Automatic partition structure for trapezoidal channels

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Abstract. Based on the analysis of existing and proposed designs of automatic gate structures, as well as the design of an automatic water level regulator on the canal developed earlier with F.A.Kadirov, a design of a mobile automatic partition structure in the form of an automatic shutter for channels of a trapezoidal section of irrigation systems was developed. And also, based on model studies conducted by the author, the flow coefficient is determined, and a formula for determining the throughput of this design is given. This design is made in the form of a gate, which is a container formed by a rigid bottom, pressure, and spillway parts of the flexible rubberized meliorative fabric, passing into flexible side elements. The level control in front of the partition structure is carried out with the help of a level controller. This partition structure does not require large expenditures; it can be portable or stationary, it is not metal-intensive, lightweight, transportable, combines the functions of stabilizing the required water level in the channel, dumping excess water, fin, and debris, and provides the necessary water inflow into the discharge channels.

1 Introduction

The current state of development of hydraulic engineering and land meliorative poses 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 the channel in front of the partition structure and supply a given constant volume of water to the outlet channels for economical water consumption by consumers, automation of partition structures on the channels is carried out. Based on the features of existing partition structures, the mass use of gates on the partition structures of irrigation systems, and their remote location from power lines, among them, from the point of view of economic efficiency, hydraulic automation of them is most appropriate, that is, equipping them with automatic hydraulic gates, hydraulic level auto 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

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costs. Currently, only some designs of automatic hydraulic gates 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], E.E. Makovsky [7], I.B. Khamadov, M.V. Butyrin [8] are used on partition structures of irrigation canals. They are made of traditional metal materials. A special feature of them is a metal gate (flat, segmental, valve, sector) of a certain design, the requirement for them to have significant water level drops, to prevent water overflow through the upper part of the gate, the requirement for periodic mechanical cleaning of the space in front of the gate from floating bodies and debris, the need for a rectangular capital structure. This, of course, is expensive and prevents their widespread introduction into production. The creation of flexible rubberized fabrics as a new type of building material with low weight, flexibility, the ability to change shape with 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 automatic water level regulators, as well as the design of the hydraulic autoregulator of the water level on the channel with flexible working elements, developed by us together with F.A.Kadirov [9]. These constructions are shown in the works of O.G. Zatvornitsky [10], B.I.Sergeev, P.M. Stepanov, V.V. Shumakov [11], I.A. Petrov [12], V.N. Shchedrin [13], [14], V.I.Loginov, S.M.Rtishchev, V.N.Kozyrev, M.V.Ilemenov, E.D.Mikhaylova[15]. However, the main disadvantage of the widespread use of these structures on trapezoidal channels is the inconvenient trapezoidal section of the channel for installing the automatic shutter and the need for periodic mechanical cleaning of this section from floating bodies and debris in front of the automatic shutter. Therefore, implementing all these structures on the channels of irrigation systems of the trapezoidal section is difficult.

   And today, there is interest in finding simpler designs of such hydraulic valves and automatic level regulators for channels of the trapezoidal section of the irrigation system, 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 place to place.

2 Methods

Based on the analysis of existing and proposed designs of automatic valves for irrigation system channels, we have set ourselves the goal of developing an automatic partition design for irrigation system channels of trapezoidal cross-section, operating entirely due to the hydraulic energy of the water flow, automatically regulating the water level along the length of the channel to the installation site of this design, ensuring the passage of floating bodies and debris. At the same time, this design should be non-metal-intensive, lightweight, and, if necessary, portable, mobile. And also determine its throughput. Based on this goal, we have set ourselves the following tasks. 1) Selection of the original analog design. 2) Based on the initial design, the development of a new modified design of an automatic partition structure, which is an autoregulator of the water level with flexible working bodies for channels of the irrigation network of trapezoidal section. 3) Choosing the model's scale and determining the model's dimensions by the method of physical modeling of the model in kind, 4) Performing an experimental setup and a model of the developed design. 5) Conducting trial model studies on the operability of the structure. 6) Conducting model studies on an experimental installation to determine the structure's capacity. 7) Processing the results of experimental studies of the model's throughput and, on this basis, determining the flow coefficient to determine the model's throughput.

