

Autoregulatory of water level with flexible working bodies for partition structures on channels

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Abstract. To improve the existing designs of hydraulic automatic gates with flexible working bodies for partition structures on channels, the object of the study was the development and study of an innovative design of an autoregulator of the water level with flexible working bodies. The study's main objective was to create a structure that provides automatic level control, discharge of excess water, washing of deposits in front of the partition, and determining its throughput. The developed design consists of a gate with flexible working bodies and a water level regulator combined with it. The article provides a theoretical formula for determining the flow rate of lateral water flows through the gate of the water level autoregulator. Experimental studies were carried out on an experimental installation by the method of physical modeling using the criterion of geometric similarity of the model and nature. As a result of these studies, simpler formulas were obtained for determining the flow rate of lateral water flows through the gate and a formula for determining the total flow rate of water passing through the gate of the water level autoregulator with flexible working bodies for use during operation.

1 Introduction

Modern trends and the scale of development of hydraulic engineering and land reclamation put forward the problem of effective water level management in the irrigation system, which can be achieved only by automating this process. Currently, much attention is paid to the issues of uninterrupted operation, continuous modernization of irrigation systems and other water management and hydraulic structures, the development and implementation of modern innovative and resource-saving technologies in the water sector, and improving the efficiency of the operation of structures on irrigation canals. To maintain the required water level in front of the partition structure and supply a given constant flow of water to the outlets of the channel for economical water consumption to consumers, the partition structures are automated. The massive use of gates on partition structures of irrigation systems and their remote location from power lines, from the point of view of economic efficiency, shows that their hydraulic automation is the most appropriate. This equips them

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with hydraulic automatic water level regulators operating entirely on renewable hydraulic energy of the water flow. They ensure economical use of water, saving electricity spent on their operation and reducing operating costs.

Currently, from those described in the works of Sh.S. Bobokhidze [1], Ya.V. Bochkarev [2, 3], A.M. Globa[4], P.I. Kovalenko [5], V.B. Kovshevatsky[6], I.B. Khamadov, M.V. Butyrin [7], E.E. Makovsky [8], N.A. Zakusilov [9], only some designs of hydraulic automatic gates have found application on partition structures of irrigation channels. They are made of traditional metal materials. Their peculiarity is the presence of metal gates (flat, segmental, valve, sector) of a certain design; they require the construction of capital structures. This, of course, is expensive and prevents their widespread introduction into production. Thanks to the rapid development of the chemical industry, flexible rubberized fabric has appeared today as a new type of building material. Their properties: low weight, flexibility, the ability to change shape when the load changes, and high maneuverability, create great prospects for their use as flexible organs in hydraulic water level regulators. Therefore, today there are combined flexible designs of hydraulic valves – automatic machines and auto regulators.

These constructions are shown in the works of V.I. Loginov, S.M. Rtischev, V.N. Kozыrev, M.V. Ilemenov, E.D. Mikhailova [10], I.A. Petrov [11], B.I.Sergeev, P.M. Stepanov, V.V. Shumakov [12], V.N. Shchedrin [13, 14], O.G. Zatvornitsky [15], M.-G.A. Kadirova[16, 17, 18, 19]. However, the main disadvantage of these structures is their inconvenient use in reconstructing existing partition structures and the lack of the possibility of flushing the channel section from alluvial deposits in front of the partition structure. The mass use of gates on partition hydraulic structures of irrigation systems naturally puts forward interest in finding simpler designs of such hydraulic automatic gates, the designs of which differ in the absence of metal consumption, ease, cheapness, maintainability, environmental cleanliness, and, if necessary, mobility, the ability to transfer them from one place to another place. Therefore, now there is an autoregulator of the water level with flexible working bodies, which is proposed for consideration here.

