Hydrodynamic pressure upon elements of the shutter with flexible working bodies

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Abstract. For automatic control of the water level in the part of the channel in front of the hydraulic structure, a hydraulic automatic water level controller was proposed. Its main element is a shutter with flexible working elements, consisting of a reservoir formed by a shield for draining water from the channel and flexible cloth. To ensure stable operation without vibration, experimental studies of this shutter with a spillway in the form of a non-vacuum profile were carried out. These studies were carried out by the method of physical modeling of the model and nature in an experimental setup. The aim of the study was to determine the hydrodynamic pressure acting on this shutter, the forces of hydrodynamic pressure, and the centers of application of these forces to the shutter in the form of a non-vacuum profile. Studies have shown positive hydrodynamic pressure on the spillway of the shutter, the absence of vibration, the stability of the shutter. The obtained dependences for determining the forces and centers of application of hydrodynamic pressure forces to the elements of the spillway part of the shutter allow us to calculate this shutter.

1. Introduction
To supply the required flow rate of water to consumers in the discharge channels on the older channel, partition structures are being built. For economical water consumption, their automation is carried out. Due to the widespread use of shutters on partition walls of irrigation systems and their remote location from power lines, hydraulic shutters-automatic machines are most effective. They work on the use of hydraulic energy from a moving jet of water. The most widely used of them are the designs developed and described in the works of SH.S. Bobokhidze [1], YA.V. Botchkarev [2, 3, 4], N.A. Zakusilov [5], O.G. Zatvornitsky [6], P.I. Kovalenko [7], E.E. Makovsky [8]. The core in these designs is the metal shutter (flat, segment, sector) that or design, the requirement at them considerable differences of a water level, a non-admission of modulation of water at the top a shutter, necessity of periodic mechanical clearing of space before a shutter from a fin and dust, the necessity of the device of capital constructions. It expensively also disturbs their wide introduction in manufacture. Today with the advent of soft rubberized (meliorative) fabrics there were combined soft (flexible) designs of hydraulic shutters-automatic machines. They combine properties of soft (flexible) materials with traditional rigid materials described in works, M.-G.A. Kadirova [9], I.A. Petrov [10], B.I. Sergeev, P.M. Stepanov and V.V. Shumakov [11, 12], B.I. Sergeev [13], V.N. Schedrin [14]. However, in these designs, the main disadvantage is either the impossibility of cleaning the upper part of the channel before the sash from deposits or the need for periodic mechanical cleaning of floating bodies. The designs of these blinds are cheap, economical, do not require metal, are simple, environmentally friendly, maintainable, as they can be mobile, portable, and collapsible. To eliminate the aforementioned disadvantages of
automatic shutters, automatically maintain a constant water level in the channel before the partition structure, automatically let floating bodies pass through and clean deposits in front of the partition structure together with professor Ya.V. Botchkarev, I proposed automatic control of the water level [15]. It includes a water-containing shutter with flexible working bodies, a bottom shutter of the "valve" type installed in the washing gallery; a device (sensor-regulator) for controlling the operation of an automatic water level controller. This automatic water level regulator is fully powered by the energy of a moving water stream, automatically maintains a given water level in the channel before the partition structure, and automatically ensures the passage of floating bodies and sediments from the upper part of the channel to the lower part of the channel. The main element of this automatic water level regulator is a water-containing shutter with flexible working elements, consisting of a container formed by a rigid board for draining water and a soft cloth. Studies of the hydrodynamic pressure acting on a shutter with flexible working elements consisting of a reservoir formed by a rigid board for draining water and a soft cloth were carried out by V.N. Schedrin [14]. They showed that when the angles of raising the plane of the board relative to the horizontal exceed half the maximum height of the shutter, this shutter is characterized by vibration and unstable operation. This is due to the appearance of reduced pressure under the jet in the upper part of the plane of the rigid board during the discharge of water. To ensure its stable operation in the entire range of water level settings in the channel to the partition, we propose replacing its rigid board with the rigid part of the frame in the form of a non-vacuum spillway profile [16], constructed according to the coordinates of the Kriger-Ofitserovs [16, 17], covered with soft (reclamation) fabric.

For the purpose order to identify the stable, vibration-free operation of this a shutter with flexible working bodies with a part of the spillway in the form of a non-vacuum profile, to determine the hydrodynamic pressure acting on this a shutter in the entire range of its opening, for the possibility of performing its static calculation, we set up experimental studies.

