The dairy industry must focus on sanitation and hygiene requirements to ensure product safety, control of detergents, tanks, pumps. Compliance with these requirements will provide conditions for the production of a high-quality dairy product, maintenance of technical and mechanical frequency at the enterprise, and prevention of the reproduction of harmful bacteria. Under these conditions, the problem of cleaning technical equipment from harmful residues on site is urgent. The object of the study is the basic processes in the Cleaning-In-Place system in the dairy industry. It is recommended to design a human-machine interface for on-site cleaning in the Siemens WinCC Flexible software. It is worth noting that the proposed interface takes into account the reduction of equipment downtime during the washing of technological equipment, a convenient user interface, and ease of maintenance. The state of use of existing visualizations of on-site cleaning interfaces that do not use simultaneous washing of two tanks with cleaning solutions (alkaline and acid) and the state of controlled values in selected washing lines were evaluated. Numerical evaluations of the results use modern programming technology and high information productivity of the user interface. A human-machine interface was designed with the possibility of parallel cleaning of two tanks at different ends of the workshop and the selection of recipes for different groups of tanks. This interface displays emergency messages, the status of the washing process of production lines and control based on data from sensors. The practical use of the obtained scientific results is that the designed interface can be used not only in the dairy industry but in any other food industry

Keywords: human-machine interface, dairy industry, systems, cleaning in place, WinCC Flexible

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DESIGN OF THE HUMAN-MACHINE INTERFACE FOR THE CLEANING-IN-PLACE SYSTEM IN THE DAIRY INDUSTRY

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1. Introduction

One of the main branches of the food industry is the dairy industry, which is engaged in the production of milk and various dairy products. The main component of this industry is technological equipment. It affects important indicators of industrial development, such as the volume of industrial products sold, the level of operational profitability, and the share of industrial products.

Hygiene (sanitary standards) is also important in the dairy industry, as there is a high risk of bacterial contamination. Therefore, the cleaning of the production line, tanks and pipelines (pumps) from residues is achieved by designing the CIP human-machine interface. Cleaning In Place (CIP) is an important scientific and technical task for the sanitary washing of technological equipment and pipelines [1, 2]. The type and composition of contaminants, the quality of the water used, the concentration and temperature of the cleaning solution, the speed of its movement and the duration of the treatment, as well as the disinfection technique and the type of disinfectant used, affect the effectiveness of sanitary treatment.

Contamination remaining on equipment surfaces can be of the following types:

– pollution formed when cold milk comes into contact with the surface of the equipment (coolers, pumps, tanks, pipelines, filling machines). These impurities consist mainly of fat, protein, and a small amount of mineral salts, and are removed relatively easily;

– pollution formed when the surface of the equipment comes into contact with heat-treated milk (mainly in pasteurizers and vacuum devices). These impurities consist of heated milk residues, mineral salts contained in water, and under the influence of cleaning solutions form the so-called milk stone and milk scale.

Most milk processing plants use a circulating non-disassemble washer (CIP washer) with the return of cleaning solutions for reuse. The implementation of this principle is carried out with the help of imported and domestic washing units of the block-modular type, intended for washing technological equipment and tanker trucks.

Direct washing of closed milk containers and pipelines is impossible due to their design features. Therefore, for these purposes, non-dismantling washing systems are used – CIP washers.

Scientific research into this topic is important because the dairy industry occupies an important and significant place in the food market. The results of such research should be applied in practice since the dairy industry is mandatory in the structure of population consumption.

2. Literature review and problem statement

The analysis of modern approaches to the organization and implementation of washing milk tanks allows us to highlight the main purpose of its operation – cleaning and disinfection of technological equipment, reducing the labor intensity of the washing process, as well as the production of quality products.

The KMZ-SCM (Kalyniv Machine-Building Plant, Ukraine) CIP-washing system for equipment is well-known. Non-dismantling automated equipment washing stations KMZ-SCM are manufactured for enterprises of the dairy industry and the beverage industry, with different productivity and design features, depending on the wishes and preferences of the customer [3]. In [3] it is not specified which methods of object-oriented programming were used (station, program, functions).

Also known is the CIP mini-washer of the Lakta-Service [4] company, which carries out workshop washing at large enterprises. The system is designed for washing tanks, technological equipment, pipelines, and packaging machines. The washing solution is sent back to the tank of the installation for reuse in the next washing cycle. In [4], there is information about the technical materials used in the CIP-washer but there is no information about the design methodology. Also, the mini washer has a multi-window interface but there is no schematic diagram.

According to [5], the DONICIP automated non-disassemble washing system is designed for disinfection, neutralization. All this is done with the help of acidic and alkaline solutions in a closed circuit. This system allows one to correctly choose the washing concept, taking into account all the nuances of the manufacturer. In [5], it is not specified how the main HMI program (controller, processor, operators) is processed.

