UDC 681.5:626.86
DOI: 10.37128/2520-6168-2025-3-7

MATHEMATICAL MODEL OF THE SYSTEM OF AUTOMATIC WATER LEVEL CONTROL OF THE HYDRAULIC PRESSURE RESERVOIR OF THE IRRIGATION SYSTEM

Oleg IVANOV, Candidate of Technical Sciences, Associate Professor
Oleksii BURLAKA, Candidate of Technical Sciences, Associate Professor
Anton KELEMESH, Candidate of Technical Sciences, Associate Professor
Sergii LIASHENKO, Candidate of Technical Sciences, Associate Professor
Poltava State Agrarian University

ІВАНОВ Олег Миколайович, к.т.н., доцент
БУРЛАКА Олексій Анатолійович, к.т.н., доцент
КЕЛЕМЕШ Антон Олександрович, к.т.н., доцент
ЛЯШЕНКО Сергій Васильович, к.т.н., доцент
Полтавський державний аграрний університет

The paper presents a mathematical model of the system for automatic water level control in a hydraulic pressure tank of an irrigation system. The object of control is the water level, which changes as a result of the supply of liquid by a centrifugal pump. The system is implemented according to the feedback principle, which uses an ultrasonic level gauge as a measuring element, an electric actuator of the pump and a proportional-integral controller for correcting the control signal. To simplify the analysis of dynamics, the system is linearized in the vicinity of the operating point, which corresponds to a stable operating mode, and is presented in the form of transfer functions of individual links. The transfer function of the control object describes the inertial properties of the change in the liquid level in the tank.

Based on the constructed mathematical model, an analysis of the dynamic characteristics of the system was performed, in particular, transient processes and root trajectories were investigated at different values of the controller gain coefficient Kp. The range of its change was taken from 0 to 8 with an increase step of 0.1. The simulation results showed that at small values of Kp < 0.2 the system reacts slowly, demonstrating an aperiodic but prolonged nature of water level establishment. In the range of Kp =0.6…2 the transient characteristic takes on an optimal form - the system reaches the set level without significant fluctuations, providing a compromise between speed and stability. Further increase of Kp > 2.5 leads to a decrease in the transient process time, however, the system acquires an oscillatory character with possible overregulation. At Kp > 7.0 there is a risk of loss of stability, which is confirmed by the location of the roots in close proximity to the imaginary axis.

Graphical analysis of transient characteristics confirmed that an increase in the Kp coefficient reduces the system establishment time, but at the same time increases the amplitude of oscillations. The constructed response time curves and root trajectories allow us to quantitatively assess the stability limits and the influence of the controller parameters on the quality of the regulation process. The results obtained indicate that the use of a PI controller provides effective stabilization of the water level, reduces the static error and increases the reliability of the pumping unit.

The developed methodology can be used to optimize the settings of automatic control systems in hydraulic and irrigation systems, as well as for the further synthesis of controllers with improved dynamic properties.

***Key words**: water level, mathematical modeling, hydraulic pressure tank, pump, transient response, stability, proportional-integral controller.*

Eq. 8. Fig. 3. Ref. 20.

1. Problem formulation

Modern water management, especially in the field of irrigation, faces a dual challenge: the need to overcome the consequences of climate change and increase food security [1]. The introduction of automation is a strategic step that transforms traditional and energy-intensive systems into energy-efficient ones. Pilot

Article received 24.10.2025. Article accepted 08.12.2025. Article published 25.12.2025.

projects and reforms are already being implemented in Ukraine that directly encourage the use of energy-efficient equipment and digital tools for water resources management, the purpose of which is to increase sustainability and reduce operating costs [7]. Among the numerous technical and technological approaches to ensuring the economical use of water resources, the following can be distinguished: precision irrigation [10, 8, 13], automation and digitalization of water supply processes [1, 5], remote monitoring of water supply and water use in irrigation systems [18, 15], increasing the energy efficiency of water supply equipment [19, 2], minimizing water losses during storage in open reservoirs [17, 16].