The aim of the research was to study the hydrodynamic pressure acting on a shutter with flexible working elements with a part of the spillway in the form of a non-vacuum profile, constructed according to the Kriger–Ofitserov coordinates [16, 17], at different angles of raising the chord of its part of the spillway. And the determination of the values of the hydrodynamic pressure forces acting on the soft shell and part of the spillway in the form of a non-vacuum profile, and the centers of application of the hydrodynamic pressure force acting on the part of the spillway, for the possibility of performing the static calculation.

Experimental studies of a water-containing shutter with flexible working bodies were based on earlier studies of water-containing shutters made of soft shells and traditional materials A.P. Nazarov [18, 19], I.A. Petrov [10], A.I. Lemeshev [20], V.N. Schedrin [14], and aquiferous dams B.I. Sergeev [13]. And also following the known results of theoretical and experimental studies of traditional spillways [17, 21].

2. Methods

Researches were spent by a method of physical modeling, using the criterion of geometrical similarity of model and nature. Modeling of the investigated phenomena was carried out by criteria of gravitational similarity of Froud and dynamic similarity of forces.

In the study of the hydrodynamic pressure of water acting on a water-containing shutter with flexible working bodies, the following research structure was planned:

Research and graphing of the distribution of hydrodynamic pressure on a water-containing shutter with flexible working elements: its soft shell made of rubberized reclamation fabric and its part of the spillway, in the form of a non-vacuum profile constructed on coordinates of Kriger–Ofitserov.

Investigation of the effect of the lateral flow on the hydrodynamic pressure forces.

The scale of the model of a shutter with flexible working bodies concerning nature has been accepted 1:4. The experimental setup consisted of a tray 10 m long, 1.0...0.5 m high, 0.378 m wide. The maximum expense of the water submitted to a tray made 0.0561 m³/s. The tray had the closed system of supply by the water which giving was made by means of the pump.
The shutter model with flexible working elements on the upper side was made of a soft shell (rubberized reclamation fabric), having a length of $L_{ob} = 0.38$ m, and on the lower side in the form of a spillway of a non-vacuum profile, covered with a soft rubberized reclamation fabric. The maximum angle of the chord of the spillway of the model to the horizon was adopted $[alpha]_{max} = 0.611$ radians, the chord length of the spillway of the model was adopted $L_x = 0.38$ m, and the length of the model body $L_{kor} = 0.54$ m. The width of the model body was adopted equal to the width of the tray $B = 0.378$ m.

The filling of the water-containing shutter was carried out from a pipe with a diameter of 0.025 m adjacent to the shutter box through the side wall of the pallet and supplying water from a tank that controls the water level in the channel. The device for monitoring the water level in the channel to the installation site of the shutter was a container made with a base of 0.1 m $\times$ 0.1 m from organic glass in the shape of a rectangular prism. It is installed near the side wall of the tray. The level control device communicated with the part of the tray (channel) to the place of installation of the shutter by a pipe with a diameter of 0.04 m, the inlet of which was located at a distance of 1.5 meters from the beginning of the location of the water-containing shutter. The float of the level control device was made of polystyrene foam and mounted on a vertical centered rod, at the lower end of which a conical valve, which, being at a predetermined level in the upper part of the channel to the location of the shutter, could partially or completely block the pipe opening with a diameter of 0.025 m.

![Figure 1. A water-containing shutter with flexible working bodies: a is model with display of elements of a shutter 1 is a water drain part, 2 is the soft cover executed from rubberized fabric; 3 is the side part of the soft shell (reclamation rubberized fabric), 4 is the lower part (box) of the shutter model; b is model with display of points of connection of pezometers.](image)

For a conclusion of air in filling the capacity of a shutter with water in the top part of a water drain part of the model of a shutter it has been made an air taking out the aperture in diameter 0.006 m.

The shutter is emptied through a discharge outlet with a diameter of 0.016 m, located in the lower part of the shutter body. The regulation of the water level in the channel in front of the shutter was carried out using a device to control the water level in front of the shutter at various flow rates of water supplied to the tray.

Modeling of an elastic material was made on the maximum running tension. This question is considered in A.P. Nazarov’s works [18, 19].

