Computerized Intelligent System for Remote Diagnostics of Level Sensors in the Floating Dock Ballast Complexes

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Abstract. In this work the development of a specialized computerized system for remote diagnostics of level sensors of floating dock ballast system is presented. Ballast system of floating dock and requirements for reliable measurement of liquid levels in ballast tanks are described in detail. The hierarchical functional structure of the proposed remote diagnostics system consists of a multiprocessor computing complex with the corresponding software and the branched structure of digital devices. The authors propose the method of checking the correctness of level sensors that generally increases system reliability. The diagnostics calculations of the measurements correctness of the level sensors are performed on the basis of programmable logic device (PLD) with the Field-Programmable Gate Array (FPGA) architecture. The collection of diagnostics information from PLD is processed by a single-board computer that transmits data via the Internet to the cloud service "ThingSpeak". The overall results of work of the remote diagnostics system for level sensors are displayed graphically in real time on any, specialized for these tasks, computer or mobile device that has Internet access.

Keywords: diagnostics; cloud service; modeling; FPGA; liquids level measurement, single-board computer.

1   Introduction

The floating dock is a complex technical construction mainly intended for performance of docking operations of immersion and emersion with the vessel and without it. Though in some cases the specialized floating dock is used as a platform for vessels' transportation on shallow ways [1, 2].

Among the complex of floating docks systems the ballast system is the main one to perform docking operations, because the processes of filling and emptying of the ballast tanks lead to changes in the floating docks draft. Another important function for ballast system is eliminating of critical deformation of the floating dock and unwanted inclinations due to distribution of liquid ballast among the ballast tanks.

Moreover, the tanks of a dock are a part of the volume durable body in pontoons or towers, separated by watertight partitions from another volume. The correct ballasting and reliable level control of the ballast compartments guarantee the safe operation of floating dock.

Calculation of ballast system needs to be carried out for set time on the natural flooding of the floating dock. The pressure head of the outboard water coming into the dock is constantly changing. It is impossible to obtain the same resistance of the pipeline from any outlet valve or damper to any ballast tank without excessive complication of the valves. Accordingly, levels of water in ballast tanks at different time intervals may be differ from the given values. So, the calculation is carried out at the time of filling the most distant tank from the receiving hole.

This circumstance in case of simplification of the diagram and valves complicates operation of computer control system software and the Dockmaster-operator. For uniform filling of the dock it is necessary to manipulate gate valves, accelerating, decelerating water inflows in this or that tank depending on water level indices in tanks.

Operational control of ballast compartments' parameters with high precision and timely control of ballast supply for dock operations performing as well as ensuring of the absence of dangerous inclinations and large deflection is a complex problem.

Consequently, the problem of efficient operation of complex technical objects, which includes a floating dock, arises in the field of precise and reliable measurement. So, solutions of tasks of sensors' choice and their technical diagnostics should be obtained along with automation of floating dock. The questions of parameters measuring and calculating of the floating dock in one way or another are considered in a number of scientific papers [2-4], [9]. So, the systems of measurement and control of floating docks' parameters are developed using sensors, which are based on different principles of action. In particular, the sensors, that are based on pulsed reflection method and have a single electronic and structural design are used for determination of liquid level parameters of the floating dock [3]. The disadvantage of such solution is the significant mass-size indicators and specialized pipes that have the ability to contaminate. In addition, radar-type sensors find an application for liquid level measurement in ballast compartments [2]. Some sensors allow to measure the level with high accuracy (up to 1 mm). In addition, the accuracy and stability of measurements don't depend on the effect of destabilizing factors (temperature of the medium, evaporation and dust in the tank, the aggressive nature of the controlled product, etc.) when using radar sensors. However, this method has a high cost service of automation level control systems due to the periodic carrying out of preventive checks of the radar sensors normalcy. Also membrane type sensors [9], in which the deflection of membranes under the pressure of a water column is converted into the resistance of the electrical circuit, are used. Such sensors have flaws related to the sensitivity to frost, which may cause a failure of measurement accuracy.