   The design of the automatic partition structure in the form of an autoregulator of the water level (Figure. 1 and Figure. 2) is made in the form of a gate, the capacity 1 of which is formed by the bottom 2, made in the form of the bottom of a trapezoidal channel, part 3,

which is under pressure, and part 4, which is the spillway part. Parts 3 and 4 are made of flexible rubberized meliorative fabric.
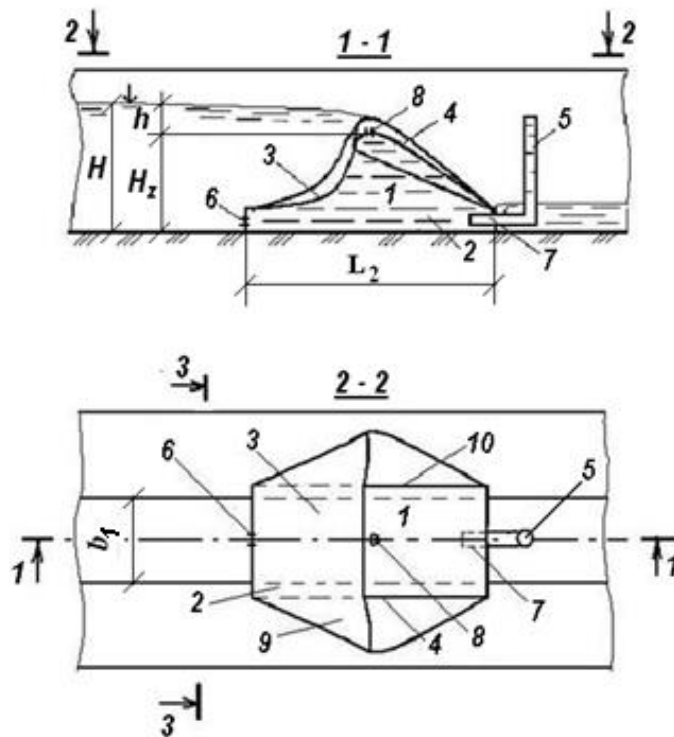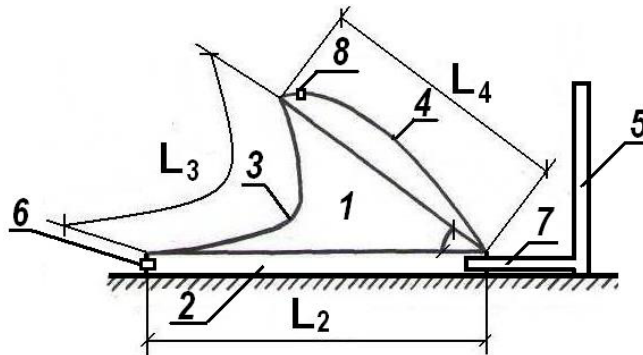

Fig. 1. Design of an automatic partition for trapezoidal channels: 1 is the capacity of the water–retaining gate, 2 is the bottom of the gate, 3 is the pressure part of the water-retaining gate, made of rubberized meliorative fabric, 4 is the spillway part of the water-retaining gate, made in the form of a rigid frame in the form of a non-vacuum profile, covered with rubberized meliorative fabric, 5 is water level regulator, made in the form of an open-topped pipe, 6 is inlet pipe, 7 is outlet pipe, 8 is air outlet, 9 is flexible side elements of the water-retaining gate, 10 is non-vacuum profile of the spillway part of the water-retaining gate.
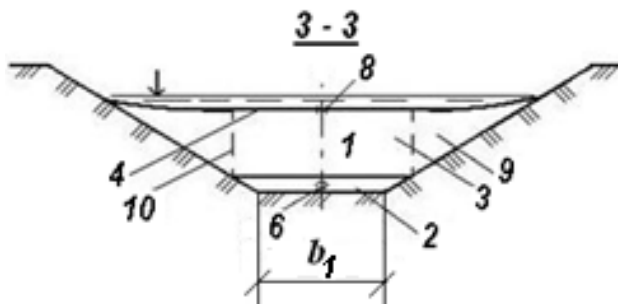
Fig. 2. View of the design of the automatic partition for trapezoidal channels in section 3 - 3, shown in Figure 1: 1 is the capacity of the water–retaining gate, 2 is the bottom of the gate, 3 is the pressure part of the water-retaining gate, made of rubberized meliorative fabric, 4 is the spillway part of the water-retaining gate, made in the form of a rigid frame in the form of a non-vacuum profile, covered with rubberized meliorative fabric, 5 is water level regulator, made in the form of an open-topped