2. Analysis of recent research and publications

The regulatory framework of Ukraine, in particular the State Building Standards (DBN) V.2.5-74:2013, establishes clear requirements for the automation of water supply systems and the design of external networks [20]. In all reservoirs and tanks, regardless of their purpose, it is mandatory to provide for the measurement of water levels and their control. This information is used for automation systems or for transmitting signals to a pumping station or a central control point [20].

According to these standards, several critical water levels are subject to control, each of which has its own functional purpose: the level of the intact fire volume, the level of the emergency volume and the minimum level required for trouble-free operation of pumping units [20]. In addition, the DBN requires that pumping stations and installations have automation of auxiliary processes, such as washing of rotating screens (by time or level difference), pumping out drainage water, as well as electric heating and ventilation systems [20].

Therefore, automation of water level maintenance processes is one of the key tasks in modern irrigation and water supply systems [3,9]. The efficiency of water resources use, energy efficiency, and reliability of pumping equipment depend on the accuracy and stability of the regulation system [6, 11, 14].

3. The purpose of the article

The purpose of the research is the development of a mathematical model of a system for automatic water level control in a water tank, as well as the study of its stability based on the analysis of dynamic characteristics.

Research objectives:

– develop a mathematical model of a system for automatic water level control in a water tank, taking into account the dynamics of the pump and hydraulic parameters of the irrigation system.

– obtain the transfer function of the system and determine the main dynamic characteristics of the control object.

– to investigate the stability of the system under different operating modes.

4. Results and discussion

The research involves the use of analytical methods for describing hydraulic processes underlying changes in the water level in a water tank, and key theoretical principles of the theory of automatic control. The mathematical model of the automatic control system is built on the basis of the equation of the balance of fluid consumption, taking into account the characteristics of the pump and tank.

To simplify the analysis of dynamic properties, the system was linearized around the operating point. The operating point corresponds to the steady state operation of the system, in which the water level, pump flow rate, and drain flow rate remain constant. In this mode, all model variables are considered as the sum of constant values and small deviations from them.

As a result, nonlinear relationships describing hydraulic processes (e.g., orifice flow or pump characteristics) are replaced by first-order linear approximations obtained by Taylor series expansion near the operating point. In this case, products of small deviations are discarded as insignificant.

This approach allows us to represent the system in a linear form, which makes it possible to further apply the methods of automatic control theory for stability and dynamics analysis. As a result, the linearized system is presented in the form of transfer functions that describe the relationship between the water level deviation and the control signal to the pump.

The stability study was conducted using the Hurwitz criterion and the frequency response method. System dynamics modeling and transient evaluation were performed in the Control System software environment, which made it possible to determine the influence of the controller parameters on the quality of water level regulation.

The system for automatic water level control in a hydraulic pressure tank consists of the following components: a hydraulic pressure tank of a certain volume, a centrifugal pump, an ultrasonic level gauge, a level regulator, and an electronic pump drive control device.

The system automatically maintains a constant water level in the hydraulic pressure tank, from which water is supplied for irrigation.

Physically, the control process is based on the balance of water inflow and outflow.

Water enters the tank through a centrifugal pump, which lifts it from an open reservoir to the height of the hydraulic pressure tank, creating a flow under the action of the pump pressure.

The volume of water in the tank changes according to the difference between the pump flow rate Q_{in} and expense Q_{out}.

When the water level in the tank drops, the ultrasonic level sensor detects the decrease in distance to the liquid surface, and the control system increases the pump power. This leads to an increase in flow until the inflow equals the outflow.

Otherwise, the system reduces the pump speed, reducing the flow.

Thus, due to hydrostatic balance and dynamic flow control, the system automatically maintains a constant water level necessary for the stable operation of the irrigation network.

From the point of view of the provisions of the theory of automatic control, the proposed system is a closed system with negative feedback (Fig. 1). The feedback signal associated with the current value of the water level $h(t)$ in the tank, is formed by a measuring element - an ultrasonic level gauge. This signal is compared with the set level value hin and the control error is determined $\delta(t) = h_{in} - h(t)$, on the basis of which the level controller, setting the control algorithm, forms the control effect $u(t)$ дfor an electronic device for controlling the pump drive. Depending on the characteristics of the pump electric drive, the electronic device forms the output electrical power parameters to regulate the pump volumetric flow rate $Q_{in}(t)$.

