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Intelligent liquid level controller

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Abstract. The process controller created by using intelligent control system has become more and more widespread use at present. Using the example of an intelligent liquid level controller the development order of an effective controller with intelligence functions is considered in the present paper. Intelligence functions consist in presetting control parameters with elimination of uncertainties inherent in real objects and automatic control systems: sensor and actuator hysteresis, nonlinearity of the regulator's characteristic and so on. The results of experimental bench test of such a controller are presented.

1 Introduction

The relevance of the development of intelligent control systems (ICS) is primarily due to the emergence and development of high technologies associated with the widespread use of computing technology, allowing to replace traditional control schemes with negative feedback using the capabilities of artificial intelligence [1-5]. The use of such systems is justified in cases when automated control systems with constant coefficients operate unstably or their use is impossible at all due to the presence of uncertainties and significant nonlinearity of the control object parameters [6-8]. Intelligent control systems are applied in many fields, such as geological exploration [9].

ICS, which include blocks of probability forecasting using the capabilities of neural networks, make it possible to control the technological process quite easily and with high efficiency. At the same time, there is no need to increase material costs for modification of electronics of the control system (application of correctors, predictors and other functional blocks typical for traditional control systems), as all necessary data-processing operations are assigned to the controller of the regulator, which has sufficient memory and speed of calculations [6-8].

2 Materials and methods

This paper represents some experience in creating ICS for a real object, namely a flow tank, the schematic of which is shown in Figure 1. The task is further complicated by the fact that

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some sensors are not available (in particular, inflow and outflow flow meters) and the existing ones have design flaws that affect the accuracy of the readings.

The difficulty of control in this case is primarily due to the uncertainty introduced by the hysteresis of the potentiometric level sensor, which causes a transport lag as well as an insensitive zone at levels below 10% of the scale. Level forecasting by the opening degree of the regulator valve on the inflow also becomes a difficult task due to its significantly non-linear characteristic and the lack of a tank flow sensor.

Usually relay control system is used for regulation of such objects according to the established practice. The accuracy of level control does not exceed 10-15% of the scale, which is determined by the hysteresis of the sensor itself and the need for constant switching on and off of the pump drive. In addition, there is no possibility to change the set point level due to the static parameters of the relay control circuit.

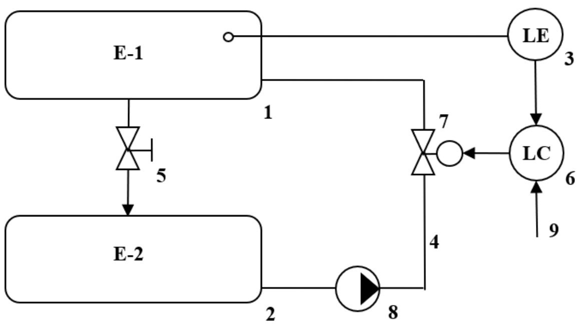

Fig. 1. Functional diagram of the automated control system: 1 – flow tank; 2 – drain tank; 3 – floating level sensor; 4 – fluid supply line; 5 – full port ball valve; 6 – level controller; 7 – control valve; 8 – centrifugal pump; 9 – level setter.

The application of a controller based on the use of negative feedback with constant coefficients in this case leads to instability caused by a large transport lag and significant variations in the flow rate at the outlet.

3 Results and discussion

Start developing the structural scheme of ISC it is necessary to determine the characteristics of the blocks included in the scheme of ISC: the flow tank, as well as the control valve and the level sensor.

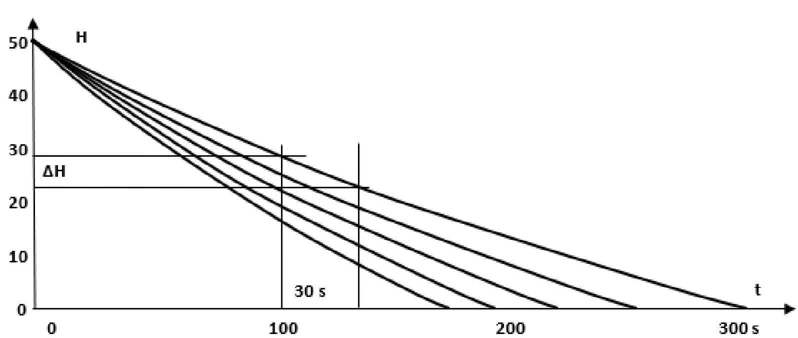

Fig. 2. Characteristics of the E-1 flow tank at different valve openings (5).

