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Low Power Smart System Development for Water Flow Measurement and Level Controls in Open Canals

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ABSTRACT: Nowadays, several type of water flow and level measurement and control systems for open canals have already been developed. But the most water distribution weirs have dispersed location and remoteness from the power line. This problem requires development a low power smart system for water level and flow measurement in open canals. In this paper is considered the questions of development of a low power smart measurement system for water flow and level measurement in open canals in terms of energy efficiency. Theoretical and experimental research results are submitted.

KEY WORDS: water flow, water level, smart system, flow measurement, vertical opening slide gate, horizontal opening overshot gate, hydrostatic pressure force, open canal, energy efficiency, weir.

1. INTRODUCTION

Nowadays water and energy resources are becoming scarcer as people exploit these vital resources aggressively. If the water consumption from 1950 to 1990 increased by 2-2.5 times and amounted to 300 cubic kilometre, now the amount of water consumed exceeds 500 cubic kilometre in the world. Because of this issue, agricultural irrigation as the biggest water and energy consumer requires advanced water and energy saving technology.

In this study, the authors attempt to determine influential parameters to the energy efficiency of flow measurement and water level control systems, and further develop more energy efficient and accurate smart system for water flow measurement and level controls in open canals.

Various types of water flow measurement and level control systems for open canals have been developed now [1, 2, 3, 4, 5]. The most commonly used in open water distribution canals are rectangular weir with vertical opening slide gate and pivot weir with horizontal opening overshot gate [6,7,8]. But, growing interest for energy efficient smart control system requires an advanced method, which allows significantly decrease wastage of water and energy resources.

The gate driving process at water flow measurement and level control operated by electric motors in smart control system. The primary loads for electric motor drive gate controlling system in open canals are hydrostatic pressure forces which acting on the plane surface and weight of the gate, mechanical frictions, metal corrosion and etc [6,7,8].

Which type of the gate has low hydrostatic pressure force and mechanical friction or comfortable in terms of accurate water flow measurement are considered below. Of course, the answer this question requires some theoretical and experimental investigations.
Objectives of the study are:

- investigate and determine low power flow measurement and water level control system for open canals;
- further, develop an low power smart system for flow measurement and water level controls.

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II. SIGNIFICANCE OF THE SYSTEM

The study mainly focuses on low power smart systems development for water flow measurement and level controls in open canals. The study of existing problem is presented in section I, materials and methods is explained in section III, section IV covers the experimental results of the study, and section V discusses the future study and conclusion.

III. MATERIALS AND METHODS

We will consider a vertical plane surface submerged in static water as schematic shown in figure 1 below. As known in fluid mechanics theory that the hydrostatic pressure force F is acting perpendicular to the plane surface, when water is at rest.

The upstream and downstream head (water levels) variation laws can be expressed as:

$$H_{up} = H_{up.min} + \Delta H \cdot y \qquad (1)$$

$$h_{down} = h_{down.max} \cdot (y_{max} - y) \qquad (2)$$

where H_{up}, $H_{up.min}$ – upstream head (water level) and its minimum value, ΔH – differences between upstream water head and its minimum value, h_{down}, $h_{down.max}$ – downstream head (water level) and its maximum value, y, y_{max} – coordinate of the gate and its maximum value.

Taking into account equations (1), (2), area of the gate in contact with water and the centroid of the immersed surface from the figure 2 we obtain:

$$F_{up} = \frac{1}{2}\rho \cdot g \cdot w \cdot \left[H_{up.min} + \Delta H \cdot y - h_{down.max}(y_{max} - y)\right]^2 \qquad (3)$$

where H - water level or height of the gate (m), w - width of the gate (m), A is total flat area of the gate under hydrostatic pressure force.
So, the resultant hydrostatic pressure force acting on vertical opening slide gate F_R becomes:

$$F_R = F_{up} = \frac{1}{2}\rho \cdot g \cdot w \cdot \left[H_{up.min} + \Delta H \cdot y - h_{down.max}(y_{max} - y)\right]^2 \qquad (4)$$