2 Methods

To eliminate the shortcomings of previously developed designs of automatic hydraulic water level regulators with flexible working bodies, we have set ourselves the task of developing an innovative design of a hydraulic level autoregulator with flexible working bodies, which provides flushing of possible deposits in the channel in front of it. And also, to ensure the stable operation of this hydraulic level autoregulator with flexible working bodies, justify the shapes of its elements, specify their parameters and dimensions, and find a theoretical formula for determining its throughput, taking into account side drains. And based on experimental studies of the model of the proposed design of a hydraulic level autoregulator with flexible working bodies, to propose simpler formulas for determining its throughput for use in practice.

Based on the existing designs of water-filled sector gates on the partition structures of irrigation network channels, we have developed an innovative design of a hydraulic water level autoregulator with flexible working bodies, Figure. 1.

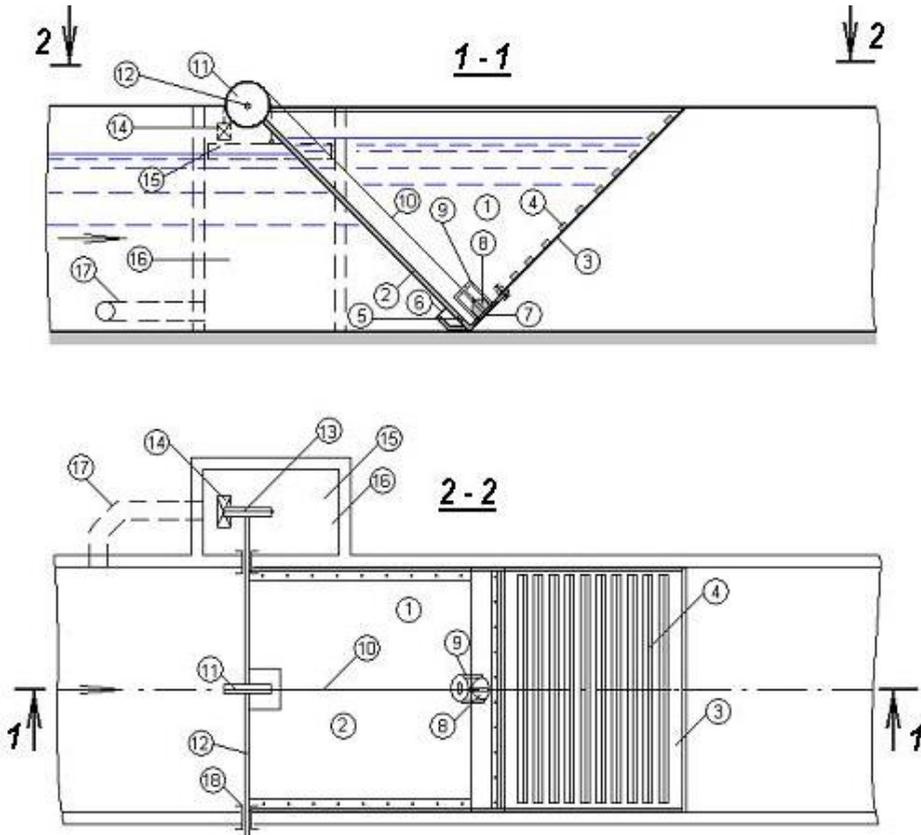


Fig. 1. Water level autoregulator with flexible working bodies: 1 is shutter capacity, 2 is rigid pressure part, 3 is soft rubberized meliorative fabric, 4 is rigid bar, 5 is entrance to the shutter capacity, 6 is visor, 7 is exit from the shutter capacity, 8 is ball valve, 9 is guides, 10 is cable, 11 is rigid block, 12 is axis of rotation of the water level regulator shutter, 13 is rigid block, 14 is counterweight, 15 is float, 16 is float chamber, 17 is pipe, 18 is hinge.