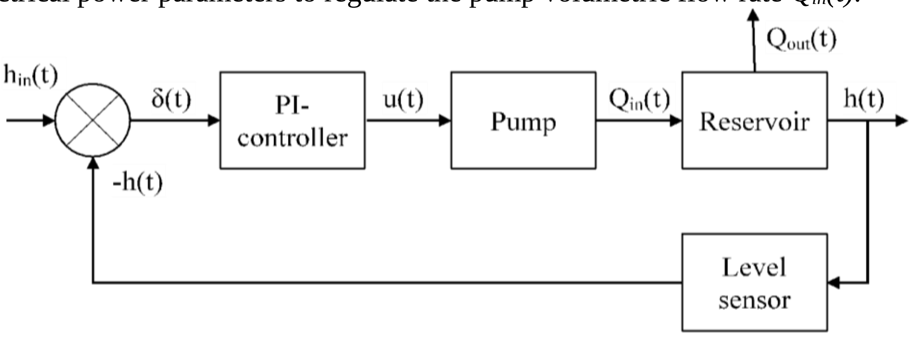

Fig. 1. Block diagram of the automatic water level control system in a hydraulic pressure tank

Thus, the system automatically maintains the water level in the tank at a given level, compensating for disturbances caused by changes in irrigation water flow.

The fundamental equation of the mathematical model is the equation of the balance of the amount of water when entering and emptying the reservoir:

$$F\frac{dh}{dt} = Q_{in}(t) - Q_{out}(t), \tag{1}$$

where F – cross-sectional area of the tank; $\frac{dh}{dt}$ – instantaneous rate of change of the water level function relative to the independent variable time t; $Q_{in}(t)$ – pump feed; $Q_{out}(t)$ – water consumption by consumers.

The flow rate of water from a tank depends on certain physical and hydraulic factors, including the hydrostatic head in the tank, the hydraulic resistance of the consumer system, the area of the outlet or guide pipe, and the dynamic conditions in the tank itself.

For the case of water leaking through the outlet of the tank near its bottom, the water flow rate can be determined:

$$Q_{out}(t) = C_d F_o \sqrt{2gh(t)}, \tag{2}$$

where C_d – consumption coefficient, F_o – cross-sectional area of the outlet, g – acceleration of free fall.

The amount of water supply to the tank is determined by the pump performance, which in a first approximation can be expressed as follows:

$$Q_{in}(t) = k_p u(t), \tag{3}$$

where k_p – pump transmission ratio, proportional to the pump impeller speed or control signal.

To simplify the analysis of the stability of the system, the study of its time characteristics, and the development of the controller operation algorithm, the system is linearized in the vicinity of the operating point, which corresponds to the stable mode of its operation.

After linearization, the balance equation (1) takes the form:

$$F\frac{d(\Delta h)}{dt} = \Delta Q_{in} - K_h \Delta h, \tag{4}$$

where $K_h = \frac{C_d F_o g}{\sqrt{2gh_o}}$ – flow rate after linearization.

After applying the Laplace transform, the transfer function of the hydraulic pressure tank as a control object takes the form:

$$W(s) = \frac{H(s)}{Q_{in}(s)} = \frac{1}{Fs + K_h}. \tag{5}$$

The formed transfer function corresponds to the transfer function of an aperiodic first-order link.

The formed transfer function describes only the control object – the process of changing the water level in the tank under the influence of water supply to the tank. The transfer functions of the pump and the level gauge are not taken into account at this stage, since their dynamics are much faster compared to the inertia of the object itself. The pump in the model is considered as an ideal flow source, and the level gauge is considered as an inertialess measuring element that does not affect the shape of the transient process. This approach allows you to simplify the analytical description of the system and focus on the study of the main dynamic properties of the tank as a controlled object.

