# Hydrostatic method in an adapted device level control for on-farm channels

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**Abstract.** The operation of a hydrostatic water level control device is based on determining hydrostatic pressure readings when the height of the liquid column changes. A device for such measurements with differential sensors requires the installation of a surge vessel, which narrows the possibilities for using such sensors. Therefore, the task was set to get rid of the equalization vessel, which makes it possible to adapt this method to control the level in on-farm channels in the agricultural sector. The experimental studies carried out made it possible to establish the ability of the developed hydrostatic method and device to measure and generate the output electrical signal.

## 1 Introduction

As is known, in the territories of the agricultural complex there is an on-farm irrigation system (IOS). It performs the tasks of water transportation and targeted water consumption, taking into account the irrigation structure and areas of agricultural crops. At the same time, water treatment facilities are in dire need of automated technologies, control tools, converters, information and digital systems for their use in on-farm irrigation structures. A hydrostatic converter can serve as such a means of level control.

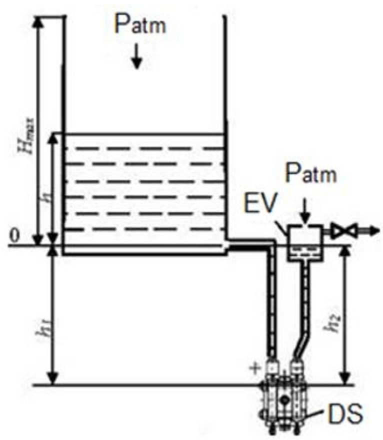


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**Fig. 1.** Level measurement with equalization vessel

Hydrostatic level control sensors have a simple design, low cost and reliable operation. The existing model range allows their use in any industry, including monitoring the water level in open irrigation canals. However, the methods and engineering solutions used for organizing measurements do not allow the use of hydrostatic devices more widely.

One of the reasons for their limited use is the need for an equalizing vessel in a device with differential pressure sensors. The reason for this is the location of the sensor under the measurement object. The level measurement diagram with an equalizing vessel for objects under atmospheric pressure is shown in Fig. 1. The equalizing vessel is used to compensate for the static pressure created by the liquid column h1 in the impulse tube.

That is, the main disadvantage of this measuring system is the need to locate the DS sensor below the measured level, namely below the bottom: irrigation canal, observation well, reservoir, etc. And this is impossible in real production. Or it is associated with significant unreasonable construction, technical, and material costs.

## 2 Methods

Thus, these studies were aimed at adapting hydrostatic measurement principles to the above conditions for controlling water levels in irrigation system facilities. In our case, the proposed solutions meant abandoning the surge vessel. The task is achieved in such a way that the sensor is located above the measured level and the hydrostatic principle is implemented on the basis of measuring the vacuum pressure caused by the weight of the liquid column.

The measuring system of a hydrostatic device for irrigation and drainage objects is illustrated by the drawing shown in Fig. 2.

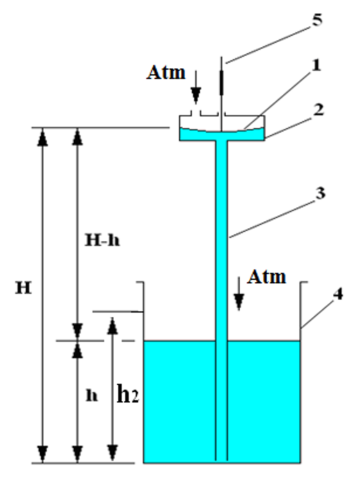


**Fig. 2.** Diagram of level measurement with a hydrostatic device without an equalizing vessel. 1- sensitive element membrane; 2 – differential pressure sensor; 3- measuring tube; 4 – object of measurement; 5- plunger of the inductive converter.

The essence of the recommended method is that a differential sensor 2, which has a sensitive element, a membrane 1, isolating the upper and lower chambers of the sensor from each other, is installed above the measured level of the object 4. (a tank is indicated as an object; in real production, this could be an on-farm channel).

The upper chamber communicates with the atmosphere, and the lower chamber and measuring tube 3 are filled with water and the latter is lowered below the measured level [1]. In this case, the influence of a column of liquid (water) in the measuring tube on the differential pressure meter membrane with a downward vector occurs and is achieved. That is, this method creates vacuum pressure and draws the sensitive membrane of the sensor down, rather than pressing on it with its weight from above, when the sensor is located below the liquid level measurement object, and the measuring system requires the installation of an equalizing vessel.

The general expression of this measurement system is:

$$P_{meas.} = P_{atm.} + \rho g H - \rho g h - P_{atm.} \tag{1}$$

or

$$P_{meas.} = \rho g (H - h) \tag{2}$$

where:
Pmeas – the value of the measured pressure;
Ratm – the value of atmospheric pressure;
$\rho$ – specific gravity of liquid (water);
g – free fall acceleration;
N – maximum possible measured level;
h – measured level;
(H – h) – height of the column causing vacuum pressure.