The hydraulic water level autoregulator design with flexible working bodies consists mainly of a water-filled reservoir-gate and a float water level regulator in front of the partition structure. The tank filled with water is a triangular prism in a closed position, one of the edges of which is lowered down. At the same time, the pressurized part of the shutter 2 is made rigid, and the side and non-pressure parts are made of soft rubberized reclamation fabric. To reduce the cost of the shutter, it is better to perform part of the shutter 2 in the form of a rigid flat frame covered with a soft rubberized meliorative cloth. When closed, the part of the shutter 2 forms an angle with the horizontal equal to 0.785 radians. To improve the hydraulic conditions for the passage of water flow from under the gate, pressure part 2 of the gate is equipped with a rigid visor 6 in its lower part. The capacity of the shutter has an inlet 5, the area of which is 4..6 times less than the area of outlet 7. This provides a condition for rapid emptying of the gate tank when the water level in front of the partition structure rises above the set one. The capacity of the gate 1 is filled through a permanently open inlet 5 and emptied through an outlet 7 equipped with a ball valve 8. This valve 8 is connected using the cable 10 to a rigid block 11 installed in the middle of the axis of rotation of the shutter 12. The movement of the valve is limited by guides 9, which allows it to move in the direction of closing and opening the outlet from the container of the

gate of the water level autoregulator. At one end of the shutter rotation axis, there is the block 13 rigidly connected to the shutter rotation axis. On one block side, a float 15 is suspended on a cable and lowered into the float chamber; on the other side, a counterweight 14 is suspended from the block. The float chamber's capacity to ensure the same water level in it as in the channel in front of the partition structure is communicated by a pipe 17 with a part of the channel in front of the installation site of the partition structure.

Regulation of the water level in the channel section in front of the partition structure is carried out as follows. In the absence of water in the channel, the flap is lowered by its own weight, and the float is lowered, the exhaust valve closes the outlet, and the release of water from the reservoir of the flap does not occur. When the water enters the channel, the water enters the shutter tank through the inlet of the shutter tank, and the shutter is lowered by its own weight and the weight of the water in the shutter tank. When the water level in the channel section in front of the partition rise above the set level, the float rises with the water level. Under the action of the weight of the counterweight, the shutter axis rotates, the rigidly attached block rotates with it, and the valve cable connected to it is partially wound onto the block. In this case, the valve rises, opening the exit from the container of the gate of the autoregulator. After that, the capacity of the shutter begins to empty, and its weight decreases. The pressure part and, consequently, the entire gate are raised, increasing the water flow from under the gate. At the same time, the non-pressure and side parts of the autoregulator shutter, made of soft rubberized meliorative fabric, are neatly folded, thanks to the slats located on the inside of the non-pressure part the autoregulator shutter, providing water drainage from under the autoregulator shutter. As a result, the water level in the canal section in front of the partition structure decreases. When the water level in the channel section decreases in front of the design of the water level autoregulator, the float is lowered. The valve closes the outlet. The shutter capacity is filled with water through the constantly open inlet, its weight increases, and the shutter is lowered, raising the water level in the channel in front of the partition structure.

Further, the water level in the channel section in front of the partition structure rises above the set one, and the process is repeated until the set water level is set in the channel section in front of the partition structure. The flow capacity of the shutter of the water level autoregulator consists of the outflow of water flow from under the lower part of the shutter and the outflow of water flow through the side slits of the pressure part of the shutter. The passage of the water flow from under the shutter of the proposed autoregulator of the water level can be considered as the passage of the water flow from under the pressure part of the shutter, forming in the closed state the maximum angle $\theta_{max} = 0.785$ radians with the horizontal. During the operation of the shutter, the angle of inclination of the pressure part of the shutter [tetta] can vary from 0.785 radians to 6 radians.

The flow rate from under the inclined shield part of the gate at an angle [tetta] to the horizon is determined by the well-known formula described in the work of P.G. Kiselev, A.D. Altshul, N.B.Danilchenko, A.A.Kasparson, G.I. Krivchenko, N.N. Pashkov, S.M. Slisky [20].

$$Q_1 = \mu a b_p \sqrt{2g(H - \varepsilon a)} \quad (1)$$

where Q_1 is the water flow rate from under the shutter of the water level autoregulator in the absence of lateral outlets of the water flow, H is the depth of the water flow in front of the shutter of the water level autoregulator, b_p is the width of the shutter opening of the water level autoregulator, a is the opening height of the shutter of the water level autoregulator, g is the acceleration of gravity, ε is the coefficient of vertical compression of the water flow passing under the gate of the water level autoregulator, $\varepsilon = f(a/H, \theta)$.

