Computerized System for Remote Level Control with Discrete Self-Testing

Yuriy P. Kondratenko[1,2], Oleksiy V. Kozlov[2],
Andriy M. Topalov[2], Oleksandr S. Gerasin[2]

[1] Petro Mohyla Black Sea State University, 10, 68th Desantnykiv Str.,
Mykolaiv, 54003, Ukraine
`y_kondrat2002@yahoo.com, y_kondratenko@rambler.ru`
[2] Admiral Makarov National University of Shipbuilding,
9 Heroes of Ukraine Av., Mykolaiv, 54025, Ukraine
`oleksiy.kozlov@nuos.edu.ua, topalov_ua@ukr.net,`
`oleksandr.gerasin@nuos.edu.ua`

Abstract. This article describes the functional structure, human-machine interface as well as software and hardware means of a computerized system for remote control of liquid level with discrete self-testing implementation. The system has a hierarchical structure in which information processing is decentralized, and software and hardware components are removed from each other. The proposed by authors method of self-testing of hydrostatic sensor correctness, that generally increases system reliability, is considered in detail. Resulted system is then tested on computer simulation and experimental setup.

Keywords: self-testing; human-machine interface; modeling; PLC; liquids level measurement.
Key Terms: Research, ICTComponent, Computer science, Industry

1 Introduction

Tasks requiring level measurement of liquid products are extremely diverse and are found in various areas of technology. Level measuring is required in most production processes; in the systems of environmental monitoring and safety; for mass or flow rate of liquid products accounting during their storage and transportation. The urgency of liquids level measurement increases with increasing degree of automation of production processes, monitoring and registration systems.

There are many different methods and devices of measuring the level of liquid products [1, 2]. Some of them are widely used in industry, others have highly specific destination due to certain shortcomings. The most common methods of level measurement are divided into the wave, non-wave and combined.

Wave methods include:

- ultrasonic local;
- radar;

- local laser;
- optical.

Non-wave methods include:

- capacitance;
- hydrostatic;
- buoyancy;
- mechanical float.

Combined include:

- magnetostrictive float;
- float radar.

Effects associated with the spread of electromagnetic or acoustic waves in the liquid, vapor or a mixture of structural elements (waveguides, sound guide pipes) in contact with the environment are used in the wave level measurement methods.

Other principles of measurement based on the change in capacitance of constructive capacitor compiled by pressure liquid column, buoyancy force acting on a body immersed in fluid are used in non-wave level measurement methods.

The combined level meters unite elements of wave and non-wave ones. Magnetostrictive level gauges are fixed by float, which position determination is performed by mechanical vibrations in a sound conductor.

All methods of measurement have inaccuracies and errors limiting the scope of their use. Errors can be partially compensated by various technical means, but as a consequence this obstacle leads for rise in price. The impossibility of full compensation of errors is caused by physical, economic and operational constraints.

The implementation of the digital level control system based on the principles of remote monitoring using the SCADA (Supervisory Control And Data Acquisition) software [3] is considered as the main way of versatile, fast reconfigurable system for remote control with discrete self-testing, which enables monitoring and control of tank liquid level in real time with sufficient precision and self-testing for correct operation of the hydrostatic pressure sensor.

2 Implementation of the Computerized System for Remote Level Control with Discrete Self-Testing

Computerized system for remote level control with discrete self-testing is designed for the measurement of liquid level, volume, temperature and pressure in five tanks as well as automatic alarm signalization in case of the acceptable limits exceeding of the above-mentioned values [4] or if the system self-testing operation regarding no exact measurement of liquid level.

The main technical parameters of the measurement and control system are: liquid operating temperature is −50..+120°C; the range of the measured liquid level is in range of 0..30 m; operating pressure in the tank is 0..0.3 MPa; the distance from the tanks to the control station is more than 50 m. Relative error should not exceed 0.5%.