But, as above mentioned any electrically operated gate controlling system working under the several forces. These include the weight of the gate, weight of the hoist beam and stem, the frictional resistance caused by the hydraulic pressure force against the gate, and the weight of the water above the horizontal opening overshot gates.
Taking into account equation (4) we determine the overall force required to drive a gate as follows:

$$F_{overall} = k(f \cdot F_R \pm W) = k[\frac{1}{2} \cdot f \cdot \rho \cdot g \cdot w(H_{up.min} + \Delta H \cdot y - h_{down.max}(y_{max} - y))^2 \pm W] \qquad (5)$$

where k - reserve factor, W – weight of the gate (N), f - friction coefficient (dimensionless). In equation (5) weight of the gate (W) has negative and positive sign. The positive sign means that weight of the gate at the closing process has the same direction with closing force helping to close the gate and at the opening process directed opposite to the opening force.

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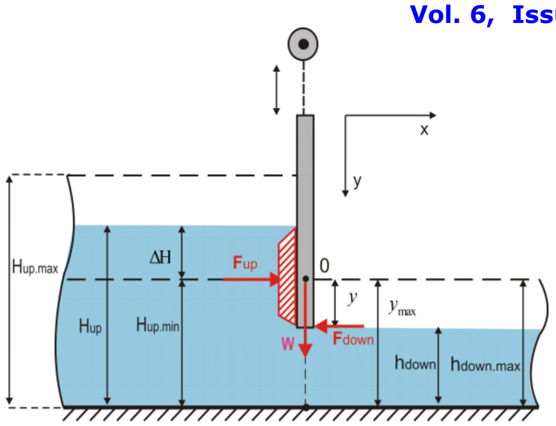

Figure 1.Hydrostatic pressure forces acting on both upstream and downstream sides of the vertical opening slide gate.

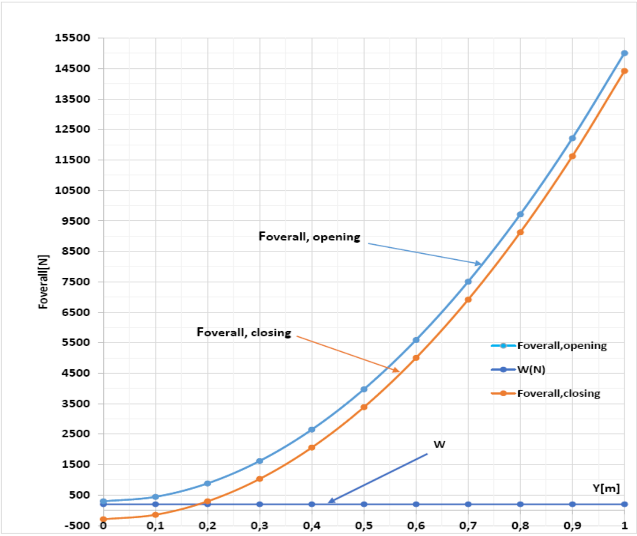

Figure 2. Overall forces acting on plane surface of the vertical opening slide gate at the opening and closing process.

We plot the overall force acting on the gate versus gate moving coordinate at opening and closing operations (see figure 2). The hydrostatic pressure force will have less magnitidute at the gate closing process than opening process due to weight of the gate. This design is mechanically simpler and well suited for general use as well as easy to install and service in the field. But, we can itemize following drawbacks of this design based on above noted analysis and equations;

- power consumption of the motor is increased due to weight of the gate;
- some mechanical influence as corrosion and binding of teeth of the gears or other mechanical parts will create additional loads to driving mechanism of the gate and electrical motor as well.

The second type of flow measurement and level control system is pivot weir or horizontal opening overshot gate that acts so that the water passes over the gate. The weir is operates in submerged in water condition and flow measurement based on an equation relating to the water level and weir opening angle (α) (see figure 3 below) [8,9,10].

Nowadays pivot weir has become popular and finds more application in irrigation systems for water flow measurement and level controls in open canals. Because the design has ability to handle water flow waves with limited depth or water level changes, easy water flow and level measurement, simple design and so on [8,9,10].