In [6], the CIP method of cleaning the dairy production line is considered. This method is used for pre-washing the bottling machine. The disadvantage of this CIP method is the difficulty in washing some inaccessible corners of the equipment.

The CIP system, which provides a high level of sanitation through the one-time use of washing solutions and the system itself, was also considered [7].

The use of pulsed flow is present in the system for washing the food industry line, especially in dairies. This CIP system uses a milk circulation line made of stainless steel [8].

The purpose of the CIP system is to avoid random (stochastic) errors that can lead to unexpected plant failure of the CIP itself. The analysis of these processes is carried out when assessing the risks of removing protein milk deposits [9].

In [10], a system for on-site cleaning of equipment intended only for milking cows on dairy farms is proposed.

According to [11], the cleaning system is designed for washing the inner walls of the technological equipment of the dairy industry. The system uses cleaning solutions, both for single and repeated washing.

The analysis of existing CIP washers showed that they are characterized by high functionality (one-time washing, design, safety, quality of washing, setting a recipe, closed circuits).

However, [3, 5, 7, 11] lack information about software, programming language, algorithms and research methods, which are important components in the development of new interfaces and the analysis of existing ones. Thus, it is advisable to design a completely open HMI, which contains information about research methods, a programming language, a schematic diagram of a CIP washer, and its software implementation.

From the above review [4, 6, 8, 9, 10] it follows that there are several ways of washing tanks and using detergents. However, each of the CIP washers involves large costs for their development, as well as maintenance.

Works [3–11] did not mention the problem of parallel washing of two lines at different ends of the workshop and the selection of recipes for different groups of tanks. It is unrealistic to explain the absence of these solutions in the considered sources since each developer decides independently whether to show only the open part of the interface with functionality, or to reveal the step-by-step processes of its development. Each developer retains the copyright for the use and demonstration of the materials of their development.

And this also allows us to claim the need to design a new HMI for a CIP washer with the ability to use the recipe base and simultaneously wash two lines in different places.

3. The aim and objectives of the study

The purpose of this study is to design the CIP-washer HMI for the possibility of parallel washing of two lines at different ends of the workshop and the selection of recipes for different groups of tanks based on Siemens hardware and software tools.

To achieve the goal, the following tasks were set:

– to reveal the main processes of CIP-washer HMI and build a schematic diagram;

– to reveal the methods of developing the human-machine interface of the CIP-washer;

– software implementation of the human-machine interface in WinCC flexible for parallel washing of two lines at different ends of the workshop and selection of recipes for different groups of tanks.

4. The study materials and methods

The object of our research is the basic processes of the on-site cleaning system in the dairy industry.

The main hypothesis assumes the following: the interface displays information about washing processes, about the selection of recipes, control over input values, output of emergency messages, simultaneous washing of two tanks at different ends of the workshop. This allows the operator to monitor the washing process in real time and intervene as necessary.

Research methods: to solve the tasks set in the work, the basic principles of the CIP-washer operation principle and methods of object-oriented programming were used.

Object-oriented programming methods are the main software tools for launching SIMATIC WinCC flexible, namely: the S7-300 series controller station and the loop program. It should be noted that the representations of the cyclic program and the controller station are not visible in the designed HMI because they are written in the WinCC flexible startup directives.

Research materials: Siemens SIMATIC WinCC flexible hardware and software (country of origin, Germany) for the development of the human-machine interface of a CIP washer.

SIMATIC WinCC flexible is intended for application directly at the machine level and can be used to build solutions ranging from SIMATIC HMI operator panels to single-user HMI systems based on a personal computer (WinCC flexible Runtime).

For the configuration of WinCC flexible Runtime on PCs and SIMATIC HMI operator panels, the WinCC flexible

family offers the integrated and scalable software packages WinCC flexible Micro, WinCC flexible Compact, WinCC flexible Standard, and WinCC flexible Advanced. SIMATIC WinCC remains a process visualization system for production management with the possibility of building both single-user and multi-user solutions and as a platform for the integration of IT and business. The next step is to use WinCC flexible to integrate SIMATIC WinCC. As in the case of ProTool V6 projects, WinCC projects will also be compatible [12, 13]. HMI is developed by Scada program using SIMATIC WinCC flexible software.

The main advantages of the human-machine interface are the visibility and completeness of the information presented on the screen, the availability of control, a convenient user interface, effective interaction of the operator with the interface, as a result of which constant control over the automated technological process is carried out [14].

5. Results of research on the design of the human-machine interface of the CIP-washer in the dairy industry

5. 1. Basic processes of CIP-washer HMI and construction of the main diagram

When developing the human-machine interface of the CIP-washer for the dairy industry, the developed schematic diagram (Fig. 1), which was designed in the automated design and drawing system AutoCAD, was taken into account.