The functional diagram of the proposed remote system of level measurement and control is shown in Fig. 1, where the following abbreviations are accepted: OTS –

operator touchscreen; PLC – programmed logical controller; TDAM – temperature data acquisition module; CIM – current input module; DIM – discrete signals input module; DOM – discrete output module; TS, PS – the sensors of temperature and pressure respectively; HPS – hydrostatic pressure sensor; FLS – float level switch; *L*, *T*, *P* – the values of liquid level, temperature and pressure in the relevant tanks; *V* – drain valves; *Q* – the value of liquid flow at the opening drain valve.

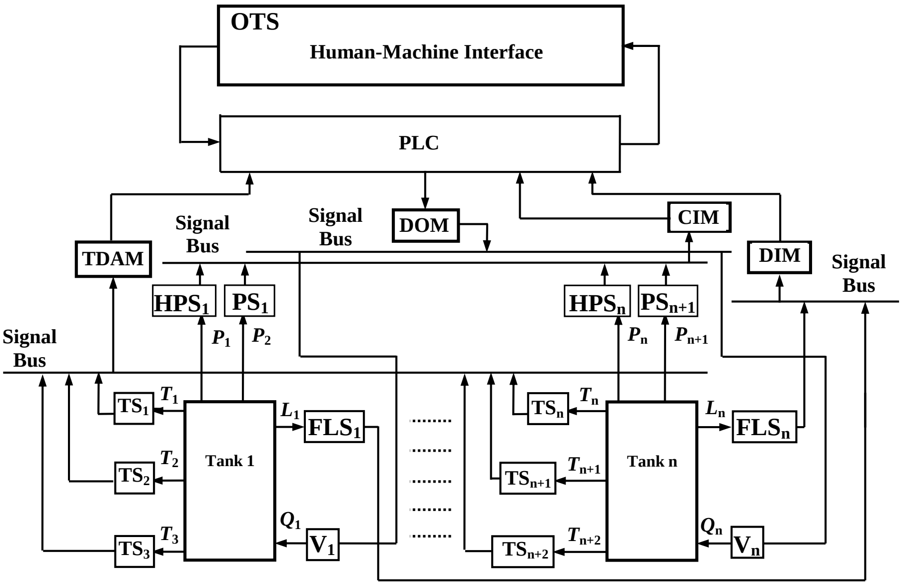

Fig. 1. The functional diagram of the system of remote level measurement and control.

Three-tiered SCADA-system for remote level control with discrete self-testing is developed by the authors on the basis of TRACE MODE 6 software package.

It is advisable to use PLC and I/O devices of the ICP DAS company as hardware means in the developed computerized liquid level control system. The advantages of this hardware include industrial design, versatility of application and easy integration into modern widespread SCADA systems. Also, products of the ICP DAS company possess big life cycle and high reliability as well as the optimal combination of cost and quality.

The TRACE MODE is used in this computerized system for remote level control as a software platform. The TRACE MODE software has its own integrated development environment with more than 10 editors arranged in it. Moreover, it includes the built-in drivers for more than 2572 PLCs and I/O devices (including the products of the ICP DAS company) and has its own industrial real time database management system. The perfect 3D graphics and at the same time easiness of the graphical editor can be also considered as the benefits of the TRACE MODE software.

The lower level of the developed system include the following sensors and actuators: Dwyer Instruments 673-type pressure sensor, thermocouples of the L-type, discrete float level sensors and normally closed Jaksa D224 valves. The average level (level of controllers) consists of programmable logic controllers and the peripheral input/output (I/O) modules: PLC ICP DAS WP-8131 [5] is used in the given control and measurement system as the main execution unit; ICP DAS I-7018P modules are used as the data acquisition modules for the thermocouples readings; ICP DAS I7017C modules with current input signal are used for data acquisition from the pressure sensors; ICP DAS I-7051 module for 16 inputs is used as the data acquisition module for the discrete input signals; in addition, ICP DAS I-7061 module with 12 relay power outputs is used for valves control. The upper level is a level of visualization, dispatching (monitoring) and data acquisition. Therefore, steering computer is equipped with a real-time monitor TRACE MODE 6 for successfully launching of liquid level control system with discrete self-testing.