The pivot weir consist of rectangular panel that is hinged to the bottom of the canal. Two cables connected the top of the panel to drive mechanism and can be then used to raising and lowering the gate to control the upstream and downstream water levels as well as flow in open canals [1, 8,9].

Upstream and downstream water levels variation for this design are:

$$H_{up} = H_{up.min} + \Delta H \cdot \sin\alpha \qquad (6)$$

$$h_{downstream} = h_{downstream\,max} \cdot \sin(\alpha_{max} - \alpha) \text{ or } h_{downstream} = h_{downstreammax} \cdot \cos\alpha \qquad (7)$$

where α, α_{max} – gate moving angle and its maximum value, $\alpha_{max} = 90^0$.

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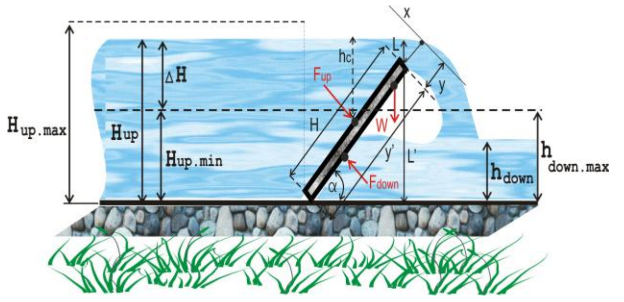

Figure 3. A horizontal opening overshot gate schematic.

According to equation (5) we can determine the overall force required to drive the horizontal opening overshot gate at the opening and closing process as follows:

the overall force at the gate closing process is:

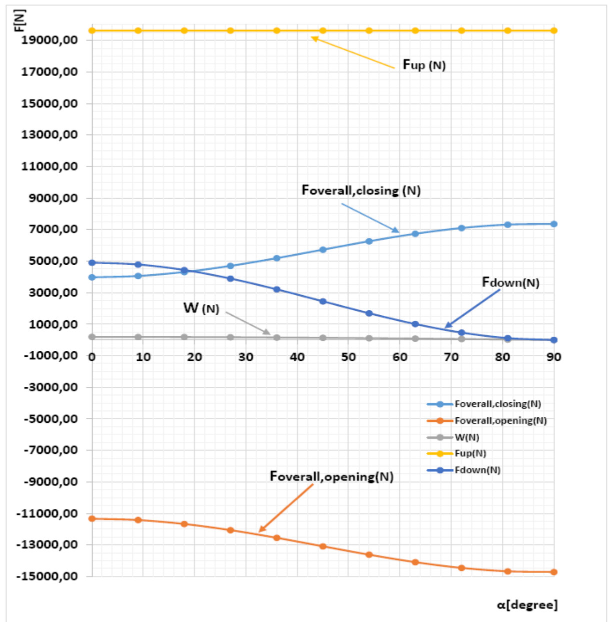

Figure 4. Overall forces acting on the horizontal opening overshot gate at the opening and closing process.

$$F_{overall,cl} = k(f \cdot F_{R,cl} \pm W) = k\left[\begin{array}{l} f \cdot \rho \cdot g \cdot w((H_{up.min} + (\Delta H - \frac{H}{2}) \cdot \sin\alpha\ ) \cdot H - \\ -\frac{1}{2}(h_{down.max} \cdot \cos\alpha\ )^2) + W \cdot \cos\alpha \end{array}\right] \tag{8}$$

or at the gate opening process:

$$F_{overall,op} = k \cdot \left[\begin{array}{l} -f \cdot \rho \cdot g \cdot w((H_{up.min} + (\Delta H - \frac{H}{2}) \cdot \sin\alpha\ ) \cdot H - \\ -\frac{1}{2}(h_{down.max} \cdot \cos\alpha\ )^2) - W \cdot \cos\alpha \end{array}\right] \tag{9}$$

According to equations (8) and (9) we plot the overall force acting to the horizontal opening overshot gate at opening and closing operations. See figure 4 below.