Today measurement and control of parameters of technological processes of floating docks are carried out using SCADA (Supervisory Control and Data Acquisition) systems regardless the sensor types. Using of SCADA systems allows collecting information about technological process, provide an interface with operator, accumulate

database and implement automatic control of the executive mechanisms. An important feature of SCADA-systems is the question of controlling the reliability of the process and emergencies prevention. In the case of non-complicated technical diagnostics, you can restrict the standard capabilities of commonly used SCADA systems. Operations with events, analog and digital alarms should be related to standard diagnostics testing capabilities of SCADA systems [5-10]. SCADA-systems are complemented by additional software, hardware and diagnostics equipment to implement more complex technical diagnostics.

Particular attention deserves the approaches of technical diagnostics of industrial information control systems based on programmable logic. The development of control and diagnostics equipment of various applications based on PLD with FPGA architecture is considered in a number of papers [11-13]. Active FPGAs are implemented to provide information safety and cyber security of information and control systems for nuclear power plants [11]. In work [12] the method of self-testing of digital circuits at the enterprise of their manufacture is considered, where in the given circuits at the time of production control the necessary diagnostics support is installed. Also, FPGA technology for technical diagnostics found its application in radio communication with the transmission of information at a distance along the radio [13].

Thus, the issue of designing of effective high-precision computerized systems for controlling parameters of the floating dock with the use of diagnostics equipment, software and hardware remains open. Using new types of sensors and modern principles of constructing of distributed control systems based on SCADA software systems will give the opportunity to solve this problem, create a universal highly effective computerized control system, and control the parameters of the floating dock.

2 Functional Structure of Computerized System for Monitoring and Control of Ballast System Parameters of Floating Dock

The ballast system of the floating dock can have a linear or circular pattern in keeping with the design and carrying capacity of the floating dock. In the linear scheme the pumps are arranged on one board of the floating dock pontoon and connected to the distribution box, which distributes the processes with the corresponding gate valves to the ballast compartments. In turn, the distribution boxes are connected by linear pipelines with gate valves. The linear scheme provides pumping of water by the pump of the neighboring distribution box at the emergency failure of any of the pumps. The circular circuit consists of two board masters, connected by at least two jumpers. The main line combines ballast pumps and ballast compartments with spindle shutters. At the event of failure of part of the pumps on the ring system, such a system allows to pump water from any compartment by other pumps.

Regardless of the ballast system, the general view of the location of ballast compartments on a number of floating docks is shown in the Fig 1. From the drawings one can see that the ballast tanks of large capacity BT13-BT18 are located in the central part of the dock, and ballast tanks of small capacity BT1-BT12 - in the bow and stern.
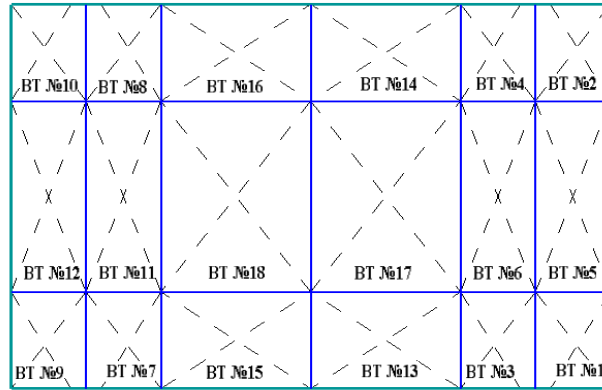
Fig. 1. The layout of the ballast tanks

The authors developed a special multifunctional computerized system based on the remote monitoring and control principles using multiprocessor devices and SCADA software [8] for control of level and physical parameters of liquid products in ballast floating docs. This system is built on a modular (variable-configuration) structure and has a separate distinct system of remote technical diagnostics using cloud-based ThingSpeak technology.

The functional structure of intellectual computerized system of monitoring and control of fluid level is shown in Fig. 2.

Each tank of the floating dock is equipped with pressure sensor PS, three temperature sensors TS, one discrete level sensor DLS (or float level switch), hydrostatic pressure sensor HPS and an input IV and output OV valve.

Level sensors and temperature sensors are used to obtain information of current level L and water temperature T in ballast tanks. A discrete level sensor is required for fixing a certain level value. The pressure sensor PS serves to determine the presence of excess pressure P inside the tanks.