(In expressions 1 and 2, the difference in atmospheric influence at the membrane location mark and the level mark h is not indicated for the purpose of a fundamental explanation of the method).

Thus, the level h measured in the object, changing, changes the value of the water column (H – h) in the measuring tube in accordance with expressions (1 and 2), which sets the sensitive element of the differential sensor in motion [2]. This movement can be converted into the required electrical output signal using the plunger 5 for inductive transducers. If you use sensors with piezoresistive sensors, then the generation of the output signal can proceed similarly through the pressure of the filling liquid, which is transmitted to the measuring membrane.

It is known from hydraulic theory that the operation of hydrostatic level control devices is associated with determining hydrostatic pressure readings when the height of the liquid column changes. If we agree that an inductive (according to Fig. 2) converter with an output electrical signal of 1-0-1 V is used for this, then when it is connected to a voltmeter, the latter will record the electrical signal. which indicates the excitation of membrane 1 (Fig. 2.) The latter, as is known, is the result of the pressure difference in the sensor chambers [3]. If in the first it is equal to atmospheric (P1=Patm), then in the second it is determined by the weight of a water column of height H–h, i.e.

Taking into account that the vectors of both pressures have the same direction, the desired pressure acting on the membrane is expressed:

$$P = P_{ATM} + \rho g (H - h) \tag{3}$$

Where:
$\rho$ is the specific gravity of water;
$g$ is the acceleration of free fall.

If we take into account that pressure - **Patm** - acts on the sensor membrane and on the side of the lower chamber through the water column **H**, then the expression takes the form:

$$P = \rho g (H - h) \tag{4}$$

If the value of the level h increases to the value h2, then the pressure P should correspondingly decrease by the amount

$$\rho g(H-h) \text{ those } P=\rho gH-\rho gh_2 \quad (5)$$

or

$$P=\rho g(H-h_2) \quad (6)$$

Where:
H is the distance of the water column in the measuring part;
h - measured level.

Considering that the output signal of the sensor is the result of the desired pressure, we can write that

$$U=f[\rho g(H-h)] \quad (7)$$

Considering that the output signal of the sensor is the result of the desired pressure, we can write that

$$U=f(-h) \quad (8)$$

The minus sign is associated with an understanding of the effect of vacuum pressure on the membrane of the sensor and means for the measurement process that the static characteristic of the readings of the measuring voltmeter will have the opposite form. That is, an increase in the level in the measured object will lead to a decrease in the voltmeter readings.

Thus, the level, according to the developed principle, is determined through the weight pressure exerted by a column of water enclosed in the cavity of the measuring tube and the sensor chamber, between the membrane and the boundary of the measured level [4]. In this case, level fluctuations change the value of the desired pressure, which is converted by an inductive converter into voltage, and thereby determines the value of the sensor output signal.

Results and discussion. Based on the results of the study of the above method, laboratory tests were carried out. The experimental work was aimed at determining the static characteristics of the hydrostatic device.

In order to determine the nature of the dependence U=f(h), the static characteristic of the sensor was taken. The work was carried out on a real laboratory installation, created according to the scheme in Fig. 2. in the scientific laboratory of the Department of Automation and Technological Process Control of the National Research University TIIIMSH.

The results of the experiment are summarized in Table 1. Based on the obtained values, a static characteristic was constructed, which gives a linear dependence of the output signal on the level of Fig. 3. The figure shows a family of static characteristics, taking into account the explanations below regarding statistical testing. The measurement error was assessed by calculating the average, absolute error, standard deviation, and coefficient of variation v. To clarify the issue of the influence of temperature on the measurement process with a hydrostatic sensor, laboratory tests were carried out on it. Tests were carried out on the same laboratory model. Observations were carried out over 8 days, with h=23 cm (const). During this time the temperature air fluctuated randomly from 17 °C to 34 °C, while the level gauge readings remained stable.

**Table 1.** Results of the experiment

| $h_{cm}$ | Instrument readings U in V | | | $\overline{U}$ | $\lvert\Delta U\rvert$ | $\sigma$ | $v$ |
|---|---|---|---|---|---|---|---|
| | repetition | | | | | | |
| | 1 | 2 | 3 | | | | |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 0 | 0,805 | 0,800 | 0,800 | 0,802 | 0,002 | 0,005 | 6,846 |
| 10 | 0,700 | 0,700 | 0,705 | 0,702 | 0,002 | 0,004 | 2,965 |
| 20 | 0,615 | 0,605 | 0,600 | 0,607 | 0,005 | 0,005 | 2,415 |
| 30 | 0,505 | 0,500 | 0,500 | 0,502 | 0,002 | 0,002 | 0,732 |
| 40 | 0,415 | 0,400 | 0,400 | 0,405 | 0,006 | 0,002 | 0,621 |
| 50 | 0,305 | 0,300 | 0,305 | 0,303 | 0,002 | 0,002 | 0.631 |
| 60 | 0,200 | 0,205 | 0,205 | 0,203 | 0,002 | 0,004 | 0,881 |
| 70 | 0,115 | 0,100 | 0,100 | 0,105 | 0,006 | 0,004 | 0.760 |