A proportional-integral controller (PI controller) was chosen as the controller because it combines the advantages of two components – proportional and integral. The proportional part ensures a fast response of the system to level deviations, reducing transients, while the integral component eliminates the static error inherent in systems with purely proportional control [12].

The transfer function of the PI controller is described by the equation:

$$W_p(s) = K_p\left(1 + \frac{1}{T_i s}\right), \tag{6}$$

where K_p – gain coefficient;T_i – continuous integration.

Taking into account the transfer functions of the reservoir and the regulator, the transfer function of the closed-loop control system as a whole is described by the expression:

$$W_{sys}(s) = \frac{W_p(s)W(s)}{1 + W_p(s)W(s)} = \frac{K_p(T_i s + 1)}{T_i F s^2 + (T_i K_h + F K_p)s + K_p}. \tag{7}$$

Using the obtained transfer function of the automatic water level control system, it is possible to analyze its dynamic properties, in particular, to determine the system's resistance to external influences.

To assess the dynamic properties and determine the stability of the system, it would be advisable to conduct simulations in the time and plane domains using the root-path method and the construction of transient time characteristics. In this case, the analysis is carried out for several combinations of the gain pair K_p and continuous integration T_i, which correspond to different PI controller setup options.

The root trajectory method is used to estimate the change in the location of the poles of a closed-loop system when the gain is changed. K_p.

To construct the root trajectories, a second-order characteristic equation is used according to the transfer function $W_{sys}(s)$:

$$T_i F s^2 + (T_i K_h + F K_p)s + K_p = 0 \tag{8}$$

According to the Hurwitz criterion, for second-order systems, the stability condition is formed from the inequalities:

$$F > 0, K_p > 0, (F K_p + T_i K_h) > 0.$$

Based on the above inequalities, it can be stated that for positive values K_p the system is stable.

To determine the nature of the influence of the gain coefficient K_p Calculations were made on the dynamic properties of the system for its various values with fixed parameters. T_i = 12, F = 5 м² and K_h = 0,5.

The results (Fig. 2) showed that with the increase K_p the system poles gradually shift to the left along the real axis, which indicates an increase in the system speed and a decrease in the transition time. In the range $K_p \approx 0{,}3\text{-}6{,}7$ acquire a complex-conjugate form, which corresponds to the oscillatory nature of the transient process with moderate damping. At small values of $K_p < 0{,}2$ the system is characterized by an aperiodic but slow response, while at excessively large values $K_p > 7$ cthe system returns to aperiodic behavior, but may lose stability or undergo significant down-regulation. Optimal range $K_p = 0.6…2.0$ provides a compromise between system performance and stability.

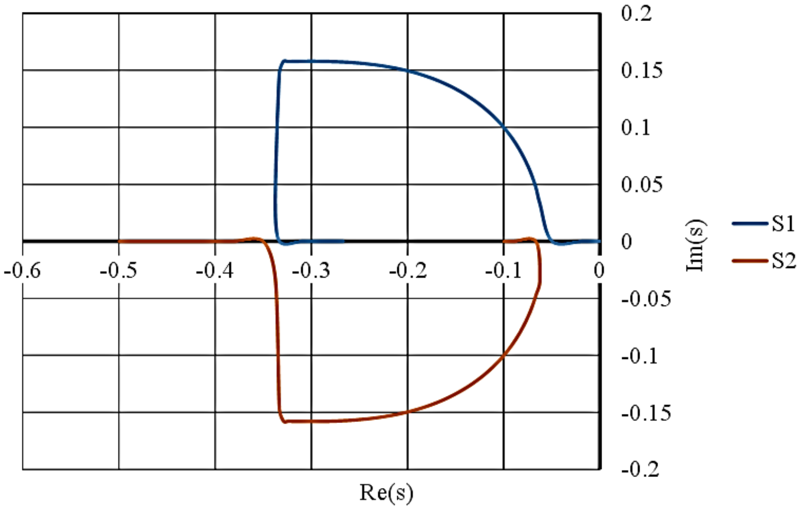

Fig. 2. Root trajectories of the automatic water level control system when changing the gain coefficient K_p = 0…8 (T_i = 12 s)

To confirm the assumptions made, the transient characteristics of the system under a single stepwise influence were calculated and constructed (Fig. 3).