pipe, 6 is inlet pipe, 7 is outlet pipe, 8 is air outlet, 9 is flexible side elements of the water-retaining gate, 10 is non-vacuum profile of the spillway part of the water-retaining gate.

Fig. 3. Structural elements of an automatic partition in longitudinal section for trapezoidal channels: 1 is the water-filled tank of the water-retaining gate, 2 is the bottom of the gate, L_2 in length, 3 is the pressure part of the water-retaining gate, L_3 in length, made of rubberized meliorative fabric, 4 is the rigid spillway part of the water-retaining gate, L_4 in length, made in longitudinal section in the form of a non-vacuum profile frame covered with rubberized meliorative fabric, 5 is the regulator water level, made in the form of a pipe with an open top, 6 is inlet pipe, 7 is outlet pipe, 8 is air outlet pipe. (The side elements of the water-retaining gate are not shown in the figure).

The position of the auto regulator and its filling and emptying are adjusted automatically using the level 5 regulator. At the same time, the upper part of the level 5 regulator tube is installed at the mark set by the water depth in the channel in front of the automatic partition. In this case, water with a higher level mark than that installed in the channel in front of the automatic partition comes from the channel section in front of the automatic partition through the inlet 6 into the reservoir of the gate. And then into the pipe 7 and, being installed according to the law of communicating vessels with a level equal to the water level in front of the partition structure, it drains through the upper part of the pipe 5. After that, the water level in the reservoir of the shutter of the automatic partition structure in the form of an autoregulator of the water level and, consequently, the hydrostatic water pressure acting on the internal elements of the shutter decreases.

This causes lowering, opening of the gate, and, consequently, an increase in the flow of water through the gate, as well as lowering the water level in the channel in front of the automatic partition to the level set in the channel. The principle of operation of the proposed automatic partition structure is as follows: in the absence of water in the channel, the capacity of the gate 1 is empty, and the spillway part 4 of the gate is in the lowest position. As water is supplied to the channel through the permanently open inlet pipe 6, the capacity of the gate 1 is filled. The gate, with its spillway part 4, rises, blocking the channel bed and raising the water level to the installation site of the automatic partition structure.

If the set level in the channel in front of the partition structure is exceeded, the water level in the reservoir of the gate 1, into which water enters through the inlet 6 from the channel to the installation site of the automatic partition structure, increases. Water from the reservoir of the gate 1 through the pipe 7 enters the water level regulator 5, made in the form of a pipe with an open top. It flows through it into the channel behind the partition structure since its top is set at a given water level mark in front of the partition structure. As a result, the amount of water entering the reservoir of the shutter will be 3...4 times less than the amount of water flowing out of the reservoir of the shutter, the reservoir of the

shutter 1 begins to empty, the spillway part 4 begins to descend, thereby increasing the flow of water passing through the upper part of the shutter and lowering the water level in front of the automatic partition to a predetermined level. To determine the capacity of the automatic partition structure, which is an autoregulator of the water level with flexible working bodies for the channels of the irrigation network of the trapezoidal section, we have delivered and conducted its experimental studies.

When the water level in the channel in front of the automatic partition structure is lowered below the set one, the water will not drain through the top of the water level controller tube 5. Through the inlet, water will constantly flow into the reservoir of the shutter, but it will not flow out of the reservoir; the hydrostatic pressure inside the reservoir of the shutter will increase and the shutter, filling with water, begins to rise, blocking the channel section until the water level in the channel becomes higher than the mark set by the water level in front of the automatic partition structure. After that, the water from the reservoir of the water-retaining gate begins to train through the top of the level controller.