To measure the level and temperature values of liquids each tank of the remote level measurement system according to Fig. 1 is equipped with: two analog pressure sensors (PS and HPS), three temperature sensors (TS) and one discrete level sensor (FLS). The values of level, temperature and pressure are measured with specified sensors in each tank. The according data acquisition module then converts the analog signals from sensors into the proper digital ones, which are transmitted to the PLC.

PLC receives the data of process parameters and gives control commands to the actuators. PLC-based control is performed by previously developed algorithm that is executed cyclically (receiving data – processing – control commands delivery (forming)). The information on the current values of level, temperature and pressure in each tank are displayed on the OTS with the help of the specialized human-machine interface developed in TRACE MODE 6 software.

In each tank the level of liquid is measured using the hydrostatic pressure sensor, installed in the lower point of the tank, and pressure sensor, placed in the upper point of the tank. The float level switch is used for self-testing operations implementation and accuracy increasing of the proposed system. The current values of the pressure from the PS and HPS are transferred to the current input module (I7017C). Then this module converts the value of the measured pressure (range 4…20 mA) into the digital signal. Then the digitalized signals are transferred to the PLC by RS485 bus with DCON protocol where level value is calculated taking into account average temperature in the tank and liquid density.

The average temperature values of the liquid are calculated for each tank separately as the arithmetic mean on the basis of the data received from the 3 temperature sensors ($TS_1 \ldots TS_3$) installed at different levels of tank height (in the lower, middle and upper points). In this case, the thermocouples are used as the temperature sensors which signals are transmitted to the data acquisition module (I-7018P).

Besides liquid level measurements, the developed system is able to calculate liquid volume V_L in each tank based on the polynomial formula [6], that is used for tanks with regular (box, cylinder) and irregular shapes

$$V_L = a_1 L^4 + a_2 L^3 + a_3 L^2 + a_4 L + a_5 , \qquad \mathbf{(1)}$$

where L – measured value of the liquid level in the tank; a_i − experimentally obtained polynomial coefficients, $i = 1…5$.

The pressures in the tank as well as the discrete readings of the average value of the level are measured by the PS, HPS and FLS. The signals from the sensor's data are, in turn, transmitted to the current and discrete data input modules.

Designed system also has the function of output valves control. The normally closed valve is programmatically opened if the level in the tank exceeds the user-specified level limit and remains open until the level of liquid in the tank returns to the specified boundaries.

Thus, the authors used two thermocouples data acquisition modules with 8 inputs each, 1 current input module with 10 inputs, 2 discrete input modules with 8 inputs and 1 discrete output module as the data input/output modules for the designed system.

To improve reliability and accuracy of the proposed system the authors developed discrete self-testing method for liquid level control systems [7].

3 Discrete Self-Testing Control of Liquid Level

For realization of the proposed method of automatic liquid level control with discrete self-testing two gauges are installed within the tank workspace (area). The first gauge is made as a hydrostatic pressure sensor, and the second measuring device made as a discrete fixed level sensor and installed on the side of the tank. The essence of the proposed method of control of liquid level in tanks with discrete self-testing is as follows.

Initialization of system components (PLC and I/O modules) is performed at the beginning (block "Start" in Fig. 2). Then hydrostatic pressure sensor, located at the bottom of the tank, measures the current value of the liquid hydrostatic pressure P_L. After that, the values of pressure (Pa) recalculated in level value of liquid (m) by the equation for hydrostatic pressure [8, 9] that binds level value L, the density of the working fluid ρ_L and the gravitational acceleration g.

At the next step the difference ΔL between the fixed value level L_S, where discrete sensor FLS installed, and the level value L, measured using HPS in the previous step of the algorithm, is calculated.