Output signals from sensors are transmitted to the data acquisition module (DAM), which transforms analog signals to the corresponding digits that are transmitted to the PLC (Programmable Logic Controller). The PLC contains a program unit for calculating the dataset parameters, a program unit for liquid volume calculation, and a program control unit for valves. All of them are implemented using specialized SCADA TRACE MODE software [9]. The information about current values of the liquid level L in each ballast tank of the floating dock is displayed on the operator's computer screen (OTS) using a specialized human-machine interface.

The human-machine interface allows operator to control input and output valves for filling and emptying the ballast tanks by controlling the flow Q. Control signals arriving from the OTS are processed in the program control unit for valves and sent to the discrete output module (DOM). In turn, DOM implements the distribution of discrete signals which mean opening and closing of IV and OV.
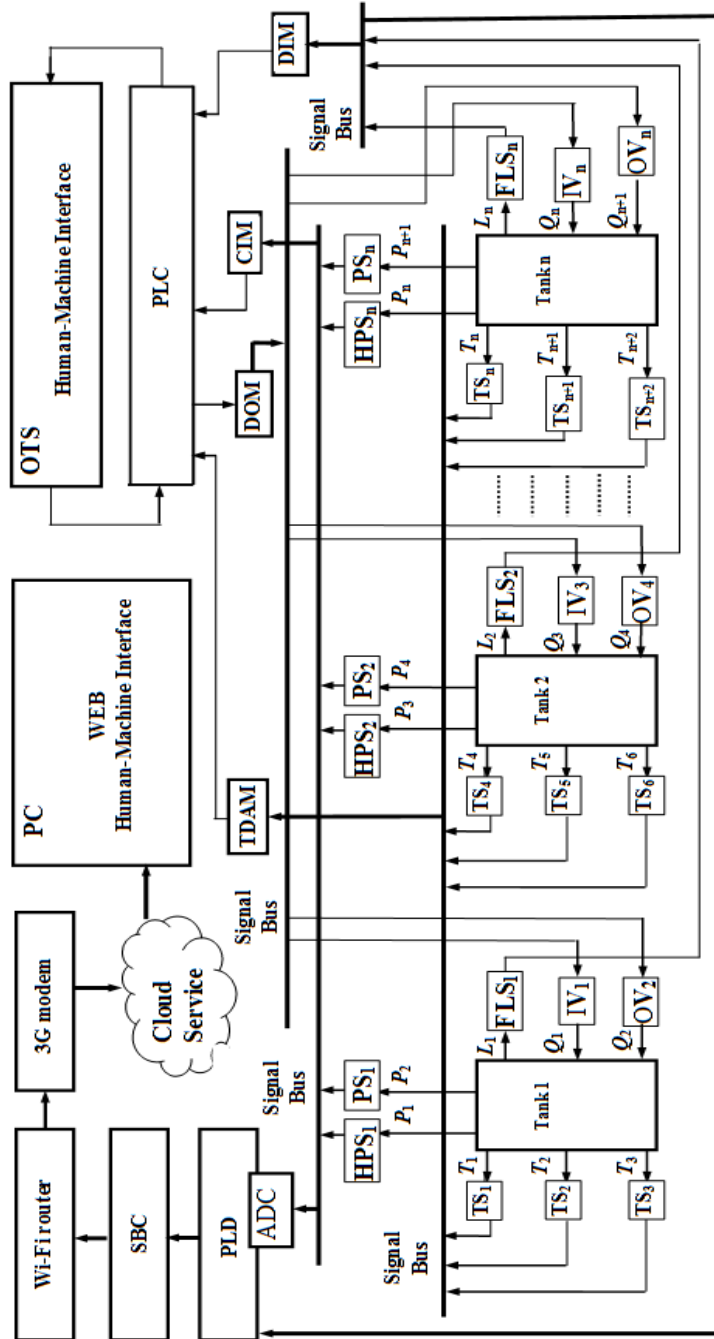
Fig. 2. The functional structure of intellectual computerized system of monitoring and control of fluid level.

This computerized system of monitoring and control of ballast tanks' parameters is also equipped with a computerized intelligent system for remote diagnostics of level

sensors. The diagnostics equipment should include discrete level sensors, PLD along with an analog digital converter ADC, single-board computer, WiFi router, 4G modem and ThingSpeak cloud service.