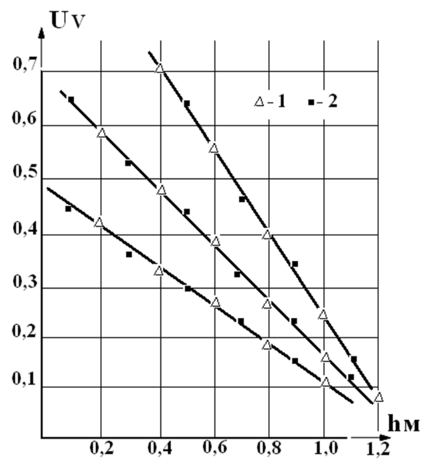


**Fig. 3.** Family of static characteristics of a hydrostatic device. 1 – control points; 2 – intermediate points.

Analysis of the experimental work carried out allowed us to establish that the temperature conditions of the hydrostatic sensor do not affect the measurement process [5]. The theoretical basis for this phenomenon is as follows.

As was established above, the sensitive element of the sensor-membrane is affected by weight pressure, determined by the value

$$P = \rho g H \tag{9}$$

If we assume that the value of H does not change, then the pressure will depend only on the specific gravity of water, because g=const [6]. As is known, the value responds to temperature changes, however, within the operating range, temperature changes do not exceed 50°. And the specific gravity of water practically does not change, which makes it possible to consider it a $\rho$ constant value.

$$\rho = \rho_0 (1 - \beta) \tag{10}$$

Where:

$\rho_0$ is the density of water at 0°C;

$\beta$ - temperature koefficient of expansion of water

$$\beta^{воды}_{(10^0 C - 40^0 C)} = (150 - 302) \cdot 10^{-6} \, {}^o C. \tag{11}$$

Thus, in the parentheses of the expression 10 is a value close to unity (0.999847 x), etc. temperature fluctuations in the system do not exceed those indicated, the product can be considered constant.

As for digital information converters, as it was established for a differential sensor, the output signals have unified parameters for voltage 0-1V and mutual inductance 0-10 mH. For this type of sensor, there is a wide range of secondary equipment in the instrumentation system.

Such devices include the multifunctional secondary device. It combines the functions of a multi-channel recorder, counter, computer and controller. Designed for a comprehensive solution to commercial metering problems using any type of flow, differential pressure, absolute and gauge pressure, and temperature sensors. Monitors the condition of equipment, the position of actuators, and automatically regulates specified parameters. Archives (stores in memory) accounting parameters. The controller provides the output of all information about the controlled object to the alphanumeric display of the front panel. It has the ability to simultaneously control parameters of various processes. Has a built-in RS232/RS485 interface.

The input signals of the recorder are universal, including from a hydrostatic level gauge with an inductive converter 0-1 V.

Mathematical channels allow you to calculate flow with correction based on signals from pressure sensors caused by hydrostatic pressure and temperature. The calculation formula is entered when configuring the device. Switching voltages and currents for active load 250 V AC or 30 V DC, 3 A; - for reactive load 250 V AC or 30 V DC, 1.5 A. Digital interfaces RS485 and RS232 via the open Modbus RTU data transfer protocol.

Application software can be integrated into top-level control systems via the RS485 bus using the open Modbus RTU protocol. It is possible to develop appropriate SCADA programs for use on the on-farm part of the irrigation system in order to create an automated system for monitoring the accounting of water resources, as well as integration into the process control system of the off-farm part of the irrigation system.

## 3 Conclusions

The conducted research allowed us to draw the following conclusions:

1. Establish that one of the reasons for the limited use of the hydrostatic principle of water level control with differential pressure sensors is the need for an equalizing vessel in the device. The reason for this is the location of the sensor under the measurement object.
2. Develop a method and an adapted device for its implementation when the task is achieved in such a way that the sensor is located above the measured level and the hydrostatic principle is implemented on the basis of measuring vacuum pressure, and not gravimetric pressure. And this leads to the abandonment of the equalizing vessel.
3. Establish the level measurement capability of the developed hydrostatic device. To experimentally establish the ability of the device to measure the level based on the hydrostatic principle in the range of level changes on on-farm canals from 0 to 0.7, keeping in mind a maximum range of 1.5 m.
4. Characterize the output parametric indicators of a differential sensor with an inductive converter in the form of an output voltage signal of 1-0-1 V, in the form of a mutual inductance signal of 10-0-10 mH, which ensures compatibility with digital information converters.
5. Recommend the secondary multi-channel recorder Metran-910 as a means of digital and information technology for managing and creating an automated control system for water resources accounting, as well as integration into the automated process control system of the off-farm part of the irrigation system.

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