Then the absolute value ΔL_A of the obtained difference ΔL, which corresponds to the level measurement error of hydrostatic pressure sensor relative to the fixed level value (height) of the discrete sensor FLS installation, is determined. During the tank filling/emptying the current liquid level L approaches to a fixed level value L_S and module of their difference ΔL_A gradually decreases.

The main stage of the self-testing method for level control system in the tank occurs at discrete sensor FLS triggering. PLC observe this time moment as the moment when the derivative value changes from the signal at the output of the discrete level sensor. When filling the tank, the liquid level increases and reaches a fixed value (where the FLS is installed), the electric contacts of the FLS are locked. At the FLS contact closure signal differentiating a certain positive value D is formed. In turn, if the current liquid level value in the tank decreases relatively fixed level L_S electrical contacts of fixed FLS are unlocked. At the FLS contact unlocking signal differentiating a certain negative value *D* is formed. In either case (at the tank filling and emptying) the change in the absolute value $D_A = |D|$ of the signal from the FLS output after differentiation is monitored. When the obtained value D_A becomes greater than zero $(D_A > 0)$, the transition to the next step of the algorithm is performed.

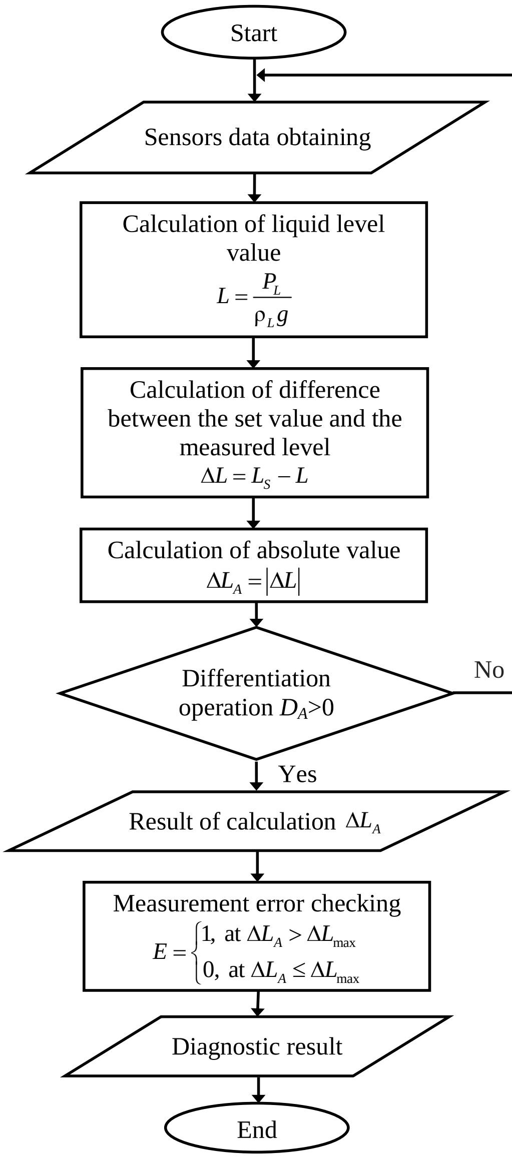

Fig. 2. Discrete self-testing algorithm for remote level control system.

On this step the current value of ΔL_A is recorded in the measurements database that can be subsequently used for correcting of liquid level values in the tank measured by hydrostatic sensor ("Result of calculation ΔL_A" step in Fig. 2).

Then PLC checks whether the obtained level measurement error value ΔL_A exceeds some maximum permissible value, which is the maximum acceptable value of liquid level measurement error $\Delta L_{\max}$ for hydrostatic pressure sensor HPS (set by the operator based on the required accuracy of level measurement and value of a fixed level for installed FLS).

Thus, self-testing process of analog measuring device HPS is implemented in the system: logical one pulse signal appearance in the variable E ($E = 1$) indicates hydrostatic sensor fault at FLS triggering. Consequently, the situation, where $E = 0$ at FLS triggering, corresponds to hydrostatic sensor operability and its functioning with a given accuracy ($\Delta L_A \leq \Delta L_{\max}$).

