



Device for Implementing the Method of Hydrodynamic Leveling

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Abstract: This article discusses a hydrodynamic leveling method and a device for its implementation, which proposes creating a stationary movement of the working fluid in the system due to the initial head in the surge tank. This head must provide the volume of working fluid necessary for a complete measurement process. The system is filled with a conventional conductive liquid, including tap water. This head is maintained by three solenoid valves. The control unit algorithm is designed so that the "start" command restores the fluid communication between the surge tank and the sensors. After the first half-set of measurements, the solenoid valves switch synchronously, and the working fluid flows from the sensors into an additional settling tank. This completes a full measurement set. To start the next cycle, the working (initial) head in the surge tank is restored using a micropump, which pumps the used fluid from the settling tank back into the surge tank through the solenoid valve system. This advancement eliminated the need for a bulky surge tank lifting mechanism, significantly reducing the overall weight of the device and facilitating its transportation.

Keywords: hydrodynamic leveling, liquid micropump, lifting mechanism, communicating vessels-sensors, surge tank, solenoid valves

INTRODUCTION

In the hydrodynamic leveling method, the comparison plane is the surface of a fluid moving uniformly within communicating vessels-sensors. In known hydrodynamic leveling systems, this process was implemented by uniformly raising a surge tank containing the working fluid using a complex lifting mechanism. This mechanism's dimensions and weight exceeded those of all other system equipment combined. In the developed device, it is proposed to replace this mechanism with solenoid valves ($\varnothing 10$ mm) operating synchronously with a liquid micropump.

The proposed device was developed based on the SHDL -10D hydrodynamic leveling system [4], which implements a relatively new method of hydrodynamic leveling. During the automation of hydrostatic leveling in the SHDL-10D [5], each vessel-sensor was equipped with a movable needle contact electrode to collect data on the fluid level position. This electrode was lowered until it made contact with the surface of the working fluid using a reversible micromotor with a complex kinematic scheme and a mechanism for transmitting fluid level data in each measurement cycle. The data acquisition and transmission mechanism separately included a rotating coded metal disk, an LED, a photodetector, and a circuit board. All these components were mounted on the sensor, making it bulky; it was referred to as a "measuring head."

In the hydrodynamic leveling method, instead of mechanically lowering the needle electrodes in each sensor (measuring head), it was proposed to uniformly and progressively raise the fluid level in the sensors until its surface contacted needle electrodes fixed stationarily in each vessel- sensor. Raising the fluid level in the system was achieved by uniformly lifting the surge tank. This allowed for the construction to be simplified and its cost reduced by a factor of "n," where "n" is the number of measuring heads in the system.

METHODS AND DEVICES

To broaden the application of hydrodynamic leveling for monitoring deformations and settlements of foundations, building bases, structures, and technological equipment, as well as for monitoring crustal points, further improvement of the device implementing this method is necessary. Specifically, the authors propose completely eliminating the bulky lifting mechanism and the surge tank with its complex kinematic scheme, as well as the data acquisition mechanism involving a rotating metal coded disk. Instead, it is proposed to replace the two conventional 10mm mechanical gas valves in the surge tank with solenoid valves that perform the same function according to a pre-programmed algorithm. Additionally, the proposed device includes a water micropump weighing 300g placed in a 0.5-liter vessel and an additional solenoid valve. In place of the legacy data acquisition mechanism – which included a rotating coded metal disk, an LED, a photodiode, and a circuit board – the authors propose using a high- precision timer capable of recording the moment of contact between the working fluid surface and the electrode tip with an accuracy of one-thousandth of a second.

A prototype of the proposed device has been assembled, the schematic diagram of which is presented in Figure 1. Figure 2 shows a view of the prototype^{1 212}.