According to Fig. 1, the main processes and designations of the CIP washer are:

– washing of tanks with water heated to 60 °C to wash away food residues within a given time in an automated system. After passing through the entire line, the water flows into the sewer;

– line emptying process. After washing with water, there is a process of emptying the line, in which all the water that remained in the tank and pipes is poured into the sewer;

– filling the line with alkali. The alkaline solution is heated to a temperature of 70 °C and goes into the line. Since the return pump cannot wash all the remaining water in the pipes, they use a solution of lye. At this time, the flow sensor gives a signal that there is a return to the CIP line. With the help of a conductivity sensor, it is determined whether alkali or water flows through the pipes. If it is water, then the valve is opened for draining into the sewer, if it is alkali, then the valve for returning to the tank with alkali is opened. The process ends when the flow sensor gives a signal that there is a flow, and the conductivity sensor shows the alkali value;

– the process of washing the line with lye. When the filling was finished, the washing process began. In this process, the lye solution heated to 70 °C circulates along the line during the time specified in the system;

– the process of leaching alkali with water. Emptying. The emptying process is similar to the filling process, only the lye solution is displaced by water.

– the process of washing with water is similar to the first process. The water is heated to 60 °C and circulated along the line;

– the process of filling with acid is similar to the process of filling with alkali;

– the process of washing with acid is similar to the process of washing with alkali;

– the process of emptying acid is similar to the process of emptying alkali;

– washing tanks with warm water heated to 60 °C;

– emptying of water after washing;

– rinsing of tanks with cold water (final rinsing);

– emptying the line;

– designation 1 – temperature sensor;

– designations 2, 3 – conductivity sensors of lines 1, 2;

– KR21 – a control cabinet, and under it an excess pressure system to ensure the integrity of components;

– 4 – TNE1 and 5 – TNE2 (heat exchangers for lines 1, 2, respectively).

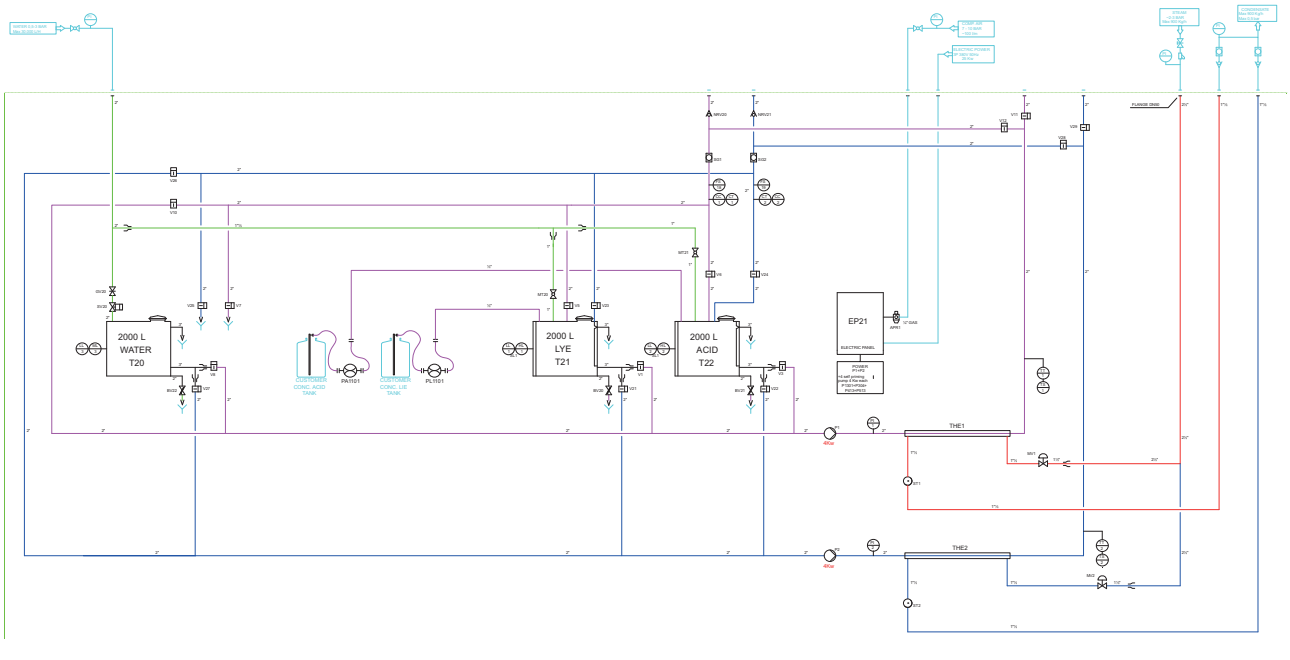

Fig. 1. Main diagram of CIP-washer

The built schematic diagram (Fig. 1) makes it possible to study in detail the main processes of the CIP washer and is the basis for designing the human-machine interface in SIMATIC WinCC flexible.