Data from hydrostatic and discrete sensors processed using a programmable logic device PLD with FPGA architecture, which, according a specific VHDL models, determines state of the hydrostatic and discrete sensor. To the diagnostics computing equipment should include the PLD, a single-board computer, WiFi router, 4G modem, cloud service ThingSpeak. Diagnostics information from PLD processed by a single-board computer that transmits data through Internet network to the ThingSpeak cloud service. Moreover, the Internet on a floating dock is provided by a 4 G modem with the help of global wireless mobile technology 4G (data transfer rate up to 1 Gbit / s) and distributed on the floating dock premises using a WiFi router and additional WiFi access points. The general results of the remote diagnostics system for level sensors are displayed in the ThingSpeak graphically in real time on any computer or mobile device that specialized for these tasks and had access to the Internet.

3 Technical Diagnostics of Level Sensors in the Floating Dock Ballast Complexes

The integrated automation of the floating dock and a large number of sensors is associated with an increased likelihood disturbance of the normal operation mode for automatic control system for filling and emptying of ballast tanks. An effective way to increase the reliability of the automatic control system is the diagnostics procedures of system elements, in particular level sensors.

Diagnostics is the control of level sensors state in order to detect and prevent failures. The diagnostics is carried out using diagnostics tools that can be embedded and external. Built-in tools allow the continuous monitoring. The periodic control is implemented using external means. In our case, a second approach is used in which the state of the sensors is checked at discrete time intervals.

The technical condition of the each sensor for level measuring is characterized by the factors, under the influence of sensor it changes in time, these include the effects of climate conditions, aging with time, regulation of mechanical and electronic components, adjustment during maintenance or repair, etc [14-18].

The sensors for level measuring can operate in different technical conditions. The conditions can be as follows:

1) operative condition - the condition of the sensor, in which the value of all parameters that characterize the ability to perform the specified functions of the sensor, corresponds the requirements of normative as well as technical and (or) design documentation;

2) fault condition - the condition of the sensor, in which the value of at least one parameter does not correspond the requirements of normative as well as technical and design documentation.

3) limit condition - the condition in which further exploitation of an object is inadmissible or inexpedient, or the restoration of the state is impossible or inappropriate.

The statistical estimation of probability of failure-free operation of sensors can be obtained as a result of studies on reliability.

To study N objects to refuse the last object, use the formula:

$$P(t) = \frac{N(t)}{N} = \frac{N - n(t)}{N} = 1 - \frac{n(t)}{N},$$

(1)

where N is the number of sensors, in the course of research; $N(t)$ is the number of working sensors at the time t, $n(t)$ is the number of sensors that stopped working at time t from the beginning of the research.

Often it is necessary to determine the probability of error-free operation of the sensor in the interval of time from t_1 to t_2, which represents the conditional probability that the sensor will not refuse this interval if it has worked without fail until the start of the interval.

Then a static estimate of the probability of failure-free operation:

$$P(t_1, t_2) = \frac{N(t_2)}{N(t_1)} = \frac{N - n(t_2)}{N - n(t_1)},$$

(2)

where $N(t_1)$, $N(t_2)$ is the number of sensors, respectively, at the beginning and at the end of the time interval, $n(t_1)$, $n(t_2)$ is the number of failed sensors, respectively, at the beginning and at the end of the time interval.

The probability of a failure $Q(t)$ is the probability that within the given outputs of the object rejected at least once.

Statistical estimation of the probability of failure in time or work:

$$Q(t) = \frac{N - N(t)}{N} = \frac{n(t)}{N}.$$

(3)

Operative and fault conditions are opposite incompatible conditions that create complete possible group of states of sensors in any time or for any developments.

$$P(t) + Q(t) = 1.$$

(4)

If $P(t=0)=1$, then $Q(t=0)=0$; if $P(t=\infty)=0$, then $Q(t=\infty)=1$;

The probability of failure operations and the probability of failure - dimensionless magnitudes expressed in parts of the unit, sometimes in percent.

The sensitivity of the diagnostics parameter characterized by the ratio:

$$r = \frac{D_{npi} - D_{ni}}{S_{npi} - S_{ni}} = \frac{\Delta D}{\Delta S},$$

(5)

where D_{npi}, D_{ni} – the nominal and limiting value of the diagnostics parameter; S_{npi}, S_{ni} – the nominal and limiting value of the structural parameter.