Characteristics of the flow tank is shown in Figure 2. The family of curves defines the rate of change of the level in the tank at different positions of the valve on the outflow. The degree of nonlinearity of characteristics, being square-law, is weakly expressed. Therefore, they can be considered as linear with an error of no more than 2% in the operating control range when calculating the flow rate on the outflow.

The flow rate from the tank can be defined using the formulae

$$F_{out} = \frac{\Delta h}{\Delta t} \tag{1}$$

The tank liquid supply control valve has a significantly non-linear characteristic, shown in Figure 3.

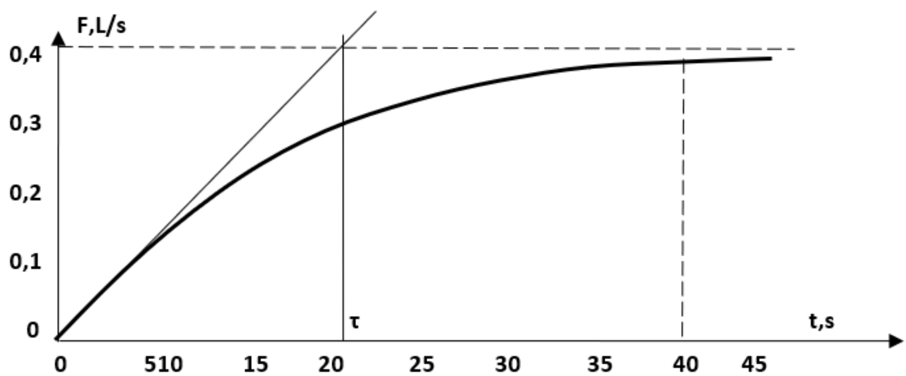

Fig. 3. Function chart of flow rate through the control valve as a function of the opening time of the valve from the initial position.

The valve characteristic is well interpreted by a first degree differential equation. The solution of this equation represents an exponent with parameters: τ =16, k=0,42. To do the calculation we need an expression to calculate the valve opening time for a given flow rate, since there is also no flow meter on the inflow.

This expression is:

$$t_{kl} = \tau \cdot \ln(1 - \frac{F_{out}}{k}) = 16 \cdot \ln(1 - \frac{F_{out}}{0.4}) \tag{2}$$

The level sensor characteristic has a hysteresis of approx. 2 L and the dead zone is below 10 L.

The structural scheme of ISC for the flow tank is shown in Figure 4.

All units except the executive subsystem are part of the control system.

The estimation subsystem contains a configurable analogue-to-digital converter (ADC) unit that receives the level sensor signal. The dashed lines show the calculated flow parameters on inflow and outflow. In addition, the control valve opening time, which is corrected in the control generation unit, is continuously monitored and stored in a database, as are the coefficients τ and k.

The parameter calculation unit performs periodic calculations of inflow and outflow flow rates using formulae (1) and (2). The results obtained are transferred to the database.

The object state control unit contains an analogue-to-digital converter of the level setter signal and controls its change in the process of operation, as well as its compliance with the value of the level in the tank. In addition, a current level control is performed. If necessary, a level drift correction is made.

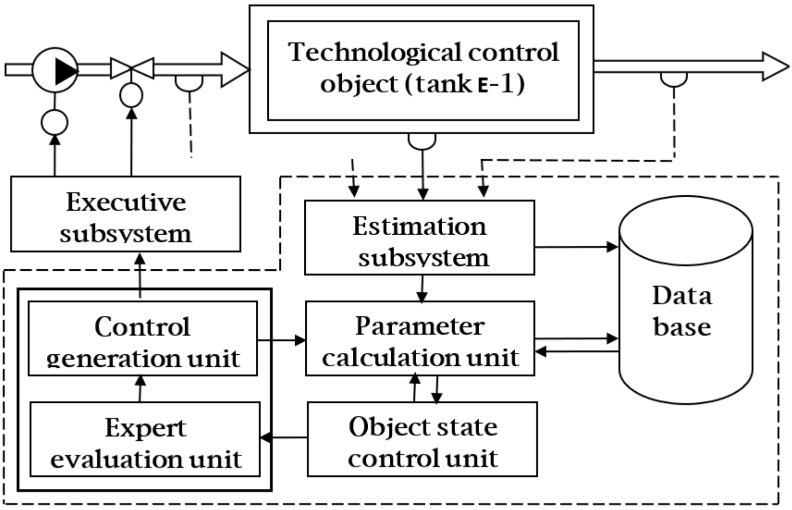

Fig. 4. The structural scheme of ISC of water level in a flow tank.

