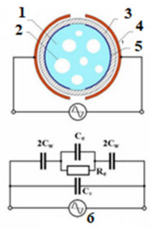


Figure 2. Equivalent circuit diagram of a capacitance sensor.

2Cw is the capacity of the pipeline walls, Cs is the capacity of the external environment, Ce is the capacity representing the capacity of two virtual electrodes on the inner pipe wall, depending on the complex distribution of liquid and free phases inside the pipeline, Re- resistance between the same two virtual electrodes[7].

Capacitance sensors are used to measure water consumption in large pipes using the physical property of the element that senses the water-air ratio inside the pipe. The construction scheme of the developed water consumption measurement and control sensor is presented in Fig. 3.

The ability to visualize multiphase flow interactions in real time has always been a highly desirable capability to better understand the complex dynamics between interacting phases in any flow system. Electrical capacitance tomography is an electrical detection method that easily meets the high-speed requirements of multiphase flow real-time imaging [8].

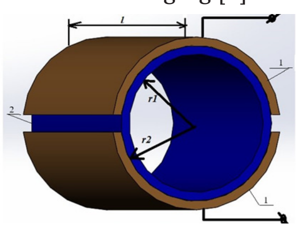


Figure 3. Construction scheme of the consumption measurement and control sensor, the empty state of the pipe

Phase interactions in a pipeline lead to geometrical distributions called flow regimes, which are particularly difficult to distinguish in real-time conditions.

The need to objectively identify these flow regimes is essential for accurate measurements of two-phase flow parameters, such as phase fractions, pressure drops, and phase flow velocities[9].

Today, relevant researches are mainly focused on speed distribution generalization and electromagnetic consumption measurement. In order to accurately determine the velocity distribution of the liquid along the cross-section of the large pipe, several electrodes and stirring rods are installed on the outer wall of the measuring pipe. Appropriate technology can be used in applications such as open channels, multiphase flow, and weakly conductive fluid measurement[6].

A capacitance sensor is an imprecise device used to measure the void fraction in two-phase currents. The potential sensor is formed by two electrodes installed on the outer walls of a dielectric tube, through which a two-phase medium flows.

The capacity of the sensor depends on the geometric arrangement of the electrodes and the distribution of the electric field, which depends on the electrical conductivity of the medium around the electrodes and inside the pipe. The electric capacity between a pair of electrode plates is defined as the ratio of the increase of the stored charge to the increase of the voltage difference between this pair of plates.

Changes in the conductivity distribution of the internal environment can be determined by measuring the external capacitance. This is achieved by electrical capacitance tomography[10].

Discussion. When using a capacity sensor, the conductivity of liquids should not be less than a certain standard. Liquids with electrical resistance p<106 om*m and dielectric permittivity ε <7 are considered electrically conductive. Dielectric permittivity is closely related to liquid density, but in this paper, liquid density is not considered relative to liquid concentration.

The electrodes are assumed to be surrounded by air with dielectric constant ε =1, and the two phases in the tube are water (ε =80) and air depending on the case being considered.

The main technical characteristics of a measuring system often depend on the correct modeling of its primary sensing element. Because the primary sensitive element is an element that provides information about the real state of the object of measurement and control.

If the following expression is valid in the measuring chain, then the given chain has an integrating property, and the larger the value of the time constant τ of the chain, the better the quality of the integrating property of the chain.

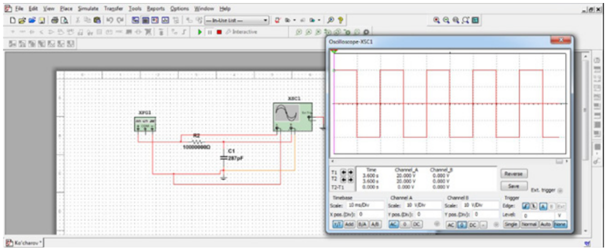
If the condition

$$U_{Ch}(t) \gg \frac{1}{RC}\int U_K(t)dt$$

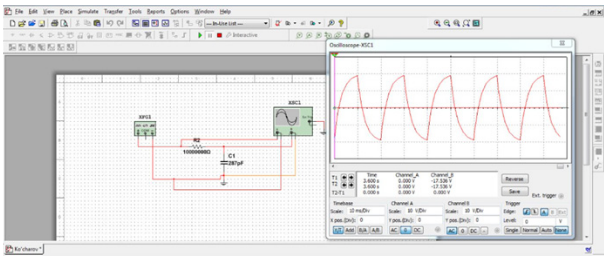
is valid, then

$$U_{Ch}(t) = \frac{1}{RC}\int U_K(t)dt$$

Package programs such as Multisim or MatLAB with high accuracy are now available to experimentally observe such properties of the measuring chain. In Figure 4 below, it is possible to observe the input and output signals of the sensor obtained in the package programs.



a)



b)

Figure 4. Input and output signals of the water consumption measurement sensor.

When τ has a large value, the sequence of pulses forms a constant voltage, and the integral of the constant is a linear function. Therefore, a sawtooth signal is generated at the output.

Conclusion. Electromagnetic and ultrasonic measuring sensors are currently the most common methods of determining flow in a pipe. The developed flow measurement method takes into account the air gap in the pipe.

Also, being a non-contact method, compared to contact methods, it is easy to operate and provides a long service life.

The method of measuring water consumption in a large pipe by capacity is simpler and more accurate. Changes in the conductivity distribution of the internal environment can be determined by measuring the external capacitance. This is achieved by electrical capacitance tomography[10].

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