5. 2. Methods of developing the human-machine interface of the CIP washer

Using the methods of object-oriented programming (controller station and cyclic program), the CIP-washer HMI was designed.

The S7-300 series controller station consists of the following main components (Fig. 2):

– processor (CPU) 315-2DP 6ES73152AG100AB0, which is placed in slot 2;

– analog input module AI 8x12Bit 6ES7 331-7KF02-0AB0, which is placed in slot 4;

– digital input module DI 32x24V 6ES7 321-IBL00-0AB0, which is placed in slot 5 and 6;

– digital output module DI 32x24V 0.5A 6ES7 321-IBL00-0AB0, which is placed in slot 7.

According to the configuration of the S7-300 station, the industrial Profibus network was configured (Fig. 2).

The program is processed by the processor cyclically. The CPU reads and executes program processes (CIP washing processes) line by line. The cyclic program (Fig. 3) is written in WinCC flexible in the language of relay-contact logic (Ladder Diagram – LAB).

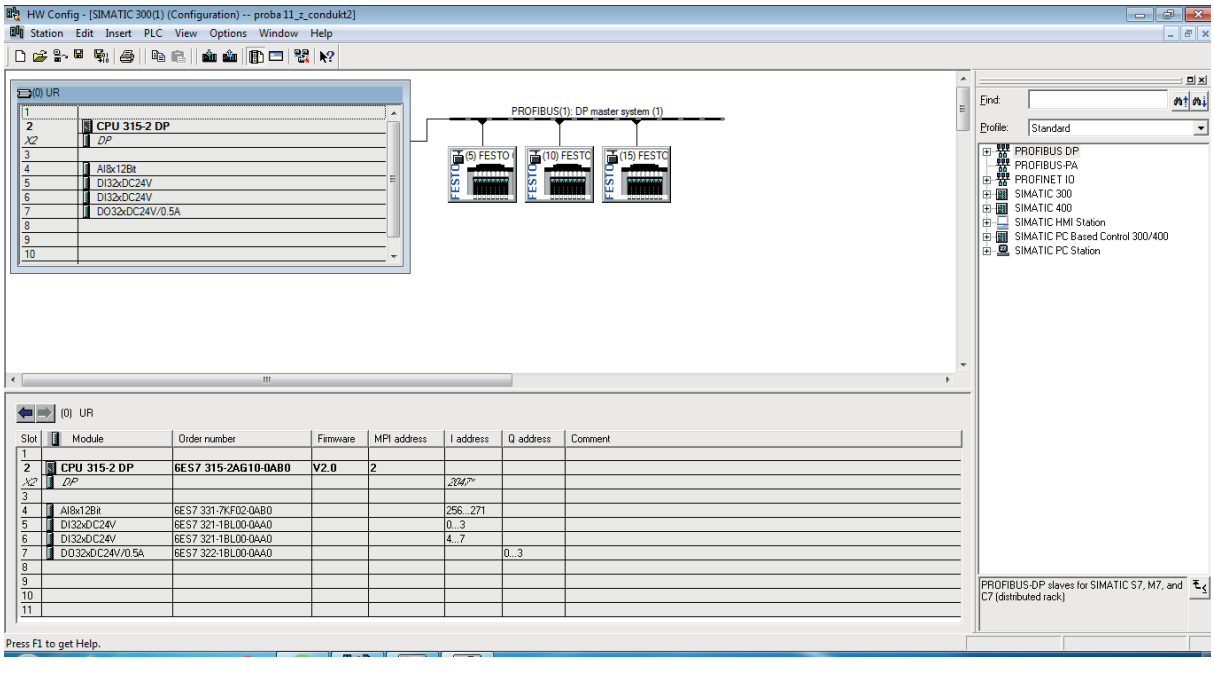

Fig. 2. S7-300 station configuration

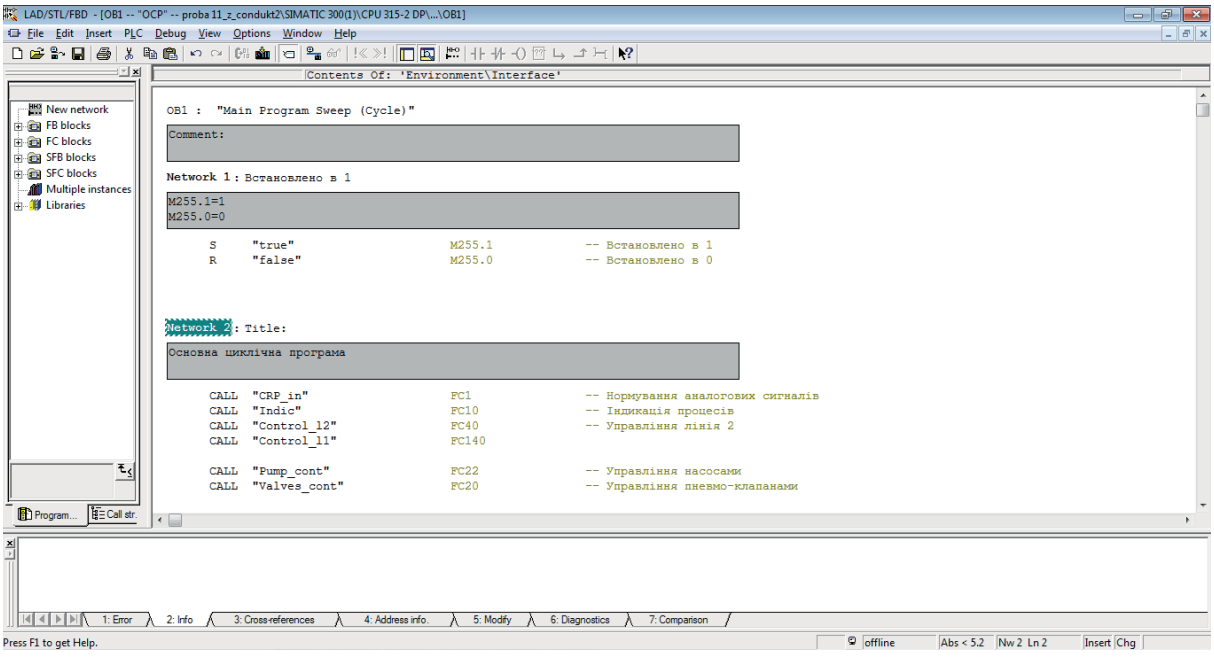

Fig. 3. Cyclical program

5. 3. Software implementation of the human-machine interface in WinCC flexible for parallel washing of two lines at different ends of the workshop and selection of recipes for different groups of tanks

The designed human-machine interface of CIP washer in SIMATIC WinCC flexible consists of the main working window (Fig. 4), which contains ten functional buttons:

– selection of washer line 1;