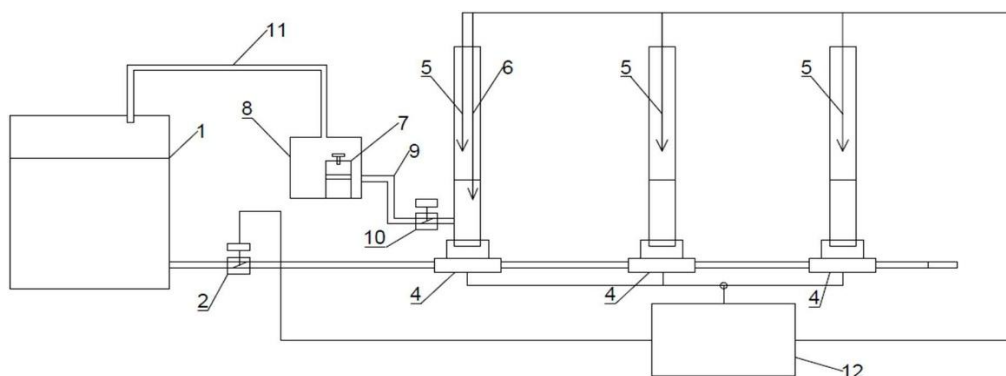


Fig. 1: Schematic electrical diagram of the device

The schematic diagram of the device (Fig. 1) shows a stationary surge tank 1 equipped with solenoid valves 2 and 3; communicating vessel-sensors 4 (the number of which corresponds to the number of monitored points), equipped with stationary contact electrodes 5 and one additional electrode 6 acting as a limit switch. The device additionally

¹ Movsesyan, R. A., Taplashvili, I. A., & Vardanyan, V. N. (1975). *Sposob gidrodinamicheskogo nivelirovaniya* [Method of hydrodynamic leveling]. USSR Author's Certificate No. 480906.

² GOST 24846-81. *Grunty. Metody izmereniya deformatsiy osnovaniy zdaniy i sooruzheniy* [Soils. Methods of measuring deformations of buildings and structures foundations]. Moscow, Standards Publishing House; 1986. 156p. (In Russ.)

includes a micropump 7 placed in a vessel 8. Vessel 8 is connected to the sensors via a pipe 9 equipped with a solenoid valve 10, and to the surge tank via a pipe 11. All contact electrodes, solenoid valves, and the electric micropump are electrically connected to the control and measurement registration unit (Surge tank) 12. The operating electrical circuit of the device is assembled using neutral and phase lines with a voltage of 12 volts. Power is supplied from the domestic electrical grid, with provision for autonomous power supply in field conditions from a battery [3,7].

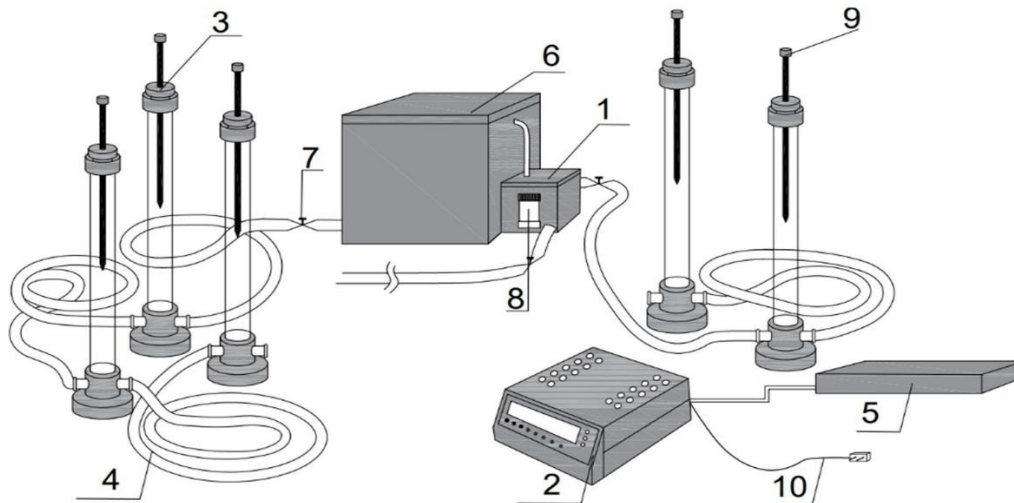


Fig. 2: General view of the prototype

1 - Vessel; 2 - Automated control and registration unit; 3 - Sensor; 4 - Connecting hose for working fluid communication; 5 - Radio modem for Internet connection; 6 - Surge tank; 7, 8 - Solenoid valves; 9 - Needle electrode; 10 - Connecting electrical cable.

Start and automatic measurement can be initiated not only by pressing the start button on the Surge tank but also remotely via the global Internet. This enables simultaneous control of several systems installed at different facilities, regardless of the distance between them. Measurement results from various sites can be collected and analyzed simultaneously, which is of great importance for specialists studying crustal deformations, seismologists, and others. The principle of the new device operation is as follows:

To raise the working fluid level in the communicating vessels 4, after pressing the start button, solenoid valve 3 opens. This valve is installed on the connecting hose between the surge tank and the first communicating vessel. At this stage, fluid flows from the pre-filled surge tank toward the sensors connected to it. Subsequently, as in the well-known prototype, the flow in the vessels enters a stationary regime after a certain interval, and once it contacts the electrodes, the readings for the first measurement cycle are recorded.

The second solenoid valve, as in the prototype, serves only to transform the sensor layout from a linear system to a ring system (i.e., open or closed-loop).