For the proposed method of technical diagnostics in the working space of the ballast tank two level sensors are installed at an appropriate fixed distance from each other in height of the tank. First sensor is performed as a hydrostatic pressure sensor and the second sensor is implemented in the form of a discrete, fixed-level sensor and

installed higher than the hydrostatic pressure sensor [19]. Moreover, the system of technical diagnostics can simultaneously define not correct measuring one sensor of the given sensors. In case of incorrect measurement of both sensors their performance can be indirectly checked by their power supply.

The level of liquid in the ballast tank is measured by means of a hydrostatic method, which allows the use of devices for measuring of pressure or pressure drop.

According to the hydrostatic method at zero value of the angles of the roll and trim of the floating dock, the real value of the liquid level in the reservoir L_r determined by the formula:

$$L_r = \frac{P}{\rho_l g},$$

(6)

where L_r is the value of the liquid level, measured with the help of LPS; P is the value of the hydrostatic pressure of the liquid, measured with the help of LPS; ρ_l is the density of the liquid; g is the acceleration of free fall.

Technical diagnostics of level sensors is based on PLD with FPGA architecture using VHDL models [20-23], implemented in the form of FSM charts is designed in computing environment Active-HDL (company Aldec Inc, USA). The solution proposed by the authors for technical diagnostics of sensors for determining the levels for one ballast tank is shown in Fig. 3.

The technical diagnostics according to the FSM diagram is carried out as follows:
– initialization of the first state of S1 in which the values of the faulty operation of the discrete level sensor (ErDLS <='0') and the value of the faulty operation of the hydrostatic pressure sensor (ErHPS <='0') are reset;
– in a state S2 measured signal LPS from a hydrostatic pressure sensor, which is preamplified and digitized and in the final form corresponds to the relative units of hydrostatic pressure, are calculated by the formula (6) in value of the liquid level LF of the tank;
– in a state S3 the difference DL is calculated between a fixed level value LF (mounting height of the level digital sensor) and the value of the level LPS, received from the previous state;
– in a state S4 the absolute value L is determined received difference DL, which corresponds to the measurement error of the level sensor of the hydrostatic pressure;
– in a state S5 conduct a test of the discrete level sensor at the time, when the absolute value of the calculated difference between the fixed value of the level LF and the value of the discrete level sensor LPS exceeds the permissible threshold P2 at which should work discrete level sensor at the rising edge of the signal (F=1) with setting values F1<='1', F5<='1' (in a state S12), and at the falling edge of the signal (F=0) with setting values F2<='1', F6<='1' (in a state S11). The values F1, F2 serve to determine the change of the signal of the discrete sensor when the fixed level LF is reached, and F5, F6 - to indicate the switching of the discrete sensor in the range of the threshold value P2, in other ranges the data values F5, F6 are reset.
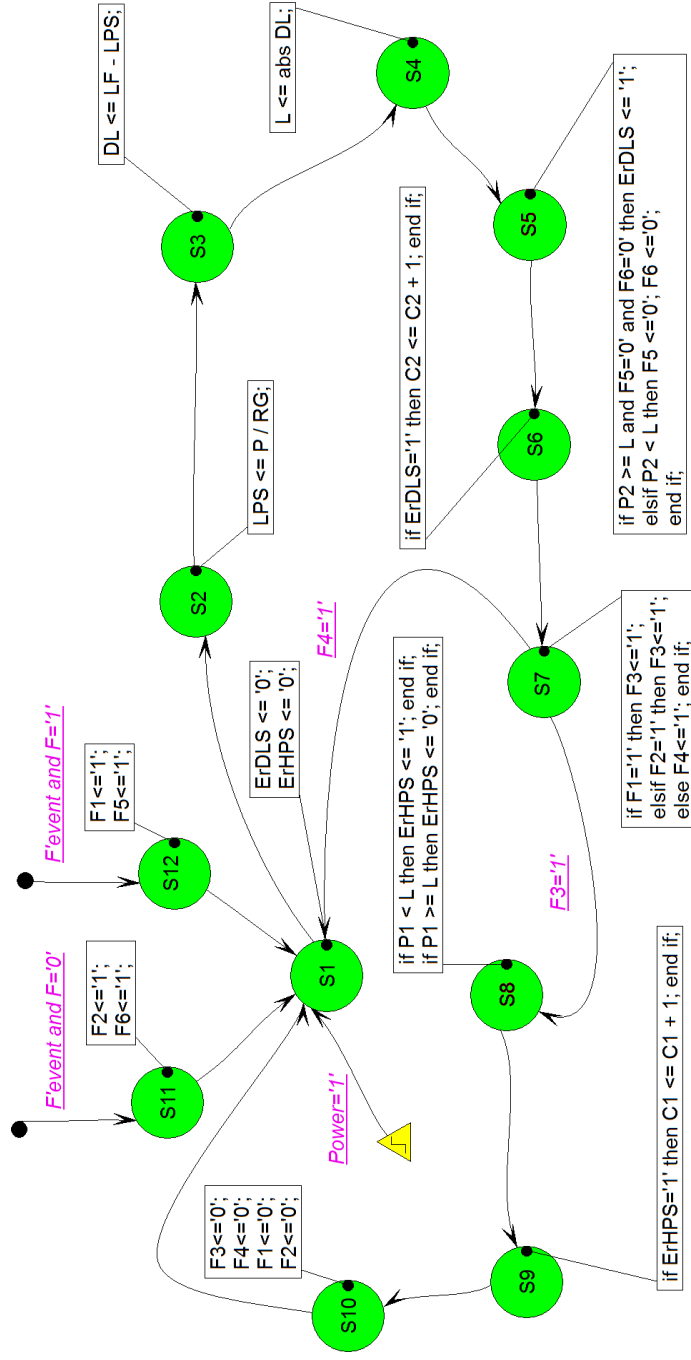
Fig. 3. VHDL model for technical diagnostics of level sensors