– recipe line 1;

– washing recipes of line 1;

– emergency messages – displays the levels of flushing fluids (Fig. 6),

– general information on lines – information on 2 lines is displayed simultaneously (Fig. 5);

– status of line 2;

– status of line 1;

– selection of washer line 2;

– service – displays the parameterization window for temperature, conductivity and reverse temperature sensors (Fig. 7, 8);

– recipe line 2.

Each of these functions performs the tasks set, namely:

– produces a pop-up list that displays the process being executed (Fig. 9);

– a time counter is displayed, which displays the time specified in the recipe and the current time;

– the selected washer object (reservoir or line) is displayed;

– functional buttons (Fig. 5): start, pause (pauses the process), stop, and skip (when a process is running that the operator considers unnecessary and can be skipped);

– line status – shows information on 2 lines at the same time (Fig. 9);

– "Values" button – displays a window where all monitored values from temperature and conductivity sensors are displayed;

– start page – returns to the initial window (Fig. 4).

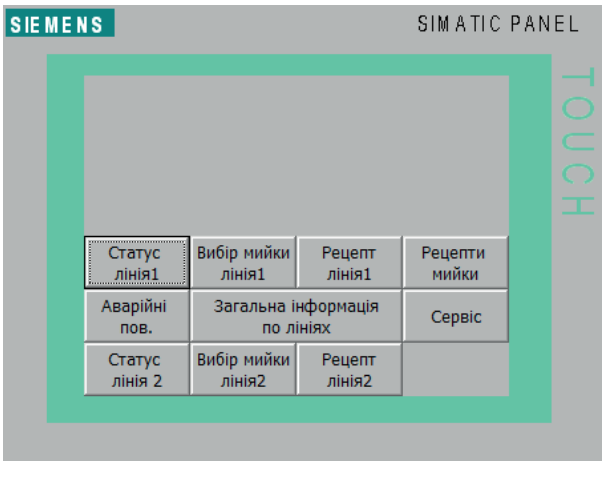

Fig. 4. The start page of the human-machine interface of CIP washer

The following windows are the status windows of lines 1 and 2 (Fig. 5), as well as the output of emergency messages (Fig. 6).

The service windows (Fig. 7, 8) show the data display of temperature sensors L1-L2 and reverse temperature sensors L1-L2 on the computer screen.