The results obtained show that when $K_p = 0{,}4$ the system has a slow but aperiodic transient process with a stabilization time of more than 100 s. When set $K_p = 0{,}8$ there is a moderate acceleration of the process without a significant increase in overshoot. Increase K_p to 2,0 and $T_i = 6$ s with the system has the fastest speed, but there is a slight fluctuation of the level near the steady value.

Therefore, increasing the gain K_p accelerates the system response, but may reduce the stability margin. Optimal settings are achieved at a ratio of parameters at which the system has an aperiodic response shape with minimal settling time.

A comparative analysis of the transient characteristics showed that the system remains stable at any controller parameters, but its dynamic properties significantly depend on the gain.

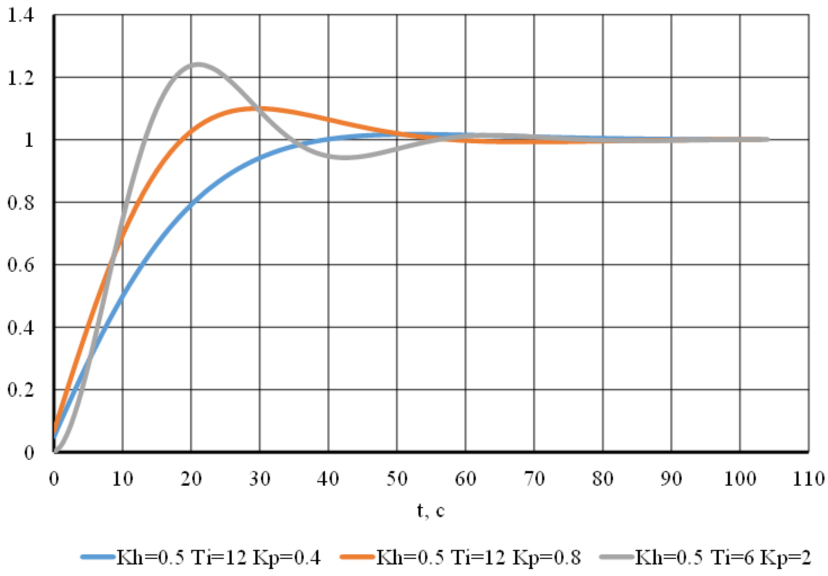

Fig. 3. Transient characteristics of the system

The proposed research methods demonstrated the influence of the gain coefficient K_p on system performance, integration time T_i on oscillation and overshoot values. At the same time, finding a compromise between the regulator settings will ensure a compromise between accuracy, speed and stability.

Thus, the analysis of root trajectories and transient characteristics made it possible to confirm the adequacy of the mathematical model and evaluate the dynamic behavior of the automatic water level control system in the hydraulic pressure tank.

5. Conclusion

As a result of the research, a mathematical model of the automatic water level control system in a hydraulic pressure tank using a PI controller was developed and analyzed. The obtained transfer function of the control object allowed us to describe the main dynamic properties of the system as an aperiodic link of the first order, which adequately reflects the process of changing the water level under the influence of the pump supply. The linearization of the balance equation in a steady state provided the possibility of applying the methods of the theory of automatic control for further analysis of stability and transient processes.

Analysis of root trajectories and transient characteristics showed that the system remains stable over a wide range of PI controller parameters, and its dynamic behavior significantly depends on the gain and integration constant. With increasing gain, the speed increases, but the stability margin decreases and the probability of an oscillatory response increases. Optimal tuning of the controller parameters allows achieving an aperiodic process with minimal settling time and no static error.

Further research should be directed towards the development of adaptive control algorithms capable of automatically changing the controller parameters depending on the operating conditions of the irrigation system. It is also promising to take into account the nonlinear characteristics of the pump, pressure losses in the pipelines, and the introduction of predictive control methods to increase the energy efficiency and reliability of the automatic water level control system in the hydraulic pressure tank.