The output of the water flow through the side gaps of the gate of the autoregulator can be determined theoretically. The scheme of the lateral gap between the clamping surface of the shutter of the autoregulator and the wall of the partition structure is shown in Figure 2.

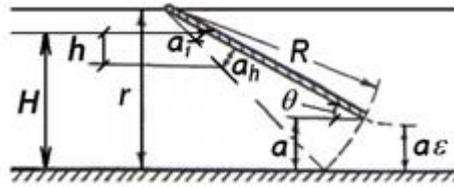


Fig. 2. Diagram of the lateral gap between the clamping surface of the shutter of the autoregulator and the wall of the partition structure.

Figures 2, the following designations are adopted: H is the depth of filling the channel section with water in front of the shutter, r is the height of the center of rotation of the shutter relative to the bottom of the partition, R is the radius of rotation of the shutter, h is the depth of water in an arbitrary area, a_1 is the lateral gap at the water level in front of the partition when the shutter is opened, a_h is an arbitrary value of the lateral the gap when opening the shutter. The elementary water flow through the side gap between the gate and the side wall of the partition, based on the design scheme in Figure. 2, can be represented as

$$dQ_2 = u b_b d\omega \tag{2}$$

where u is the velocity of water flow through the side gap, ω is the elementary area of the side gap, b_b is the width of the side gap.

When inserting the values of the velocity u and the elementary area of the lateral gap ω from the calculation scheme in Figure. 2 into formula (2), the following expression is obtained:

$$dQ_2 = d\omega \varepsilon \phi b_b \sqrt{2gh} \tag{3}$$

Based on the calculation scheme in Figure 2, a formula for determining the elementary area of the side gap is obtained:

$$d\omega = \sqrt{2} / 2 \sin(\pi / 4 - \theta) / \sin \theta [(c + h)^2 - c^2] dh \tag{4}$$

where c is a constant value, $c = r - H$.

When inserting the $d\omega$ value from formula (4) into formula (3), the following expression is obtained:

$$dQ_2 = \varepsilon \phi b_b \sqrt{2gh} \sqrt{2} / 2 \sin(\pi / 4 - \theta) / \sin \theta [(c + h)^2 - c^2] dh \tag{5}$$

Integrating the right and left sides of equation (5) gives the form (6)

$$\int_0^{Q_2} dQ_2 = \int_0^H \varepsilon \phi b_b \sqrt{g} \sin(\pi / 4 - \theta) / \sin \theta \sqrt{h} [(c + h)^2 - c^2] dh \tag{6}$$

As a result of the integration of expression (6), the total water flow through one side gap of the gate of the autoregulator of the water level is equal to

$$Q_2 = 2\varepsilon\varphi b_b \sqrt{g} \sin(\pi/4 - \theta) / \sin \theta H^{5/2} (2c/5 + H/7) \quad (7)$$

The total flow rate with a free flow of water through the gate of the water level autoregulator will be equal to

$$Q = Q_1 + 2Q_2 \quad (8)$$

$$Q = \mu\alpha b_p \sqrt{2g(H - \varepsilon\alpha)} + 4\varepsilon\varphi b_b \sqrt{g} \sin(\pi/4 - \theta) / \sin \theta H^{5/2} (2c/5 + H/7) \quad (9)$$

To find out the correctness of the theoretical formulas for determining the throughput of the proposed design of a water level autoregulator with flexible working bodies, experimental studies were conducted. The study was carried out by the method of physical modeling using the criterion of geometric similarity of the model and nature at Reynolds numbers $Re = 7145...56202 > Re_{kr}=300$, which corresponds to the area of quadratic resistance for open channels [20] and Froude numbers $Fr = 0.51...10.5$.