Let's now analyze plots we have got during theoretical investigations. Hydrostatic pressure force of upstream side (F_{up}) may be constant and may be variable. Its depend on choice of center of area (centroid) or center of pressure and parameters of the canals. But variation range is not significant. The overall force differences average value acting on the horizontal opening overshot gate at the opening and closing cycle is about 18760 N. This is about 32 times more than vertical opening slide gates. It means that there is a possibility to improve energy consumption of the gate by optimizing some controlling process.

Nowadays all electrically operated modern flow measurement and water level controlling system has actuators that provide a method of raising or lowering canal gates. The significant amount of electrical energy used for actuators of the gate controlling system during irrigation season. Moreover, the most water delivery points along the irrigation networks have not access to the power line. These all above-mentioned problems require develop low power gate

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controlling smart system. Usually there are two elements of actuators are considered as energy consumption elements in irrigation systems:

- a threaded stem or screw jack attached directly to the gate;
- reduction gear mechanisms (including chain driven sprockets) used to control the speed of the gate and provide a mechanical advantage to overcome the forces involved in lifting the gates.

The main source of drive mechanism of the gates is electrical motor. Several factors can dictate the power or energy consumption of the motor. A heaver gate, a gate operating with a big difference in water levels across the gate, a fast moving gate requires more power and more energy consumption.

All above-mentioned considerations require research investigation and optimization of gate operations. Now we can estimate the total energy consumption of the electric motor based on an equation related to the lifting motor power:

$$P = \frac{F_{overall..dose} \cdot v}{\eta} = k(f \cdot F'_{overal.close} + W) \cdot v/\eta = \Big[k \cdot f \cdot \rho \cdot g \cdot w((H_{up.min} + (\Delta H - \frac{H}{2}) \cdot \sin\alpha\ ) \cdot H - $$
$$ - \frac{1}{2}(h_{down.max} \cdot \cos\alpha\,)^2) + W \cdot \cos\alpha \Big] \cdot v/\eta, \qquad (10)$$

where $F_{overall}$ - overall force acting on the gate, η - efficiency factor of lifting gates, v - lifting speed (m/s).

In equation (10) usually gate lifting speed is v=0,25 – 0,3m/min and efficiency factor of lifting mechanism depend on what type of mechanism we are using. For example, if we use screw jack lifting mechanism efficiency factor is $\eta = 0{,}63 - 0{,}85$.

A more interesting and important point comes from the plot of lifting power versus gate moving coordinate (see figure 5). The pivot weir has about 1.8 and 2 times less power consumption then vertical opening slide gate. This advantage of the horizontal overshot gate keeps to point develops off-line power sources for smart system of water flow measurement and level control gates.

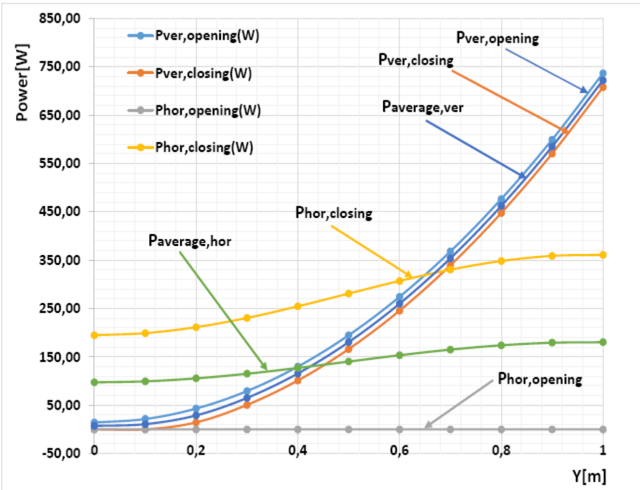

Figure 6. Energy consumption of the vertical opening slide and horizontal opening overshot gates and its average values.

IV. EXPERIMENTAL RESULTS

The smart system for water flow measurement and level control has been developed (see figure 6). Experiments where conducted in the Laboratory of Electrical Engineering and Mechatronics Department of TIIAME. In experiments, we have used PIC 18F4620-I/P-ND microcontroller, operational amplifier MCP602-I/P-ND, stepper motor WSM-237 and NPN transistors ZTX-1055A and other electronic components (figure 7).