References

1. Adedeji, K. B., Ponnle, A. A., Abu-Mahfouz, A. M., & Kurien, A. M. (2022). Towards digitalization of water supply systems for sustainable smart city development – Water 4.0. *Applied Sciences, 12*(18), 9174. DOI: https://doi.org/10.3390/app12189174 [in English].
2. Andraka, D., Kruszyński, W., Tyniec, J., Gwoździej-Mazur, J., & Kaźmierczak, B. (2023). Practical aspects of the energy efficiency evaluation of a water distribution network using hydrodynamic modeling: A case study. *Energies, 16*(8), 3340. DOI: https://doi.org/10.3390/en16083340 [in English].
3. Baratov, R., Chulliyev, Y., & Ruziyev, S. (2023). Smart system for water level and flow measurement and control in open canals. *E3S Web of Conferences, 264*, 04082. DOI: https://doi.org/10.1051/e3sconf/202126404082 [in English].
4. Bazaluk, O., Havrysh, V., Nitsenko, V., Mazur, Y., & Lavrenko, S. (2022). Low-cost smart farm irrigation systems in Kherson province: Feasibility study. *Agronomy, 12*(5), 1013. DOI: https://doi.org/10.3390/agronomy12051013 [in English].
5. Bonilla, C., Brentan, B., Montalvo, I., Ayala-Cabrera, D., & Izquierdo, J. (2023). Digitalization of water distribution systems in small cities: A tool for verification and hydraulic analysis: A case study of Pamplona, Colombia. *Water, 15*(21), 3824. DOI: https://doi.org/10.3390/w15213824 [in English].
6. Glovatskii, O., Rashidov, J., Kholbutaev, B., & Tuychiev, K. (2021). Achieving reliability and energy savings in the operation of pumping stations. *E3S Web of Conferences, 264*, 03003. DOI: https://doi.org/10.1051/e3sconf/202126403003 [in English].
7. Kyiv School of Economics. (2022). *Irrigation reform in Ukraine (2022–2025).* URL: https://kse.ua/wp-content/uploads/2025/05/Irrigation-Reform-in-Ukraine-2022---2025.pdf [in English].
8. Lakhiar, I. A., Yan, H., Zhang, C., Wang, G., He, B., Hao, B., Han, Y., Wang, B., Bao, R., Syed, T. N., Chauhdary, J. N., & Rakibuzzaman, M. (2024). A review of precision irrigation water-saving technology under changing climate for enhancing water use efficiency, crop yield, and environmental footprints. *Agriculture, 14*(7), 1141. DOI: https://doi.org/10.3390/agriculture14071141 [in English].
9. Lopes, I., Nascimento, J. M. A., Barbosa, R. S., Dos Santos, M. R., Heydt, R. D., Da Silva, E. G. M. B., De Melo, J. M. M., Vellame, L. M., De Lima, J. L. M. P., & Guimarães, M. J. M. (2025). Development of a water level monitoring and control system for pumping stations in agricultural systems. *DYNA, 92*(237), 51–58. DOI: https://doi.org/10.15446/dyna.v92n237.117596 [in English].