Suppose the set water level in the channel in front of the partition structure is exceeded. In that case, the process is repeated until the water level is set, at which the amount of water entering the reservoir with the flap will not be equal to the amount of water flowing out of the reservoir with the flap, which corresponds to the establishment of the water level in the channel in front of the partition.

The proposed design of the automatic partition structure works entirely on the hydraulic energy of the water flow. It automatically adjusts the water level along the length of the channel to the installation site of the automatic partition structure in the form of an autoregulator of the water level, the design can be both portable and stationary.

Studies of the throughput capacity of an automatic partition structure in the form of an autoregulator of the water level were carried out by the method of physical modeling using the criterion of geometric similarity of the model and nature on an experimental installation (Figure 4). Modeling of the phenomena under study was carried out following the criteria of gravitational similarity of objects and dynamic similarity of forces 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 [16] and V.A. Prokofiev, G.A. Sudolsky [17]. The scale of the model concerning nature was adopted as 1:4.

The experimental setup (Figura 4) consisted of a trapezoidal section tray with a bottom width of 0.36 m and side walls located at an angle of 0.611 radians relative to the horizontal, 12 m long, 0.5 m high, and 1.36 m wide from above. The maximum flow rate of water supplied to the tray was 0.0561 m^3/s.
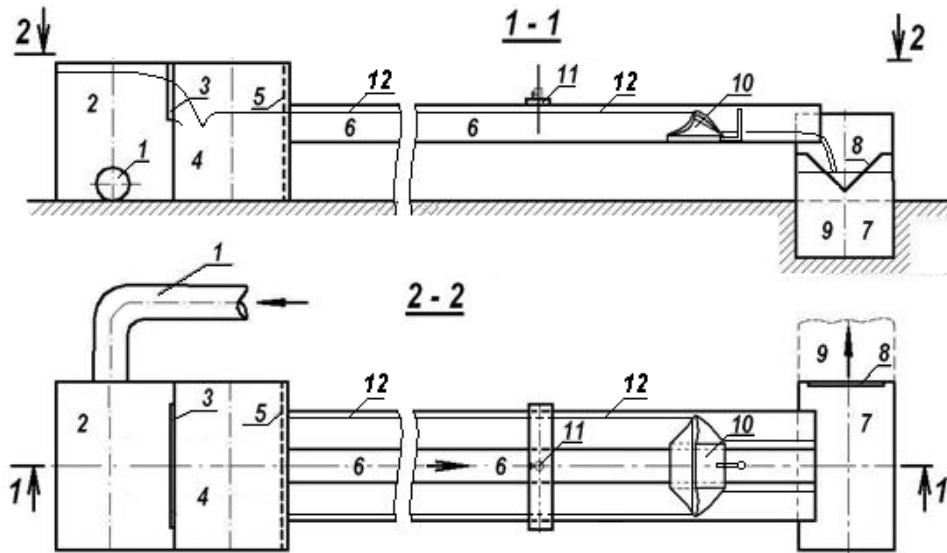
Figure 4. Experimental setup. 1 is pipe supplying water from the pump, 2 is sedative tank No. 1, 3 is dimensional triangular spillway with a thin wall, 4 is sedative tank No. 2, 5 is water flow energy extinguisher in the form of a grid, 6 is tray in the form of a trapezoidal channel, 7 is sedative tank No. 3, 8 is a three–dimensional triangular spillway with a thin wall, 9 is a spillway trench, 10 is a model of the studied automatic partition structure, 11 is a mobile shelf with a spitzen scale installed on it, 12 is water level in the tray.