Experiences were spent both at consecutive increase and at the consecutive decrease in the expenses which are passing on a tray, at various corners of a raising of the spillway of the shutter $[alpha] = 0$ radian, 0.174 radian, 0.349 radian, 0.436 radian, 0.523 radian, 0.611 radian. In the course of carrying out of researches following sizes were fixed: flow rate going along the tray, the depth of water in the tray to the position of the shutter, the height and angle of the chord of the gutter part of the sash, hydrodynamic pressure on the shutter elements: the hydrodynamic pressure on the soft shell (reclamation fabric) and of the spillway of the shutter, fitted with the reclamation fabric using
piezometers. Hydrodynamic pressure was carried out on the model of the shutter with flexible working bodies (figure 1, b). Hydrodynamic pressure was measured outside the shutter in four parallel directions. Directions were located across the width of the shutter at a distance of 0.09 m from each other. In each direction, 11 holes were made with a size of 0.0035 m at a distance of 0.09 m, as shown in figure 1, b. The ends of rubber pipes with a diameter of 0.004 m were hermetically glued with waterproof glue to the holes from the inside of the shutter tank on its soft (reclamation) fabric. Rubber tubes were guided through the inner part (capacity) of the shutter through openings made in the lower part of the shutter and the lower part of the pallet, to the measuring piezometers. Rubber tubes did not allow water from the tank to pass through the bottom of the shutter and the bottom of the pan. Piezometers were made of glass tubes with a diameter of 0.005 m, installed in a vertical position outside the tray in the box. All piezometers were numbered. Plastic adapters were used to connect the rubber tubes to the glass tubes of the piezometers. According to the testimony of the piezometers, in each measurement range graphs of hydrodynamic pressure were constructed, which were then averaged over the width of the shutter.

3. Results and discussion

As a result of the studies, 112 plots of hydrodynamic pressure acting on a soft shell (meliorative tissue) and spillway of a shutter containing water were constructed. Some of them are resulted in figure 2. Some of them are resulted in figure 2.

The analysis of the obtained pressure graphs showed that their shape on the side of the gate spillway follows the shape of the free surface water drained through the gate and represents the surface of a local surface.

The pressure of the water acting on the spillway of the shutter is positive, at all angles of the rise of the spillway of the shutter alpha; its minimum value tends to zero. Therefore shutter work is characterized by the absence of vibration and stability in work.

The hydrodynamic pressure forces acting on the soft shell and the spillway part of the shutter \( P_1 \) and \( P_2 \) were measured with a planimeter according to the obtained graphs of the hydrodynamic pressure acting on the soft shell (reclamation fabric) and the spillway of the water-containing shutter (figure 2) by numerically integrating these graphs per unit shutter width.

As a result of mathematical processing of the research data, curves of the hydrodynamic pressure forces \( P_1 \) and \( P_2 \) acting on the spillway part (figure 3) and soft shell (reclamation fabric) (figure 4) of the water-containing shutter were constructed.

And also the center of application \( X \) of the hydrodynamic pressure \( P_2 \) (figure 5) acting on the spillway of shutter relative to its axis of rotation, depending on the result of dividing the overflow thickness through the gate ridge \( h_0 \) to the shutter height \( H_z \). It also takes into account the angle of rotation of the spillway shutter [alpha]. In this case, the thickness of the water overflow through the shutter h0 ridge is taken into account together with the pressure rate.

The analysis of results of researches of hydrodynamic interaction of a water-containing shutter with flexible working bodies with a stream (without a lateral flow) for a tray with a bias \( i = 0 \) – has shown that:

- the force of hydrodynamic pressure \( P_1 \) operating on a water drain part of the water containing shutter with flexible working bodies, with relation increase \( h_0/H_z \) and with an increase in a corner of a raising of a chord of water drain part of a shutter, [alpha] increases (figure 3);

- with an increase in the angle [alpha] of the shutter spillway with flexible working bodies, the hydrodynamic pressure force \( P_2 \) acting on the soft shell of the shutter increases;
Figure 2. Graphics of the hydrodynamic pressure, operating on a soft shell (ameliorative tissue), and a water spillway part of the model of water containing shutter with flexible working bodies at various corners of a raising of a chord of a water spillway part of a shutter. A unit of measure of hydrodynamic pressure on graphics - pascal.