10. Mushtaq, M., Ali, H., Raza, A., Maqbool, S., Safdar, M., Ahmed, M., & Sattar, J. (2024). Precision irrigation for sustainable agricultural productivity. In *Emerging technologies and marketing strategies for sustainable agriculture* (pp. 184–208). IGI Global Scientific Publishing. DOI: https://doi.org/10.4018/979-8-3693-4864-2.ch010 [in English].
11. Pei, Y., Liu, Q., Wang, C., & Wang, G. (2021). Energy-efficient pressure regulation model and experiment of lift pump system in deepwater dual-gradient drilling. *Journal of Petroleum Science and Engineering, 203*, 108621. DOI: https://doi.org/10.1016/j.petrol.2021.108621 [in English].
12. Romasevych, Y., Loveikin, V., Liashko, A., & Makarets, V. (2019). Development of a method for optimal tuning of PI controllers. *Avtomatyzatsiia vyrobnychykh protsesiv u mashynobuduvanni ta pryladobuduvanni, 53*, 56–65. DOI: https://doi.org/10.23939/istcipa2019.53.056 [in Ukrainian].
13. Romero, R., Muriel, J. L., García, I., & Muñoz de la Peña, D. (2012). Research on automatic irrigation control: State of the art and recent results. *Agricultural Water Management, 114*, 59–66. DOI: https://doi.org/10.1016/j.agwat.2012.06.026 [in English].
14. Salomons, E., Cao, H., Korder, K., Ostfeld, A., & Li, P. (2025). Real-time optimal operation of water systems under demand uncertainty and maximum water age constraints. *Water Resources Research, 61*(7). DOI: https://doi.org/10.1029/2024WR038587 [in English].
15. Sanya, W. M., Alawi, M. A., & Eugenio, I. (2022). Design and development of a smart water quality monitoring system using IoT. *International Journal of Advances in Scientific Research and Engineering, 8*(3), 1–13. DOI: https://doi.org/10.31695/ijasre.2022.8.3.1 [in English].
16. Shalaby, M. M., Nassar, I. N., & Abdallah, A. M. (2021). Evaporation suppression from open water surfaces using various floating covers with consideration of water ecology. *Journal of Hydrology, 598*, 126482. DOI: https://doi.org/10.1016/j.jhydrol.2021.126482 [in English].
17. Simon, K., Shanbhag, R., & Slocum, A. H. (2016). Reducing evaporative water losses from irrigation ponds through the reuse of polyethylene terephthalate bottles. *Journal of Irrigation and Drainage Engineering, 142*(2). DOI: https://doi.org/10.1061/(ASCE)IR.1943-4774.0000972 [in English].
18. Thomson, P. (2020). Remote monitoring of rural water systems: A pathway to improved performance and sustainability? *WIREs Water, 8*(2). DOI: https://doi.org/10.1002/wat2.1502 [in English].
19. Zimoch, I., Bartkiewicz, E., Machnik-Słomka, J., Kłosok-Bazan, I., Rak, A., & Rusek, S. (2021). Sustainable water supply systems management for energy efficiency: A case study. *Energies, 14*(16), 5101. DOI: https://doi.org/10.3390/en14165101 [in English].
20. Ministry of Regional Development of Ukraine. (2013). *State building codes B.2.5-74:2013. Water supply. External networks and structures. Basic design provisions* (in Ukrainian). Kyiv, Ukraine. [in Ukrainian].

МАТЕМАТИЧНА МОДЕЛЬ СИСТЕМИ АВТОМАТИЧНОГО КЕРУВАННЯ РІВНЕМ ВОДИ ГІДРОНАПІРНОГО РЕЗЕРВУАРУ СИСТЕМИ ЗРОШЕННЯ

У роботі представлено математичну модель системи автоматичного регулювання рівня води в гідронапірному резервуарі зрошувальної системи. Об'єктом регулювання виступає рівень води, який змінюється внаслідок подачі рідини відцентровим насосом. Система реалізована за принципом зворотного зв'язку, у складі якої використано ультразвуковий рівнемір як вимірювальний елемент, виконавчий електропривод насоса та пропорційно-інтегральний регулятор для корекції сигналу керування. Для спрощення аналізу динаміки система лінеаризована в околі робочої точки, що відповідає сталому режиму роботи, і представлена у вигляді передаточних функцій окремих ланок. Передаточна функція об'єкта регулювання описує інерційні властивості зміни рівня рідини в ємності.

На основі побудованої математичної моделі виконано аналіз динамічних характеристик системи, зокрема досліджено перехідні процеси та кореневі траєкторії при різних значеннях коефіцієнта підсилення регулятора Kp. Діапазон його зміни був прийнятий від 0 до 8 з кроком зростання 0,1. Результати моделювання показали, що при малих значеннях Kp < 0.2 система реагує повільно, демонструючи аперіодичний, але затяжний характер встановлення рівня води. У діапазоні Kp =0.6…2 перехідна характеристика набуває оптимального вигляду — система досягає заданого рівня без суттєвих коливань, забезпечуючи компроміс між швидкодією та стійкістю. Подальше збільшення Kp > 2.5 призводить до зменшення часу перехідного процесу, однак система набуває коливального характеру з можливим перерегулюванням. При Kp > 7.0 спостерігається ризик втрати стійкості, що підтверджується розташуванням коренів у безпосередній близькості до уявної осі.