The tray had a closed water supply system, which was supplied with a pump. To study the throughput, one model of a water-retaining gate with flexible working bodies of an automatic partition structure in the form of an autoregulator of the water level with a rigid shape of the spillway profile in the form of a non-vacuum profile was used (Figure. 1, Figure. 2). This profile was constructed following the Krieger-Ofitserov coordinates 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 [16] and A.P. Guryev, E.S. Beglyarova, S.A. Sokolova, B.A. Hayek [18]. The model (Figure. 1, Figure. 2, Figure. 3) consisted of a rigid spillway part 4, covered with an elastic material made of rubberized meliorative fabric, passing into the pressure part 3 and the side parts 9 of the model forming one whole with it and attached to the bottom of the model made of organic glass, made in the form of a box 2, with a width of 0.36 m at the bottom and 0.51 m at the top, length $L_2 = 0.64$ m, with a height of 0.08 m, installed at the bottom of the tray. The dimensions of the model elements were adopted as follows: $L_3 = 0.45$ m, where L_3 is the length of the pressure part 3 of the gate, $L_4 = 0.45$ m, where L_4 is the length of the chord of the spillway part 4 of the gate, $L_2 = 0.64$ m, where L_2 is the length of the lower part 2 of the gate, $\alpha_{max} = 0.611$ radians, where α_{max}- the maximum angle of elevation of the chord of the spillway part of the gate above the horizon, the diameter of the inlet hole 6 in the reservoir of the gate was 0.025 m, the diameter of the outlet pipe 7 from the reservoir of the gate is 0.05 m, the diameter of the water level regulator 5 is 0.07 m. To remove air during the filling of the gate tank with water, an air outlet with a diameter of 0.006 m was made in the upper part of the spillway part of the gate model. The rigid spillway part 4 of the model is made in the form of a frame in the form of a non-vacuum profile spillway following the Krieger- Ofitserov coordinates 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. Slissky [16].

Modeling of elastic material was carried out following the maximum linear tension. This issue is considered in the works of A.P. Nazarov [18] and A.P. Nazarov, B.I Sergeev [19].

The main part of the experiment was carried out with a sequential increase in the flow of water in the tray. All parameters were measured in 15...20 minutes after changing the flow rate or any of the values. During this time, an unchangeable flow mode was set in the tray.

3 Results and Discussion

In general, the flow coefficient is the following function.

$$m = f(H, h_0/H_z, \alpha, \alpha_{max}), h_{vac}/H, \sigma_n, Fr, We, \text{Re})$$

(1)

where H is the water pressure on the structure, h_0 is the pressure above the spillway threshold-taking into account the velocity pressure, H_z is the height of the gate lift relative to the bottom of the channel in front of the structure, α is the angle formed by the chord of the spillway part of the gate with a horizontal, α_{max} is the maximum angle formed by the chord of the spillway part of the gate with a horizontal, h_{vac} is the vacuum pressure under the jet on the spillway part, σ_n is the coefficient taking into account flooding from the downstream side, Fr is the Froude number, We is the Weber number, Re is the Reynolds number.

It is almost impossible to consider the influence of all these parameters on the change in the flow coefficient. The calculation of the model's throughput was carried out according to a well-known formula

$$Q = mb\sqrt{2g}\,h_0^{1.5}$$

(2)

where m is the flow coefficient, g is the acceleration of gravity or free fall, b is the width of the spillway front, h_0 is the head above the threshold of the spillway part of the gate, taking into account the velocity head.

Because the speed in the tray was less than 1 m/s, according to the recommendations of P.G. Kiselyov, A.D. Altshul, N.B.Danilchenko, A.A.Kasparson, G.I. Krivchenko, N.N. Pashkov, S.M.Sliski[16], the velocity pressure was not taken into, h_0 was accepted as equal

$$h_0 = h = (H - H_z)$$

(3)

where H is the depth of water in front of the partition structure, H_z is the lifting height of the shutter of the partition structure.

In this case, since the width of the spillway front of the structure is not the same in height because the channel has a trapezoidal section, width b was defined as:

$$b = b_1 + m_1(H_z + H)$$

(4)

where H is the depth of water in front of the partition structure, H_z is the lifting height of the shutter of the partition structure, m_1 is the value of the ratio of the horizontal projection of the side wall of the channel to the height of the channel, b_1 is the width of the channel at the bottom.

Therefore, formula (2) is converted to the following formula (5) to calculate the shutter capacity of the automatic partition.

$$Q = m[b_1 + m_1(H_z + H)]\sqrt{2g}(H - H_z)^{1,5}.$$

(5)

Mathematical processing of the data of the results of our studies of the model of an automatic partition structure in the form of a water-containing gate with flexible working bodies and a rigid spillway part in the form of a non-vacuum profile at $H_p = 0.15$ m showed that its flow coefficient m depends on the ratio of the water depth above the threshold of the water-containing gate to its height (h/H_z). This dependence obeys the following quadratic parabolic dependence (6), Figure 5.