Accordingly, when P2 ≥ L and the discrete sensor is not switched (F5 = 0, F6 = 0), an error signal is set (ErDLS <= '1'), the failure of the discrete sensor is detected;
- in a state S6 carried count error counter of the hydrostatic pressure sensor and with each error (ErDLS <= '1') its value C2 is increased by one;
- in a state S7 branching is performed work FSM diagram to two scenarios. The first is triggered on condition (F4=1), which indicates the absence of the operation of the discrete sensor (F1=0, F2=0), in this case work FSM diagram will enter the cycle of states S1→ S2 → S3 → S4 → S5 → S6 → S7 → S1. The second scenario is possible if at the time of the first scenario (cycle), the discrete sensor operates in the case of the rising edge of the signal (F=1) or falling edge of the signal (F=0) and through the states S11 and S12 the corresponding values are entered F1=1 or F2=1, which in the future will activate the condition (F3=1) to go to the state S8;
- in a state S8 checking the measurement error level measurement is performed L to reach the maximum allowable value for this hydrostatic sensor. If the measurement error level L is equal to or less than the maximum permissible inaccuracy P1 (P1 >= L) then the hydrostatic sensor is in working order (ErHPS <= '0'), however, if the value of the measurement error of level L is more than the maximum value of permissible inaccuracy P1 (P1 < L), then the hydrostatic sensor is in fault condition (ErHPS <= '1');
- in a state S9, the value of the number of errors in the hydrostatic pressure sensor is falsified and with each error (ErHPS = 1) its value C1 increases by one;

the completion of the diagnostics of the hydrostatic sensor occurs at state S10 where the conditions of transitions are cleared (F1, F2, F3, F4), after which the work of the FSM of the diagram begins again from the state S1 until the Reset (Power = 1).

The computer simulation results of the proposed technical diagnostics of level sensors are presented at time diagrams (Fig. 4).
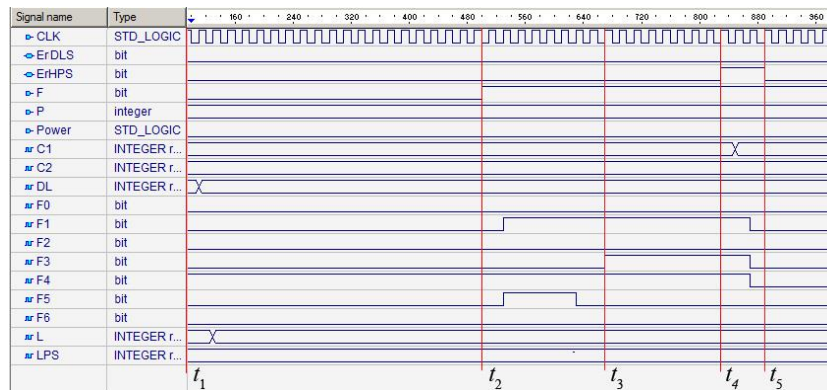

Fig. 4. Simulation of technical diagnostics of level sensors

Modeling of technical diagnostics is carried out for the case of improper operation of a hydrostatic pressure sensor. All signals of the FSM diagram are modeled digitally and linked to the clock pulse generator CLK.