The expert evaluation unit according to the data of the control unit, as well as the value of the control valve opening, the hysteresis value of the level sensor and the value of its insensitivity zone forms a predictive evaluation of the level state in the tank. This unit also develops recommendations for the control unit to generate control actions in the event of a change in setter position or a change in flow rate on the outflow.

The control generation unit, based on the recommendations of the expert evaluation unit, forms the state of the signals of closing or opening of the control valve drive, respectively changing the value of the valve opening parameter, as well as the state of the signals of stopping and starting the pump drive.

Units of expert evaluation and control generation form a single-layer neural network, whose neuron inputs receive time-distributed values of the difference of current levels in the tank. The weight of the neurons is the same or differ slightly (determined by the degree of nonlinearity of the valve characteristic (2)). The adder unit adds the algebraically weighted values and sends them to the input of the activation function, which calculates the correction value for the parameter t_{kl} of the control valve opening. When an acceptable result of tank level maintenance is achieved, the coefficients τ and k in formula (2) are also adjusted.

Executive subsystem contains anti-interference relay control units for valve and pump actuators.

The database contains the necessary information for the system operation as well as the software of controller.

The operation of the controller consists of two steps. At the first step, the current characteristics are determined: level sensor hysteresis at level rise and fall, as well as the boundary of the insensitivity zone, the values of which are entered into the database and subsequently taken into account in expert evaluation unit.

When the controller is activated after the system has been switched on, the flow rate on outflow is determined, which must be compensated by the flow rate on inflow by raising the tank level to the set value. After switching off the pump drive, the flow rate on outflow is determined by formula (1), taking into account the value of the sensor hysteresis.

Then the pump drive is switched on. The tank is filled to the set level with the controller valve fully open. The formula (2) calculates the time for closing the controller to the set flow condition. The controller closes to the set value. The value of the closing time is stored in the database.

The second step is the operation of ICS for their intended purpose.

During operation of ICS the level in the tank and the condition of the level setter are periodically monitored.

When the level set point is changed, the control valve opens fully (level increase) or closes fully (level decrease). After reaching the set level, the controller is set to the position determined by the t_{kl} value stored in the database.

If there is a significant change in the tank level (more than the set limit), the procedure for determining the flow rate on outflow and the corresponding change of flow rate on inflow is repeated.

The results of the experimental validation of ICS for the object shown in Figure 1 are presented in Figure 5.

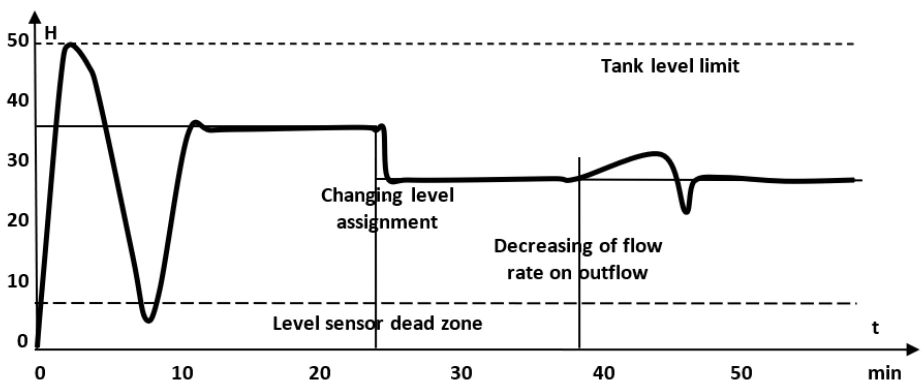

Fig. 5. Diagram of tank level changes during operation of ICS.

The results of experimental verification of the level controller built with the use of ICS allow us to conclude that it is possible to achieve acceptable accuracy of regulation at the limited possibilities of the function chart of regulation.

The observed time delays in the control process are due to the magnitude of the inflow and outflow flow rates.

4 Conclusion

The use of ICS in automatic control systems of technological processes makes it possible to obtain sufficiently acceptable results of control quality at minimum costs.

Application of computer technology allows creating control systems of a new level, including neural network models of a complex non-stationary object, significantly superior to traditional relay control systems and systems using negative feedback in terms of stability, absence of oscillations and accuracy of regulation.

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