Modeling of the studied phenomena was carried out according to the criteria of gravitational similarity of Froude, dynamic similarity of forces, similarity criterion of dynamic processes under the action of elastic forces (Cauchy criterion) described in the works of P.G. Kiselev, A.D. Altshul, N.B.Danilchenko, A.A.Kasparson, G.I. Krivchenko, N.N. Pashkov, S.M. Slissky [20] and V.A. Prokofiev, G.A. Sudolsky [21]. Modeling of elastic material was carried out according to the maximum linear tension according to the recommendations of A.P.Nazarov [22, 23].

The scale of the models about nature was adopted 1:4.

3 Results and Discussion

The experimental setup, Figure 3, consisted of a rectangular section tray with a bottom width of 0.5 m, a length of 12 m, and a height of 0.5...1 m. The maximum flow rate of water supplied to the train was 0.0561 m³/s. The tray had a closed water supply system, which was supplied with a pump.

Two models were used to study the throughput: one model of a water-retaining gate of an autoregulator of the water level with flexible working bodies for a partition structure, shown in Figure 1, and one model made in the form of a board, shown in Figure. 4.

The model shown in Figure. 4 was studied to determine water flow rate when exiting from under an inclined flat board in the absence of lateral flows. This model consisted of a pressure part of a flap in the form of a board having a width of 0.5 m and a length equal to 0.71 m, installed in the tray of an experimental installation with fixed angles θ between the board line and the horizontal.

The model shown in Figure 4 was made at fixed angles: $\theta = 0.105$ radians; 0.174 radians; 0.262 radians; 0.349 radians; 0.436 radians; 0.523 radians; 0.611 radians; 0.698 radians. The interval of change of the fixed angle was taken in the range from $\theta = 0.070$ radians to $\theta = 0.087$ radians to account for the disorder of points when constructing the dependence $\mu = f(a/H)$. The flow rate of water passing through the tray was measured using a Chipoletti measuring spillway. The water level was measured using a Spitz scale. The angle of inclination of the flat board was rigidly fixed in the side walls of the tray of

the experimental installation. It was measured by a protractor. The flow coefficient μ was determined by the well-known formula (1) for the outflow from the holes (10).

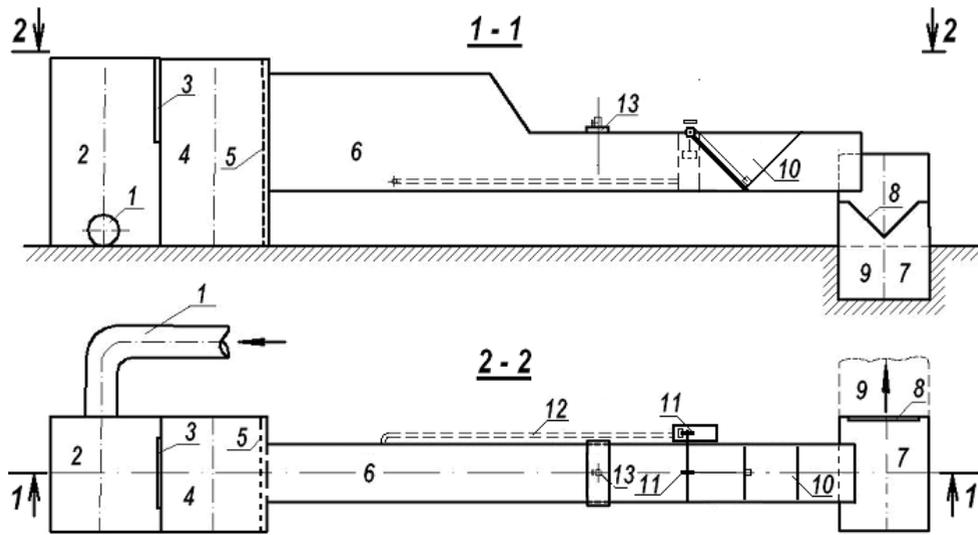


Fig. 3. Experimental setup. 1 is a pipe supplying water from the pump, 2, 4, 7 are tank for extinguishing the energy of the water flow, 3 is dimensional triangular spillway with a thin wall, 5 is a water flow energy extinguisher in the form of a grid, 6 is a tray, 8 is dimensional triangular spillway with a thin wall, 9 is spillway trench, 10 is the model under study, 11 is float level gauge, 12 is pipe communicating float level gauge with a section of the tray in front of the model, 13 is movable shelf with a scale mounted on it.