The diagnostics results of the analog sensor (operability/fault) are displayed on the operator panel ("Diagnostic result" step in Fig. 2).

The diagnostics results of the analog sensor (operability/fault) are displayed on the operator panel. At the same time, the current value of ΔL_A is recorded in the measurement's database that can be subsequently used for correcting of liquid level values in the tank measured by hydrostatic sensor ("Diagnostic result" step in Fig. 2).

Self-testing procedure can be finished ("End" step in Fig. 2) depending on user-generated conditions and other factors, such as a periodic operability checking of analog pressure sensor, low computing capacity of controller and so on.

Thus, the operability state of the hydrostatic pressure sensor HPS is performed in the proposed liquid level automatic control system every time at the filling and emptying of the tank, especially at the liquid level transition through fixed value L_S and discrete sensor FLS triggering (locking / unlocking of electric contacts), by self-testing method.

The described operations with physical quantities are implemented in practice in the algorithm with digital signals in the PLC. There other approaches to the proposed self-testing method implementation are also possible using separate electronic units, FPGA-based systems [10], etc.

4 Human-Machine Interface of the Computerized System for Remote Level Control with Discrete Self-Testing

SCADA is the main and remains the most prospective method for automatic control of complex dynamic systems (processes) in the vitally important and critical (in terms of safety and security) situations [11, 12]. Nowadays there is a real growth of SCADA-systems implementation as well as modernization of existing automatic control systems in different branches of economics and industry [13-16].

In the computerized system for remote level control with discrete self-testing the human-machine interface (HMI) is realized using the tools which are provided by the basic version of the SCADA-system TRACE MODE 6 [17, 18]. The designed HMI has multi-window interface. Main screen (Fig. 3) provides the visualization of the main indicators of the level control system on the operator control display and also grants an ability to set needed ranges of parameters. The indication of exceeding the tolerance values is provided by changing the color of the displayed value from black to red (T Bot readings of the fifth tank in Fig. 3) and by indication of the state of the discrete sensors. In Fig. 3 the green color corresponds to the open state of discrete sensors (there is no liquid at this level) and the red color corresponds to the close state (the sensor has been submerged into the liquid). The same applies for the diagnostics results of the HPS, that are also displayed on the operator panel (green color corresponds to operability state and red color means fault). Designed software also includes the additional graph screens, which indicates the dynamic of main indicators changes.

Tank 1
Level 22.61 m
Vol 70.99 m3
Pres 0.01 KPa
T Top 23.7 C
T Mid 22.81 C
T Bot 24.53 C

Tank 2
Level 0 m
Vol 0 m3
Pres 0 KPa
T Top 22.36 C
T Mid 22.54 C
T Bot 22.45 C

Tank 3
Level 30 m
Vol 94.2 m3
Pres 1.2 KPa
T Top 3.71 C
T Mid 3.58 C
T Bot 3.63 C

Tank 4
Level 7.18 m
Vol 21.3 m3
Pres 0.01 Kpa
T Top 35.7 C
T Mid 34.87 C
T Bot 27.81 C

Tank 5
Level 15.01 m
Vol 48.95 m3
Pres 0.02 KPa
T Top 75.31 C
T Mid 110.8 C
T Bot 130.73 C

Tank 1 Valve
Tank 2 Valve
Tank 3 Valve
Tank 4 Valve
Tank 5 Valve

Fig. 3. Main screen of the HMI of the remote level control system with discrete self-testing.

The proposed in section III algorithm is implemented in the FBD language program (Fig. 4) as well as other required data processing algorithms (for range checking, values conversion, etc.) are executed directly in the PLC.

