INTERACTIVE DESIGN OF CNC EQUIPMENT OPERATOR PANELS

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Abstract – Taking into account the development trends of Industry 4.0, the task of improving human-machine interfaces is becoming increasingly important. The development of user-friendly interfaces for interaction between the operator and the equipment is one of the most difficult tasks in the creation of specialized technological systems. The operator panel is a specialized input-output device designed to implement the human-machine interface in a technological system with CNC. The functional elements of the operator panel are controls and indicators. In this paper, an information model of the operator panel elements is proposed. The model combines a geometric, logical, and functional description. The possibility of various complexity and structure functional block formation is shown. Software for the interactive design of the operator panel has been created. It includes solving the problems of panel layout and logical control functions, debugging operating modes, working out the convenience of controlling CNC equipment in panel emulation mode, and automating the generation of output reports. In the software applied the approaches used to create "digital twins". This allows to implement the offline debugging mode of the operator panel project and the emulation mode of the operator panel for debugging interaction with the control system without manufacturing the operator panel or its prototype. The possibility of forming a visualization of the operator panels varying complexity and examples of manufactured panels for different types of equipment are shown.

Keywords: CNC Equipment, Operator Panel, Design, Human-Machine Interface, Emulation.

1. Introduction

The concept of Industry 4.0 involves the advent of cyber-physical systems into production, the merger of automated manufacturing, exchange between data and manufacturing technologies into a single self-regulating system with minimal human involvement in the production process [1, 2]. However, many production processes, such as high-speed machining [3, 4], laser cutting and welding [5, 6], additive manufacturing [7–9] are carried out with human involvement, which requires the improvement of human-machine interfaces [10–12].

Labor productivity on automated technological equipment is largely determined by the convenience of the user interface [13]. The development of an interface for interaction between an operator and equipment is one of the most difficult problems in creating a specialized technological system. It is necessary to take into account various equipment control scenarios, and safety issues for the use of certain functions in different operating modes [14–16].

Many manufacturers provide a limited range of operator panel models. Commercially available operator panel solutions may offer some redundancy used to control specific equipment models. In this case, some of the functions available on the panel, but not used for specific equipment, can simply be disabled. At the same time, the equipment may have some unique units, which should also be controlled from the operator panel, but not provided by the manufacturer in the typical CNC system configuration.

The complexity of taking into account heterogeneous factors in ergonomics, safety, information technology, and other factors that affect the efficiency of the operator panel design leads to significant time and material costs with traditional iterative technology for creating new equipment [17–19]. Applying an innovative approach to the interactive design of control panels using specialized software is an urgent task.

Specialized interactive design software should provide a consistent solution to the problems of styling, logical, information, and functional design. Besides, interactive design software must provide offline debugging and operator panel emulation modes for its debugging and connection to the control system without its manufacture [20, 21].

In addition, such software is expedient to use in teaching students. This aspect is of particular relevance in organizing online training, especially in the context of special periods of the COVID-19

epidemic and martial law, due to the need to ensure security, when no possibility of using real equipment [22–24].

The aim of this paper is to automate the interactive design of an operator panel for specialized CNC equipment by developing models of its elements, which provide both the design process and the process of checking its operation.

2. Interactive Design Challenges of CNC Equipment Operator Panels

The operator panel is a specialized input-output device designed to implement the human-machine interface in a technological CNC system. Functional elements of the operator panel are controls and indicators. For the interaction of the operator panel with the CNC system, a set of parameters is used, the values of which determine the states of the elements of the operator panel, technological equipment, and the CNC system. The states of the operator panel controls are used to generate commands for controlling equipment.

Operator panel development includes a number of tasks, such as:

- determination of parameters and states required for the interaction of the operator panel with the CNC system;
- determination of the controls set necessary for the command formation;
- determination of the list of parameters states requiring indication;
- determination of the parameters states in which it is allowed or prohibited to generate commands for controlling the equipment;
- selection of methods for generating commands by control elements and methods for indicating the states of parameters;
- development of the operator panel elements layout and its design;
- ensuring interaction between the operator panel and the address space of the control system;
- development of control system response algorithms to certain commands of the operator panel;
- operator panel manufacturing;
- debugging the operator panel and its interaction with the control system.