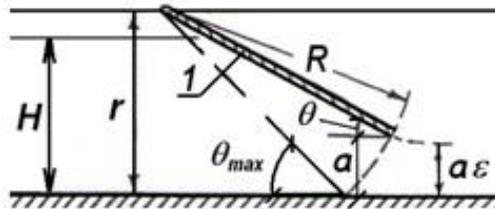


Fig. 4. A model for studying the flow of water from under the pressure part of the gate without lateral outflows, made in the form of a board. 1 is board.

The vertical compression coefficient was determined as $\varepsilon = f(a/H, \theta)$ according to the graph in Figure 5, constructed according to the data of N.E. Zhukovsky, presented in the form of a table in the work of P.G. Kiselyov, A.D. Altshul, N.B.Danilchenko, A.A.Kasparson, G.I. Krivchenko, N.N. Pashkov, S.M. Slisky [20].

From this graph it can be seen that in the range of variation $a/H = 0.2...0.75$, the flow coefficient μ , depending on the angle of inclination of the flat board to the horizon, varies within the following at $\theta = 0.105$ radians, $\mu = 0.923...0.920$; at $\theta = 0.174$ radians, $\mu = 0.903...0.891$; at $\theta = 0.262$ radians, $\mu = 0.864...0.868$; at $\theta = 0.349$ radians, $\mu = 0.833...0.840$; at $\theta = 0.436$ radians, $\mu = 0.811...0.817$; at $\theta = 0.523$ radians, $\mu = 0.787...0.795$; at $\theta = 0.611$ radians, $\mu = 0.763...0.780$; at $\theta = 0.698$ radians, $\mu = 0.744...0.761$.

The coefficient of water flow rate μ from under the gate of the water level autoregulator in the absence of lateral flow outlets was determined from formula (1) as

$$\mu = Q_1 / [a b_p \sqrt{2g(H - \varepsilon a)}] \quad (10)$$

where Q_1 is the water flow rate from under the shutter of the water level autoregulator in the absence of lateral outlets of the water flow, H is the depth of the water flow in front of the shutter of the water level autoregulator, b_p is the width of the shutter opening of the water level autoregulator, a is the opening height of the shutter of the water level autoregulator, g is the acceleration of gravity, ε is the vertical compression coefficient the flow of water when it flows out from under the shutter of the autoregulator of the water level, shown in the graph in Figure 5.

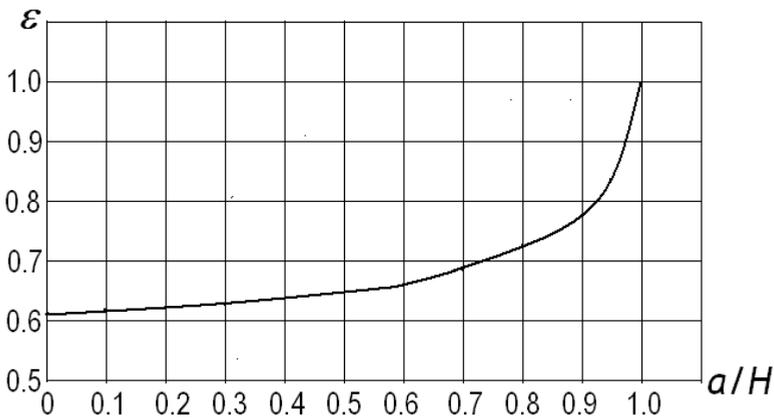


Fig. 5. Graph of the dependence $\varepsilon = f(a/H, \theta)$ for determining the vertical compression coefficient ε , when the water flow flows out from under the flat board at a fixed angle of inclination of the board θ to the horizon (in the absence of lateral flows through the flat board), a is the height of the hole under the flat board, H is the water pressure above the horizontal passing through the mark of the lower part of the partition.