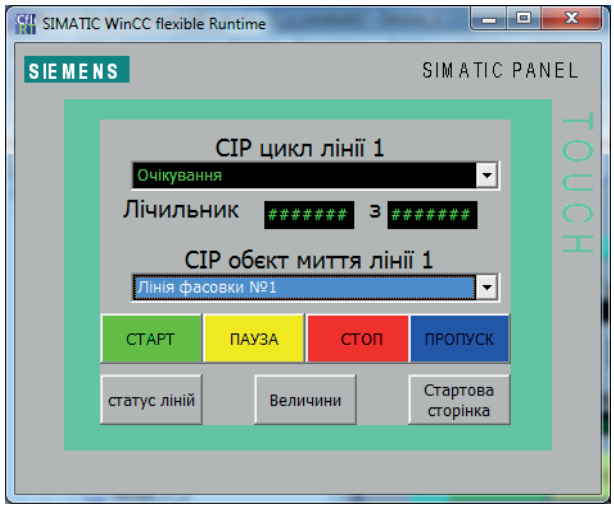

Fig. 5. Status window of lines 1 and 2

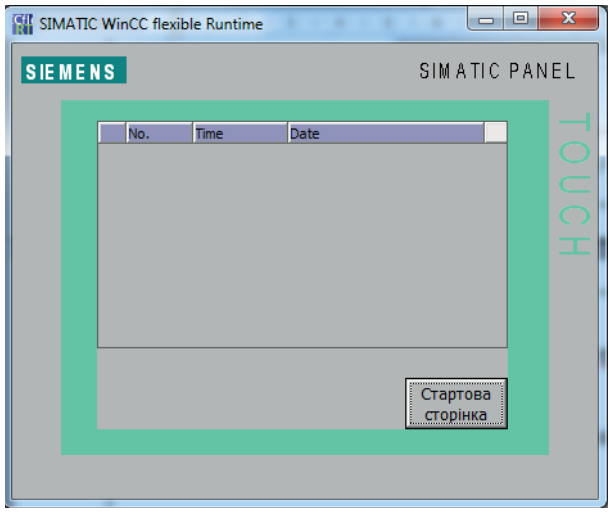

Fig. 6. Emergency message window

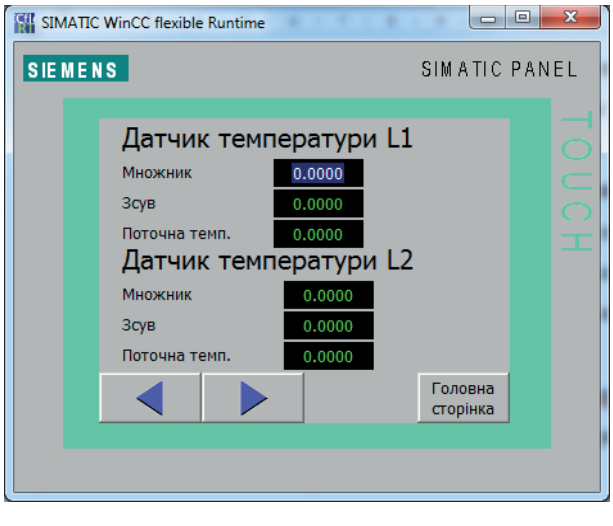

Fig. 7. L1-L2 temperature sensor data display service window

The selection of one or another button from the main window of the human-machine interface of CIP-wash-

er (Fig. 4) depends on the operator and the desired automated process. Line 1 and Line 2 status windows are identical.

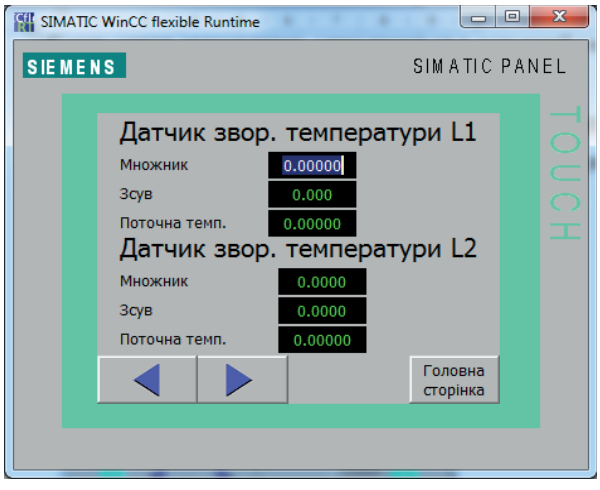

Fig. 8. L1-L2 reverse temperature sensor data display window

Fig. 9. Status window of lines 1 and 2

When developing parallel washing of two tanks at different ends of the workshop and choosing recipes for different groups of tanks, the following was taken into account:

– selection of the recipe base – selection of the washing object for which a pre-formed recipe is automatically loaded (Fig. 10–13);

– simultaneous (parallel) washing of two lines at different ends of the shop (Fig. 14).