Upon completion of the first half-set (i.e., after the final fluid contact with any electrode), a corresponding signal is sent to valve 3, which closes. Valve 10 then opens automatically, and the fluid level in the sensor vessels drops, initiating the second measurement half-set until the final contact with the electrodes (for example, with electrode 6, which acts as the reference electrode in this case). During this process, the working fluid returns to vessel 8. Once the fluid detaches from the tip of the reference

electrode 6, valve 10 closes (with or without a specific delay determined during calibration), and the micropump 7 is synchronously activated. The pump transfers the used volume of working fluid from vessel 8 back to the surge tank 11. When vessel 8 is drained, the micropump 7 shuts off. This concludes the measurement cycle. The device then prepares for the next cycle according to the schedule embedded in the Surge tank algorithm or selected individually by the operator using the designated button [2,6].

RESULTS AND ANALYSIS

Based on this scheme, an electronic control unit (7x14x17 cm) was assembled, featuring a modern display and high-quality layout and housing design. It has passed tests in accordance with the technical specifications required by GOST standards and is suitable for small-series production. The manufactured prototype of the device underwent laboratory testing.

Prior to the tests, the device was calibrated. For this purpose, a calibration template was used in the form of a polished crystalline washer ($\varnothing 800$ mm) with a thickness known to high precision (0.001 mm), as confirmed by the manufacturer's certificate.

The results of the calibration and laboratory tests are presented in Table 1.

Table 1: Results of calibration and laboratory tests

Sensor	Measurement direction	Cycle I observation results 15.02.2024r.					Average
		I obs.	II obs.	III obs.	IV obs.	V obs.	
1	forward	135743	134923	137089	138527	134284	136113,2
	reverse	166849	167148	169046	165641	168657	167468,2
2	forward	205122	201742	202082	204249	203322	203303,4
	reverse	195656	196008	198160	196721	192854	195879,8
3	forward	115738	115596	115705	116318	116102	115891,8
	reverse	131417	129552	129642	131561	130543	130543,0
4	forward	98149	99057	99181	99639	98956	98996,4
	reverse	110551	109843	109667	111770	110215	110411,2
Results of Cycle II observations with the reference standard							
1	forward	112904	113347	111146	112543	112652	112518,4
	reverse	123686	124095	121995	122546	123154	123095,2
2	forward	133014	133332	130936	132153	134211	132729,2
	reverse	126739	126739	124343	125989	125599	125881,8
3	forward	123668	123446	124557	126496	123668	124833
	reverse	115379	143702	145749	148848	115379	146099
4	forward	105485	105384	106206	107599	105485	106396
	reverse	124265	124121	125210	125097	125423	125476

The difference between the first and second cycles corresponds to the thickness of the reference sample. To determine the linear unit corresponding to a single pulse, the thickness value of the reference sample (h) is divided by the arithmetic mean of the difference in pulses between the first and second cycles ($N_2 - N_1$). The value of a single pulse corresponding to the first reference sample is:

$$C_1 = \frac{h_1}{N_2 - N_1} = \frac{10,06 \text{ mm}}{138970,6} = 0,0000724 \text{ mm},$$

The value of a single pulse corresponding to the second reference sample.

$$C_2 = \frac{h_2}{N_2 - N_1} = \frac{25,65 \text{ mm}}{356837,2} = 0,0000718 \text{ mm},$$

The arithmetic mean error will be $C = \frac{0,0000724 + 0,0000718}{2} = 0,000072 \text{ mm}$

The scale value of 1 counting pulse (second) was determined as follows. A series of measurements was conducted, yielding stable results free from potential gross errors. Then, a calibration washer of known thickness was placed under one of the sensors, and a new series of measurements was performed.

While the readings of the other sensors remained stable, the counter readings of the sensor under test changed by a value corresponding to the thickness of the calibration washer [1]. This is calculated by simply dividing the thickness of the calibration washer (expressed in mm) by the difference in the number of pulses of the respective counter in the readings before and after the installation of the calibration washer³.

CONCLUSION

An analysis of the device's laboratory tests showed that the root-mean-square (RMS) measurement error decreased by 0.05 mm, amounting to 0.05 mm.

It is evident that the increase in measurement accuracy was facilitated by a tenfold reduction in the scale value of the counting pulse, from 0.02 mm and 0.01 mm down to 0.00044 mm.

The effects achieved in the development of this new device will significantly expand the scope and volume of practical applications for hydrodynamic leveling systems. This is due to a two-fold reduction in the total weight of the device, a more than two-fold decrease in power consumption, and a 30% reduction in manufacturing cost.

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