Графічний аналіз перехідних характеристик підтвердив, що збільшення коефіцієнта Kp зменшує час встановлення системи, але водночас збільшує амплітуду коливань. Побудовані криві часу *відгуку та кореневі траєкторії дозволяють кількісно оцінити межі стабільності та вплив параметрів регулятора на якість процесу регулювання. Отримані результати свідчать, що застосування ПІ-регулятора забезпечує ефективну стабілізацію рівня води, знижує статичну похибку та підвищує надійність роботи насосної установки.*

Розроблена методика може бути використана для оптимізації налаштувань систем автоматичного контролю в гідравлічних та зрошувальних установках, а також для подальшого синтезу регуляторів із покращеними динамічними властивостями.

Ключові слова: *рівень води, математичне моделювання, гідронапірний резервуар, насос, перехідна характеристика, стійкість, пропорційно-інтегральний регулятор.*

Ф. 8. Рис. 3. Літ. 20.

INFORMATION ABOUT THE AUTHORS

Oleg IVANOV – Candidate of technical sciences, Associate professor, Associate Professor of the Department of Construction and Vocational Education, Poltava State Agrarian University (1/3 Skovorody St., Poltava, Ukraine, 36003, e-mail: oleg.ivanov@pdau.edu.ua, https://orcid.org/0000-0002-1761-9913).
Oleksii BURLAKA – Candidate of technical sciences, Associate professor, Associate Professor of the of the Department of Agroengineering and Road Transport, Poltava State Agrarian University (1/3 Skovorody St., Poltava, Ukraine, 36003, e-mail: oleksii.burlaka@pdau.edu.ua, https://orcid.org/0000-0002-2296-7234).
Anton KELEMESH – Candidate of technical sciences, Associate professor, Associate Professor of the of the Department of Agroengineering and Road Transport, Poltava State Agrarian University (1/3 Skovorody St., Poltava, Ukraine, 36003, e-mail: anton.kelemesh@pdau.edu.ua, https://orcid.org/0000-0001-9429-8570).
Sergii LIASHENKO – Candidate of technical sciences, Associate professor, Head of the Department of Agroengineering and Road Transport, Poltava State Agrarian University (1/3 Skovorody St., Poltava, Ukraine, 36003, e-mail: sergii.liashenko@pdau.edu.ua, https://orcid.org/0000-0002-3227-3738).

ІВАНОВ Олег Миколайович – кандидат технічних наук, доцент, доцент кафедри будівництва та професійної освіти Полтавського державного аграрного університету (вул. Сковороди 1/3, м. Полтава, Україна, 36003, e-mail: oleg.ivanov@pdau.edu.ua, https://orcid.org/0000-0002-1761-9913).
БУРЛАКА Олексій Анатолійович – кандидат технічних наук, доцент, доцент кафедри агроінженерії та автомобільного транспорту Полтавського державного аграрного університету (вул. Сковороди 1/3, м. Полтава, Україна, 36003, e-mail: oleksii.burlaka@pdau.edu.ua, https://orcid.org/0000-0002-2296-7234).
КЕЛЕМЕШ Антон Олександрович – кандидат технічних наук, доцент, доцент кафедри агроінженерії та автомобільного транспорту Полтавського державного аграрного університету (вул. Сковороди 1/3, м. Полтава, Україна, 36003, e-mail: anton.kelemesh@pdau.edu.ua, https://orcid.org/0000-0001-9429-8570).
ЛЯШЕНКО Сергій Васильович – кандидат технічних наук, доцент, завідувач кафедри агроінженерії та автомобільного транспорту Полтавського державного аграрного університету (вул. Сковороди 1/3, м. Полтава, Україна, 36003, e-mail: sergii.liashenko@pdau.edu.ua, https://orcid.org/0000-0002-3227-3738).