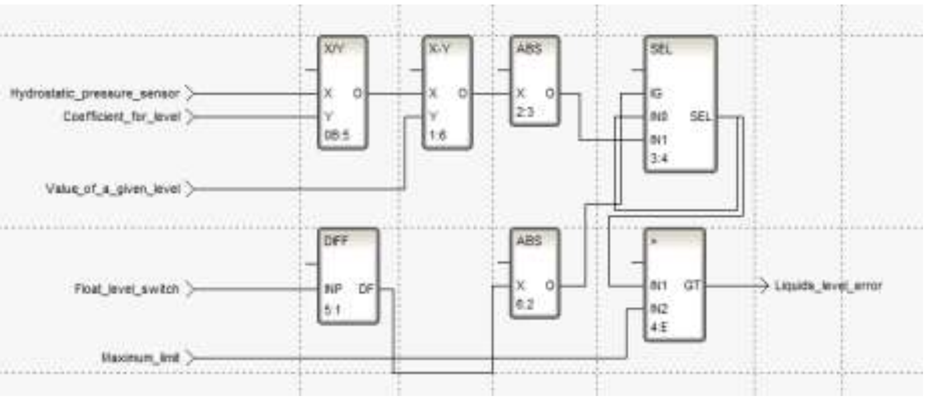

Fig. 4. FBD-based program for discrete self-testing implementation.

The developed HMI of the proposed liquid level control system with self-testing based on SCADA Trace Mode 6 is reconfigured directly in the PLC using program possibilities of Micro Trace Mode 6.

5 Computer Simulation of the Computerized System for Remote Level Control with Discrete Self-Testing

The results of computer simulation are shown in the time diagrams in Fig. 5. The liquid level L in the tank is in three states separated by time frame: the process of the level increasing in the tank from 0 m to 10 m (from 0 s to 2 s); constant liquid level in the tank (L = 10 m, from 2 s to 6 s); the process of the level decreasing in the tank from 10 m to 0 m (from 6 s to10 s).

Throughout the time interval from 0 to 10 s the registered electrical signal, which is coming from the HPS and corresponds to the current value of the liquid level in the tank L, is compared with an electrical signal that corresponds to a fixed level value L_S, on which the FLS is placed. The electrical signal, that corresponds to hydrostatic pressure sensor measurement error ΔL_A, is formed based on the mentioned above signals comparison. Diagnosing process occurs at transition of liquid through the fixed level value L_S and fixed float level switch activation (the 1 s and 8 s time moments in Fig. 5). Increasing of the FLS signal F from 0 V to 5 V (1 s) and F signal drop from 5 V to 0 V (8 s) form a certain positive and negative values of differentiated signal D. The absolute value D_A of the signal from the FLS output after differentiation operation is formed as $D_A = |D|$. At time instants (1 s and 8 s) when D_A is greater than zero, the level measurement error ΔL_A is compared with the maximum limit of the level measurement error ΔL_{max}.

When data signal ΔL_A doesn't excess maximum threshold ΔL_{max} ($\Delta L_A \leq \Delta L_{max}$), for example, at time 1 s (Fig. 5), the signal E (indicator of the hydrostatical pressure sensor fault) remains zero (E = 0). The result of self-testing procedure is the correct operation (the serviceability) indication of the installed HPS.