At time t_1 - t_2 there is a constant operation of the sensors in the long-term filling or

emptying of the ballast tank, namely the measurement of the hydrostatic pressure sensor is recorded, and the discrete level sensor remains in the unchanged state, the sensor cycle is performed at the condition of F4 = 1. At time t_2 - t_3, when the liquid level passes through the fixed value of LF, the correctness of the operation of the digital level sensor is checked by comparing its level value with the level value based on the hydrostatic sensor, if the discrete sensor has been switched at this time (in this case on rising edge of the signal F = '1'), this means that it works correctly and sets the value F1 <= '1' , F5 <= '1', then the value F5 is reset as the ballast tank is filled or desolate (P2 < L). At time t_3 - t_4, the condition F3 = 1 is set and the comparison of the registered electric signal coming from the hydrostatic pressure sensor and the correspondence to its current value of the liquid level LF in the ballast tank begins. In this case, the fault of the hydrostatic pressure sensor (ErHPS <= '1') is recorded, since P1 < L, the fault is noted in the sensor errors meter, by increasing the C1 by one. The end of the simulation of the technical diagnostics is accompanied at the time t_4 - t_5 by resetting the conditions F1 <= '0', F3 <= '0', and resetting the error rate ErHPS <= '0'.

4 Processing and Visualization of Data of Technical Diagnostics in Cloud Service

To determine the results of the technical diagnostics level sensors of the ballast system floating dock by specialized staff at the coast control post it is expedient to apply the concept of the Internet of things with modern cloud technologies [24-28].

Various cloud services are available today for processing data: Azure, Freeboard, Blumix, Thingspeak, Thingworx and others. These technologies are actively used to create technical projects. The main features that differ between them are: reliability of data, the speed of processing data streams, the ability to work in real time, etc. But to assess the different Internet of things projects in the nearby future, the standardization is actively rooted in order to form a unified and consistent regulatory normative base for the practical implementation of projects on this or that cloud service. Many international organizations, non-governmental associations, alliances of manufacturers and operators, partner projects are engaged in the issues of standardization and practical implementation of the internet of things projects.

For these tasks, the ThingSpeak service is chosen, which is an open platform for Internet of Things projects with an API for application programming. ThingSpeak allows you to create a software application for monitoring the performance of sensors in real time. An important advantage of ThingSpeak before competitors is the powerful support of MATLAB development tools for data processing and visualization of graphic images.

The organization of this approach for remote technical diagnostics of sensors begins with the transfer of PLD data processing results to a single-board computer that has an Internet access (via a connected WiFi router with a 4G modem). The functions of a single-board computer include the systematization of all diagnostics data of the level sensors as well as the preparation and subsequent transmission of them using the HTTP protocol through the cloud-based ThingSpeak service for subsequent deregulation and visualization.

The data is sent to ThingSpeak in so-called channels, with each channel allowing you to store up to 8 fields of data, using a digital or alphanumeric character each (up to 255 alphanumeric characters each). In the channel, there are also fields for recording the location of the object of monitoring or control (Latitude, Longitude, and Elevation) and others. Each channel has its own unique two 16-value API keys, the first one used to identify the channel when writing data in its fields, and the second one for reading the data from the fields of the same channel. And at suspicion of hacking of keys of channels it is possible always to generate new keys. In general the sphere of information security is actively developing with the use of ever more powerful encryption tools, highly reliable firewalls, and a variety of VPN technologies. Requirements for cybersecurity and risk assessment methodology for industrial information control systems are adapted from the requirements for IT systems [29]. This category has published a large number of NIST guidance documents [30, 31, 32]. Among them, NIST SP 800-82 [32] describes the difference between IT systems and information control systems and provides guidance for protecting systems, including SCADA systems, distributed control systems (DCS) and other systems that perform control functions. In this case, only data sending from the level sensors to the cloud without the possibility of back transfer is implemented as well as the indicators of the sensors are processed at the local control level and indirectly can be compared with the data on the cloud service.