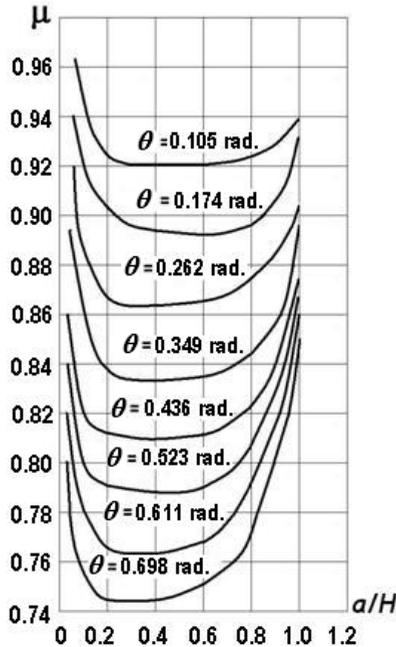


Fig. 6. Graphs of the dependence of $\mu = f(\theta, a/H)$ when flowing out from under a flat board at a fixed angle of inclination of the board (in the absence of lateral outflows).

The model of the water level autoregulator shown in Figure 1 consisted of a pressure part of the shutter in the form of a board had a width of 0.494 m, and a length equal to 0.71 m, the side gaps of the shutter were 0.003 m on each side. The diameter of the inlet hole in the shutter tank of the autoregulator of the water level was assumed to be 0.025 m and the outlet hole 0.05 m. The diameter of the ball valve was adopted at 0.06 m.

The capacity of the device for fixing the water level of the autoregulator of the water level was communicated with the capacity of the tray in the area in front of the shutter of the model of the autoregulator of the water level using a pipe with a diameter of 0.04 m, the entrance to which was located at a distance of 1.5 m in the tray to the location of the shutter of the model of the autoregulator of the water level. The float of the device for fixing the water level was made of foam. The float chamber had a rectangular shape, its width was 0.08 m, and its length was 0.10 m. The depth of the float chamber was 0.5 m. The following dimensions were: The float had the following dimensions: 0.075 m wide, 0.095 m long, and 0.06 m thick.

The main part of all experiments was carried out with a sequential increase in water flow rate. All parameters were measured after 15 minutes...20 minutes after changing the water flow rate. At this time, the tray was set to a constant water flow rate.

To determine the flow rate of the side outlets when examining the shutter of the water level autoregulator with flexible working bodies, the model shown in Figure 1 was studied. In the study, the total flow passing through the tray was measured by a Chipoletti spillway, flow rates up to 0.0561 m³/s were passed through the tray, and the initial state was assumed when there was no water flow rate during transit. The flow rate passing through the gate of the autoregulator of the water level, taking into account the side outlet, was determined by the Chipoletti spillway.

The water flow rate of the lateral exhalations of the shutter of the automatic water level regulator was determined as

$$Q_2 = Q - Q_1 \tag{11}$$

where Q is the total flow rate of water passing through the tray, Q_1 is the flow rate of water passing from the gate of the water level autoregulator.

Where Q is the total flow rate of water passing through the tray, Q_1 is the flow rate of water passing from the gate of the water level autoregulator.

Based on the data of the conducted studies, graphs $Q_1 / (Q_1 + Q_2) = f(a/H)$ were constructed in Figure 7.