At the same time, the difference between the study data relative to the obtained parabolic dependence, shown by the dots in Figure 5, is $\pm 4\%$.

$$m = -0.994(h/H_z)^2 - 0.5964(h/H_z) + 0.3505.$$

(6)

At $h/H_z = 0.05...0.45$, the flow coefficient varies within $m = 0.37...0.45$.
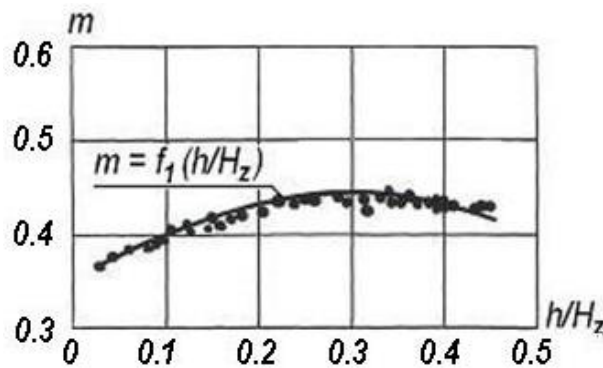
Fig. 5. A graph of the dependence $m = f_1(h/H_z)$ obtained for a water-retaining gate with flexible working bodies and a rigid spillway part in the form of an automatic partition structure without a vacuum profile for channels of the trapezoidal section of the irrigation system.

Studies of the design of an automatic partition for trapezoidal channels developed by us have shown that its hydraulic characteristics correspond to the hydraulic characteristics of the flow described in the works of A.P. Guryev, E.S. Beglyarova, S.A. Sokolova, B.A. Hayek [18] and M.-G.A. Kadirova [21, 22]. The results of our experimental studies of the automatic partition structure model at $H_p = 0.15$ m showed that the values of its flow coefficients m correspond to the values of the spillway flow coefficients in the form of a non-vacuum profile described in the work of P.G. Kiselev, A.D. Altshula, N.B.Danilchenko, A.A.Kasparson, G.I. Krivchenko, N.N. Pashkov, S.M. Slisky [16].

Thus, the results of our experimental studies of the model of an automatic partition structure in the form of a water-containing gate with flexible working bodies and a rigid spillway part in the form of a non-vacuum profile at $H_p = 0.15$ m showed the following:

1. The proposed design of an automatic partition structure in the form of an autoregulator of the water level for trapezoidal channels has a flow coefficient m, which varies according to the parabolic dependence (6).

2. The discrepancy between the value of the flow coefficient m obtained by formula (5) and the flow coefficient m obtained experimentally by formula (6) has an acceptable discrepancy of $\pm$ 4%.

3. The obtained formula (6) makes it possible to determine the throughput of an automatic partition structure in the form of an autoregulator of the water level for trapezoidal channels.

4. The design of the automatic partition works stably and remains vibration-free since the shape of the spillway part of its water-containing gate is non-vacuum.

4 Conclusion

Following the goals and objectives set in the work:

1) The author has developed the design of an automatic partition structure with flexible working bodies for channels of the trapezoidal section of irrigation systems. It does not narrow the cross-section of the channel, provides the necessary water level in the channel before the automatic partition structure, discharges excess water, floating bodies, and debris, works on the hydraulic energy of the water flow, and has sufficient accuracy of water level regulation. It is made of cheap modern materials for various trapezoidal channels, can be stationary and portable and installed on the channel by one or more workers, and is easy to operate.

2) To ensure stable, vibration-free operation of the proposed design of an automatic partition structure, the author justified and took the form of a spillway part of the structure in the form of a non-vacuum one.

3) Based on experimental studies, the author has obtained a formula for determining the flow coefficient included in the formula of the throughput of the proposed design of an automatic partition structure for trapezoidal channels, which allows for determining its throughput.

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