Work with technical diagnostics data in ThingSpeak channels is carried out using periodic POST and GET queries with the indication of the key API and the value for the corresponding channel field. Moreover channel feeds supports XML, JSON, and CSV formats for integration into applications.

Also, downloading data in channels can be implemented through URL-address. For example, if the key is API - XXXXXXXXXXXXXXXX, the URL for updating fields 1 and 2 with values 1 and 0 is the following: «http://api.thingspeak.com/update?key=ABC1234L6789STIV&field1=1&field2=0».

Each used channel of data entry is stored with a date and timestamp as well as assigned a unique entry ID (entry_id). Accordingly, the stored data can be obtained by time or by entry ID.

Thus, in the ThingSpeak service, one channel was used to send and store technical diagnostics data of two level sensors (hydrostatic and discrete). The state of operation of the hydrostatic and discrete sensors is shown on the service ThingSpeak (Fig. 4).

The Fig. 5 shows the process of technical diagnostics of level sensors in real time. The left side shows the operation of the hydrostatic pressure sensor, which, as depicted in the screen during its operation, switched to a non-operating state, the level of the red line changed $(0 \rightarrow 1)$. From the right to properly demonstrate the working sensor at the full time of its ex-operation, the red line is unchanged $(0 \rightarrow 0)$.

In real situations, there will be a need for much higher volumes of diagnostics data transmission of level sensors. The standard ThingSpeak license can be used to measure diagnostics issues of the floating docking system. With a standard license, you can update the data from the level sensors once a second, but in general, this version allows you to process and store 33 million messages within one year. Moreover, recording up to 8 fields in one ThingSpeak channel is defined as a message (each message can not exceed 3000 bytes).
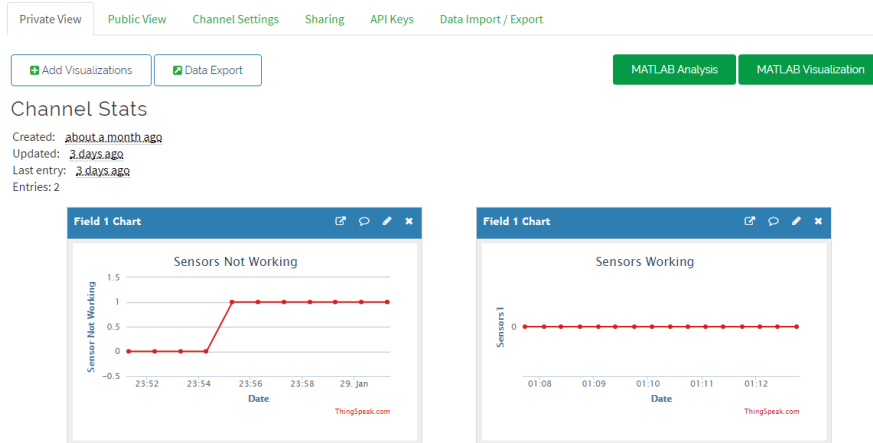
Fig. 5. Web interface of technical diagnostics of level sensors in the ThingSpeak

5 Conclusions

In this paper we propose an approach of designing the intelligent system for remote diagnostics of level sensors in the floating dock ballast complexes. Particular attention is paid to certain requirements for the safety and reliability of the system and the application of technical diagnostics of level sensors.

The process of technical diagnostics involves the presence of an object of diagnostics and a human-operator. The measurement, control and logic operations are performed during the diagnostics. Diagnostics data processing is performed using VHDL models in order to determine the true state of the level sensors.

The information about the current technical state of sensor gauges is displayed graphically on a computer monitor using the cloud-based Thing-Speak service. The results of the evaluation of the states of the sensors are used to make a decision about the further use of one or another sensor.

Further research should be conducted towards the development of the IoT based systems with improving of the network infrastructure through increasing of data transfer performance and connection reliability as well as eliminating of unexpected delays between local level devices and their serving cloud servers.

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