– selection of tank or line for washing;

– after selecting the tank, pull up or set a recipe from the base, which will be executed during washing;

– after receiving the recipe and pressing the start button, the washing process starts from the panel.

The listed processes of the two washing parameters are the main functional windows of HMI, which display the covering washing processes according to the given recipe or recipes.

Fig. 10 shows the tab “Recipe of line 1”, which consists of 4 pages, which can be accessed using the button with the icon “Arrow to the right” [11, 12].

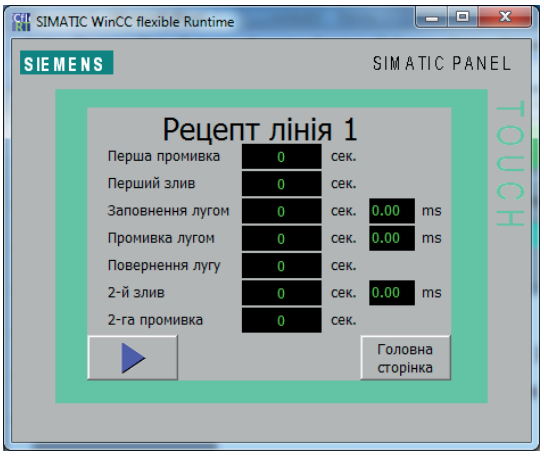

Fig. 10. List of washer options (page 1)

The second page contains the following parameters (Fig. 11):

– 3rd discharge;
– filling with acid;
– washing with acid;
– return of acid;
– 4th discharge;
– 3rd wash;
– 5th discharge.

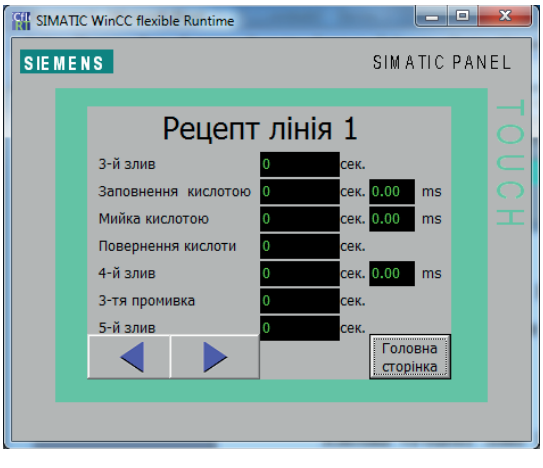

Fig. 11. List of washer options on page 2

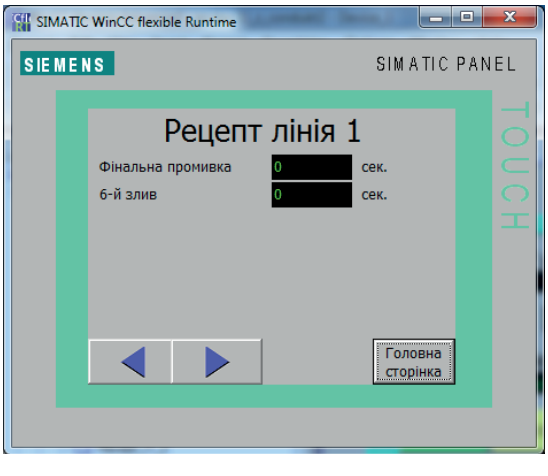

Fig. 12. List of advanced washer options (page 3)

Fig. 12 shows the process of emptying the line, that is, cleaning the lines from detergents.

On the fourth page (Fig. 13), there are parameters of the alkali recovery recipe. They are used only in the case when the "Alkali recovery" object is selected in the "Washer selection line 1" window.

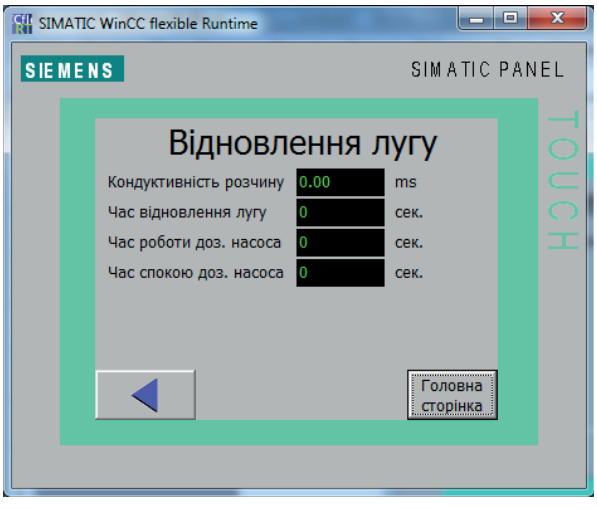

Fig. 13. List of parameters "Alkali Restore"

The "Line 1 Recipes" button (Fig. 4) displays a window with recipes for different types of washing objects. In this window, you can view and edit recipes for a certain type of washing objects (Fig. 13, 14).