In results was obtained curves of water flow Q, upstream and downstream water levels in open canals. Figure 8 shows variations of water flow, upstream and downstream water levels depend on angles of the gate.

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The experimental curve is close to a theoretical result. We use least squares method to statistical analysis. We have used the extreme method of approximating a nonlinear flow characteristic by a polynomial. The resulting solution of a 5th degree polynomial satisfies the requirements. As a result, the resulting expression is as follows:

$$Q = -2 \cdot 10^{-9} \cdot \alpha^5 + 4 \cdot 10^{-7} \cdot \alpha^4 - 3 \cdot 10^{-5} \cdot \alpha^3 + 0{,}0005 \cdot \alpha^2 - 0{,}0031 \cdot \alpha + 1{,}7977 \quad (11)$$

In this expression, the corresponding value of R^2 is very close to 1, that is $R^2 = 0.9994$. This is good fitting to the data and completely satisfies above-mentioned requirements.

V. DISCUSSION AND CONCLUSION

This research study has not concluded yet but we have preliminary theoretical and experimental outcomes. The following research investigations should be done in the future:

- experimental validation;
- dynamics study: influence of flow disturbance for flow measurement;
- develop an off-line power source;

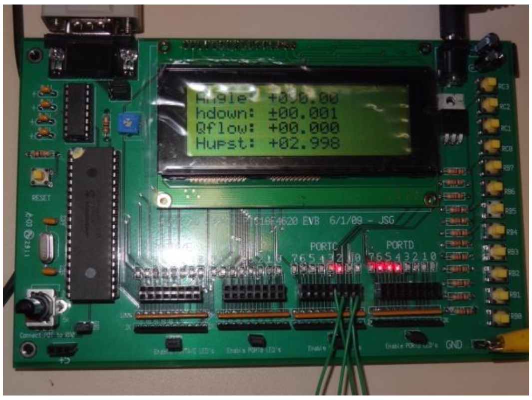

Figure 7. Developed smart system for water flow measurement and level controls in open canals.

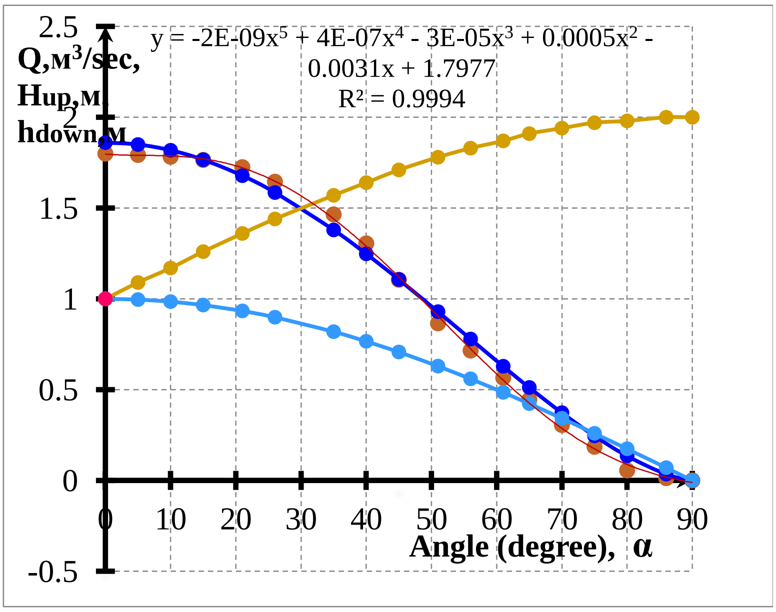

Figure 8. Variations of water flow, upstream and downstream water levels in open canals.

The pivot weir has simple design in terms of flow measurement and level control in open canals, power consumption is about two times less than the vertical opening slide gate. There is a possibility of accurate flow measurement and water level controls in a wide range of water flow, easy automation, have ability of the pivot weir to handle flow surge with limited depth changes.

Above mentioned advantages increase overall efficiency of water distribution systems, promotes precision water flow control, save significant amounts of water, decrease inefficient water distribution that promotes water waste on a large scale, promotes reliable monitoring used energy and water recourses.

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