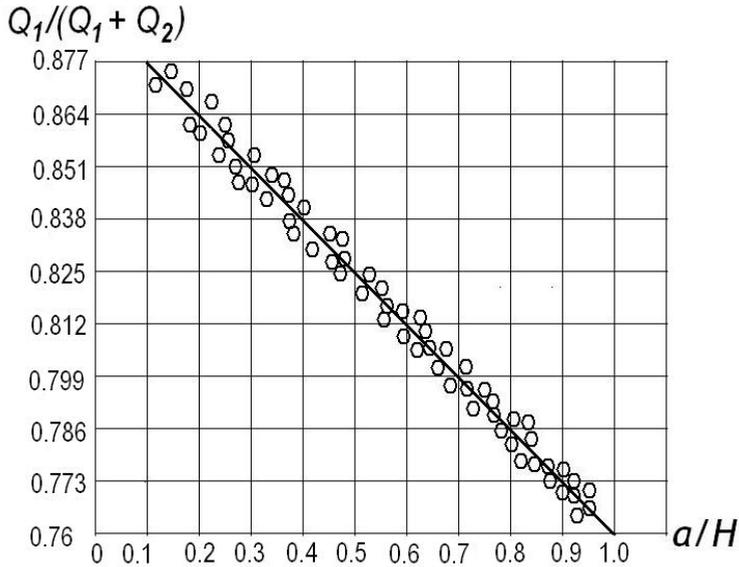


Fig.7. Dependency graph $Q_1 / (Q_1 + Q_2) = f(a/H)$.

By mathematical processing of experimental studies by the finite difference method at $0.1 < a/H < 0.85$, the following dependencies are obtained, taking into account lateral exhalations:

$$Q_1 / (Q_1 + Q_2) = 0.89 - 0.13a / H \tag{12}$$

From formula (12) can be obtained by algebraic transformations

$$Q_2 = [(0.11 + 0.13a / H) / (0.89 - 0.13a / H)] Q_1 \tag{13}$$

where Q_2 is the flow rate of the lateral releases of the shutter of the automatic water level regulator, Q_1 is the flow rate from under the shutter of the automatic water level regulator without lateral exhalations.

Based on (12), the total flow through the gate of the autoregulator of the water level will be

$$Q_1 + Q_2 = Q_1 / (0.89 - 0.13a / H) \tag{14}$$

4 Conclusion

1. The document provides a theoretical formula for determining the flow of water passing through the side gaps of the proposed gate of the water level autoregulator with flexible working bodies (7) and provides a formula for determining the total flow of water passing through the gate of the water level autoregulator with flexible working bodies, taking into account lateral outflows (9), which is consistent with the data experimental studies shown in work with an accuracy of $\pm 5...6$ percent.

2. Experimental studies conducted by the author have shown:

- 1) When the water flow passes from under the gate of the water level autoregulator with flexible working bodies in the absence of lateral outflows of water, the water flow tends to increase with a decrease in the angle between the pressure side of the water-containing gate of the water level autoregulator and the horizontal, which is explained by an increase in the height of the culvert.
- 2) With an increase in the ratio $a/H = 0.1...0.85$, the flow rate of the water flow passing with the expiration from under the flap of the autoregulator of the water level increases.
- 3) At $0.1 < a/H < 0.85$, the ratio of the water flow coming from under the automatic water level regulator flap to the total water flow, taking into account the water flow through the side gaps of the automatic water level regulator flap, obeys a linear relationship (12), and the water flow through the side gaps of the flap can be determined by the formula (13).

3. Based on the features of partition structures, to eliminate the shortcomings of previously developed designs of automatic gates and hydraulic water level regulators with flexible working bodies, the paper presents an innovative design of an autoregulator of the water level with flexible working bodies for partition structures of the irrigation network, including for equipping existing partitions of the structure, which do not require high costs during reconstruction.

4. The proposed design of the water level autoregulator with flexible working bodies effectively uses water resources, works entirely on the energy of a moving water flow, provides acceptable (within ± 5 cm) accuracy of water level regulation, does not require electricity, is economically advantageous, has a low cost, 5-7 times cheaper than traditional designs of automatic gates made of metal, non-metal-intensive, maintainable, easy to manufacture, can be manufactured and repaired by operating organizations, are an environmentally friendly design, do not pollute the environment, does not require much labor during installation and operation, it is recommended as an autoregulator on the partition structures of irrigation system channels.

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