- with an increase in the ratio \( h_0/Hz \) and an increase in the angle of elevation of the chord of the spillway part of the shutter [\( \alpha \)], the hydrodynamic pressure acting on the soft shell, \( P_2 \) at [\( \alpha \)] = 0.611 radians, significantly increases compared to the force \( P_2 \) at [\( \alpha \)] = 0 radians (figure 4);
- the coordinates of the center of application of the hydrodynamic pressure force \( P_2 \) acting on the spillway of the gate relative to its axis of rotation, the greater, the smaller the angle of the rise of the chord of the spillway of a shutter [\( \alpha \)] (figure 5);
- as shown by experiments with the maximum filling of the tray (in the worst case) to the shutter baffle at different speeds of water flow in the tray and the corners of the spillway shutter [\( \alpha \)], the hydrodynamic pressure at the edges of the spillway shutter is less than in the middle vertical. This difference increases with the angle of the spillway shutter;
- the change in the hydrodynamic pressure on the water-containing shutter with flexible working bodies due to lateral flow around has a local character. In practice, the pressure at a distance of 0.01 m from the edge of the spillway part of the shutter is equal to the pressure on the middle vertical;
- total losses, due to the relatively large excess of the total gate width over the zone of lateral gaps, where there is an effect of lateral flow around, are relatively small and do not exceed 3%.

**Figure 3.** Curve dependences $P_1 = f_1(h_0/H_z)$ the force of hydrodynamic pressure of water $P_1$ operating on a water spillway part of the water containing shutter, depending on the relation of a thickness of a poured sheet of water over a crest of a shutter taking into account a high-speed pressure $h_0$ to a height of a raising of shutter $H_z$ and a corner of a raising of a chord $\alpha$ a water spillway part of a shutter: 1 – at $\alpha = 0$ radian; 2 - at $\alpha = 0.174$ radian; 3 – at $\alpha = 0.349$ radian; 4 – at $\alpha = 0.436$ radian; 5 – at $\alpha = 0.523$ radian; 6 – at $\alpha = 0.611$ radian.

**Figure 4.** Curves dependences $P_2 = f_2(h_0/H_z)$ of the hydrodynamic pressure of water $P_2$ acting on the soft shell of the water-containing shutter, depending on the division of the thickness of the merging water layer $h_0$ above the shutter crest by the height of the shutter, $H_z$ and the angle of elevation of the chord of the shutter spillway alpha; 1 – at $\alpha = 0$ radians; 2 - at $\alpha = 0.174$ radians; 3 – at $\alpha = 0.349$ radians; 4 – at $\alpha = 0.436$ radians; 5 – at
\[ \alpha = 0.523 \text{ radians}; 6 - \text{at } \alpha = 0.611 \text{ radians}. \] The thickness of the merging water layer \( h_0 \) takes into account the velocity pressure.

**Figure 5.** Curves dependences \( X = f \left( \frac{h_0}{H_z} \right) \) of the application center \( X \) of the hydrodynamic pressure of water force \( P_1 \) acting on the spillway of the water-containing gate, depending on the division of the water layer thickness \( h_0 \), over the spillway crest by the shutter height, \( H_z \), and the angle of elevation of the gate spillway chord \( \alpha \); 1 - at \( \alpha = 0 \) radians; 2 - at \( \alpha = 0.174 \) radians; 3 - at \( \alpha = 0.349 \) radians; 4 at \( \alpha = 0.436 \) radians; 5 - at \( \alpha = 0.523 \) radians; 6 - at \( \alpha = 0.611 \) radians. The thickness of the merging water layer \( h_0 \) takes into account the velocity pressure.

### 4. Conclusions

The general results of researches of hydrodynamic interaction of a shutter with a stream allow to draw the following conclusions:

1. The full pressure of the water on the water-containing shutter with flexible working bodies of the water level auto-regulator cannot be considered according to well-known hydrostatic formulas due to the influence of the dynamic effect.
2. The coordinates of the centers \( X \) of the force of hydrodynamic pressure acting on part of the gate spillway is greater than the shutters calculated by the hydrostatic formulas.
3. Lateral flow around, in the presence of small gaps between the side walls of the water-containing shutter with flexible working elements and the tray (0.0001...0.0003 m on the model), practically does not affect the hydrodynamic pressure.

Therefore, to determine the forces and centers of hydrodynamic pressure acting on this shutter, it is necessary to apply the dependence curves obtained by me as a result of research and presented in Figures 3, 4, and 5.

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