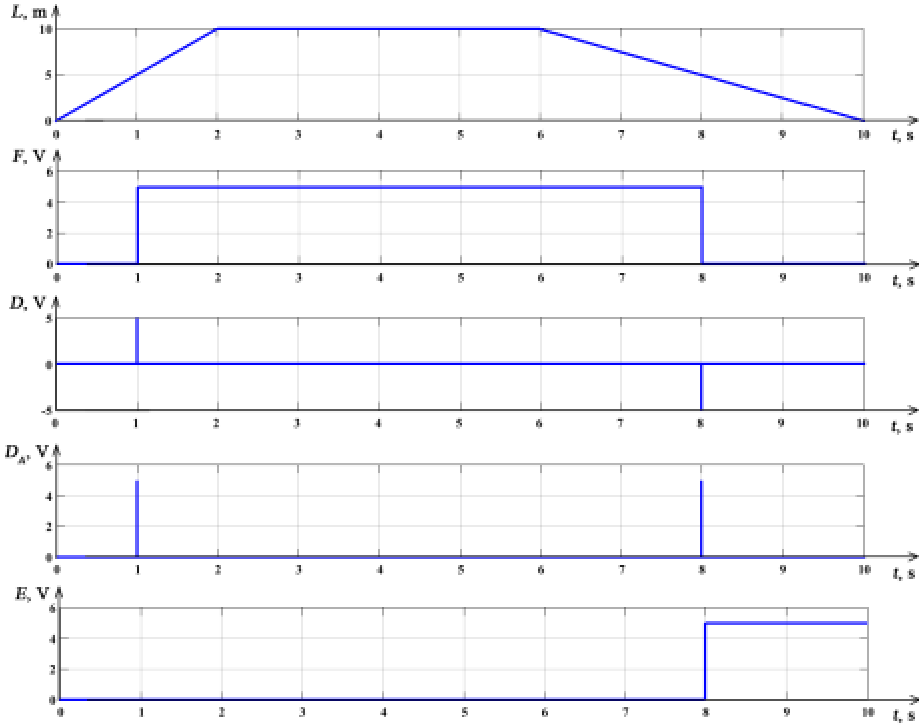

Fig. 5. Simulation time diagrams of the liquid level control system with discrete self-testing.

When data signal ΔL_A excess maximum acceptable value of the liquid level measurement error in the tank ΔL_{max} ($\Delta L_A > \Delta L_{max}$), for example, at time 8 s (Fig. 5), the indicator of the hydrostatical pressure sensor fault E signalizes about HPS fault (E = 1), that means incorrect operation. The result of self-testing procedure is the incorrect operation (malfunction) indication of the installed HPS.

Thus, the discrete self-testing procedures of the hydrostatic pressure sensor occur at every moment of discrete fixed level sensor activation (on/off) during the entire exploitation time of the corresponding tank. This gives the opportunity to perform the ongoing monitoring of the specified accuracy of the liquid level measuring as well as serviceable or faulty state of the liquid level control system HPS without conducting of periodic diagnostic checks and specialized maintenance procedures. The given quality reduces the probability of occurrence of undesirable situations or emergencies on the technological objects caused by incorrect liquid level measurements. This allows increasing safety and reliability of the technological objects [19], in particular, such an important indicator as the probability of their failure-free operation (PFFO).

Also, timely detection of low accuracy or malfunction of the hydrostatic pressure sensor allows carrying out its repair or replacement on time, that, in turn, reduces maintenance costs as well as increases safety and durability of the developed computerized liquid level control system itself [19]. Namely, increases such an indicator of system's reliability as its mean time to failure (MTTF).

Therefore, the proposed discrete self-testing method gives the opportunity to increase the reliability and safety of the given computerized liquid level control system itself as well as of technological objects in which it is applied.

6 Conclusion

In this work, the authors described the structure and main components of developed computerized system for remote control of liquid level in tanks with discrete self-testing method implementation. The self-testing procedures provide increasing of reliability and accuracy of the developed computerized system for remote level control as well as reduction of periodic diagnostic checks of hydrostatic pressure sensors serviceability. The proposed system structure can be easily adopted for bigger systems and successfully implemented into existing control and monitoring systems of plants, ships, floating docks, etc.

The designed human-machine interface of the proposed system for remote control, measurement and monitoring of the liquid's level allows the necessary information displaying on the main operator screen. Also, it provides the indication of liquid level error presence in real time mode for each hydrostatic pressure sensor placed in the tank. The information both on current indications of the system and the dynamics of their change through the graphic panels on each of the controllable parameters is available to the operator.

Temperature and pressure readings control inside the tank together with the discrete self-testing algorithm based on float level switches improve the reliability and accuracy of measurement and control, as well as reduce maintenance costs under conditions of prolonged exploitation.

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