The choice of tank or line for washing is selected using a panel (Fig. 14). The staff can independently set a new recipe for a specific object of washing technological equipment or use previous ones stored in HMI.

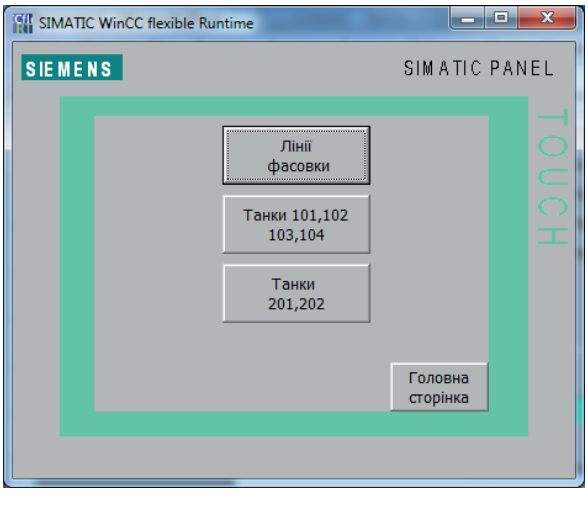

Fig. 14. Base of recipes for washing in parallel of two lines at different ends of the workshop

By clicking on one of the buttons line tanks (reservoirs) or packing (Fig. 14), windows similar to those in Fig. 10–13 will appear.

The user can set a number of recipes (recipes are stored in the control device and have their own designations), change the concentration, temperature, washing time, pressure, water volume, using commands that are understandable to humans. Constantly increasing requirements in the field of hygiene in the food industry make the procedure for washing equipment, devices and pipelines problematic, so it is necessary to solve this problem every day.

6. Discussion of results of the designed human-machine interface of CIP-washer for the dairy industry

The designed man-machine interface of the CIP washer (Fig. 1–14) allows solving the problem of parallel washing of two tanks at different ends of the workshop and the selection of recipes for different groups of tanks due to the fact that the following disadvantages of CIP washers are taken into account:

– difficulties with washing some inaccessible corners of the equipment [6];

– presence of random errors [9];

– the washing process covers only one functional purpose – washing milking machines, not washing lines or tanks [10];

– there are large expenses for detergents [7];

– washing only dairy technological equipment, i.e., lack of universality of the system [8];

– lack of a schematic diagram, development methods, programming language, software implementation [3, 4, 5, 11].

The main advantages of the proposed developed interface compared to the existing ones are the implementation of real-time monitoring of output values; user-friendly interface, system flexibility, minimal influence of the human factor. And it will also provide control of uninterrupted chemical and thermal disinfection under automatic mode.

Among the shortcomings of the developed HMI, there are problems with receiving data from sensors due to technical malfunctions and calibration. It is also worth noting that the operator of the designed interface must have working skills in SIMATIC WinCC flexible.

The limits of application are the fields of food production. The conditions for applying the obtained results are to carry out the washing process in a high-quality way to obtain hygiene and cleanliness of the technological equipment.

The main requirement for the reproducibility of our results of the designed human-machine interface of CIP-washer is the degree of closeness of the same results obtained when working with the interface of different users.

Although the CIP washer interface is universal and this is its further development of research, its application to other food facilities may have some difficulties. The main obstacles will be the staff's inability to work in SIMATIC WinCC flexible in order to rework functional windows, incorrect setting of criteria for displaying emergency messages, washing recipes.

7. Conclusions

1. The main processes have been revealed and a schematic diagram of the CIP washer HMI has been built. Interrelationships of the processes (washing, emptying, washing and filling with water, alkali or acid) of the CIP washer are shown, taking into account the principles of their action and the sequence of work. The schematic diagram designed in AutoCAD gives advantages over other solutions due to the fact that it gives the most complete picture of the composition and principle of operation of CIP washer.

2. The methods of developing the human-machine interface of CIP washer, taking into account object-oriented programming, are disclosed. They make it quick and easy to design a new HMI and provide operators with the startup information they need in a form (input and output modules, loop program) that can be quickly understood to configure the interface startup.

3. Software implementation of the human-machine interface in WinCC flexible was carried out for parallel washing of two lines at different ends of the workshop and selection of recipes for different groups of tanks. Thanks to this, a technical solution has been obtained, which makes it easier for the operator to work by receiving data from the sensors on the computer screen, which are intuitively understandable about the operation of the washing system on site. A feature of the implementation is the multi-window (openness) of the designed CIP washer HMI.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

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