These tasks cannot be arranged in a strict sequence, many of them are closely related to each other. So, for example, a clear understanding of the convenience of the location of controls and methods of command formation can be obtained only at the stage of debugging or experimental research [18, 25]. At the same time, for debugging, it is necessary to have a ready-made sample of the operator panel, or a layout as close as possible to it. The creation of an operator panel, as a rule, takes several iterations. This requires a significant investment of time and finance, which is unacceptable in the case of small-scale and single-piece production of unique equipment.

It is possible to optimize the operator panel development process for small-scale and single-piece production of technological equipment by creating specialized software that allows performing most of the tasks listed. The approaches used to create "Digital Twins" in the software make it possible to implement the offline debugging mode of the operator panel project and the emulation mode of the operator panel for debugging interaction with the control system without manufacturing the operator panel or its prototype.

Based on the foregoing, will formulate requirements for the software for the interactive design of the operator panel. Such software must operate with a number of models that organically interact with each other and perform a number of the entered information automated processing functions.

In Fig. 1 shown a generalized scheme of the interaction of models used in the design of the operator panel. From the point of view of the operator panel interaction with the CNC system for the design process, the parameter set is the defining object. The model of a functional elements is formed by specifying links between geometrical models, algorithmic models, address space model, and models of the individual elements' structure and the operator panel as a whole. The output of the project is obtained using special data sampling and transformation procedures for all involved models.

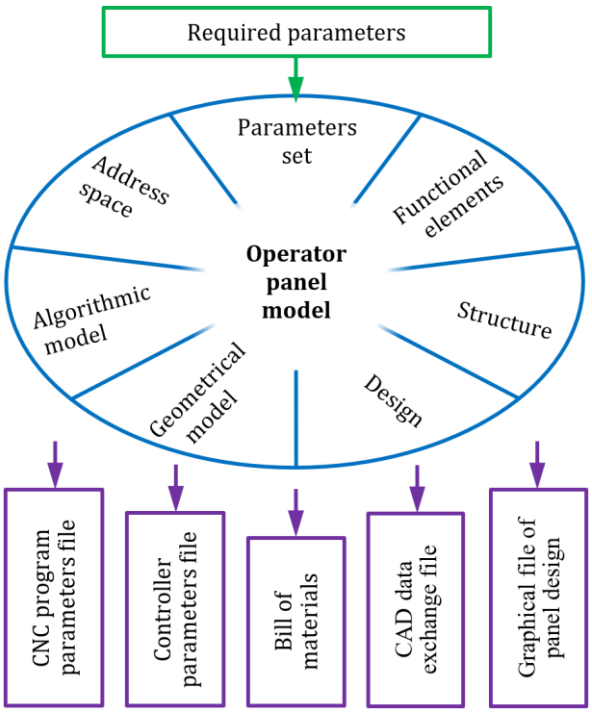

Figure 1: Information logical model of the software for interactive panel design

In this paper, we consider the results of developing software for the interactive design of operator panels for CNC equipment based on the use of an integral hierarchical model of functional elements.

3. A Hierarchical Model of Controls Elements of the CNC Equipment Operator Panels

The task of designing an operator panel is reduced to the formation of a description of a structure consisting of functional elements that form or process the states of the selected parameters. The interrelationship of parameter states can be displayed both in the creation of fixed structures (blocks) and in the creation of logical interconnections that are not displayed in structures.

In Fig. 2 shown a generalized scheme of the operator panel elements information model, which provides the ability to solve the tasks of interactive design. In accordance with this scheme, the elements of the operator panel are presented in the form of a hierarchical design model based on functional elements, which allows the creation of operator panel elements models with quite diverse functional characteristics.

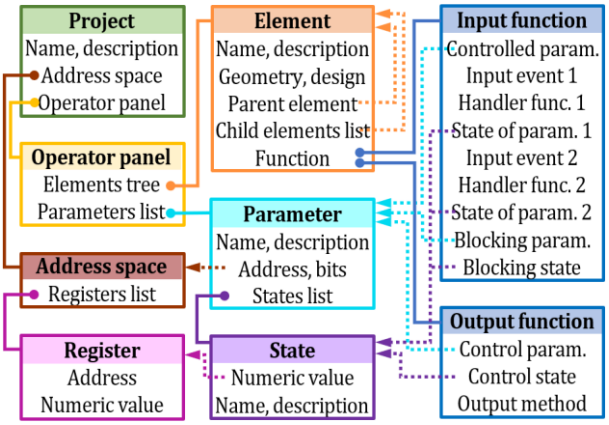

Figure 2: Generalized scheme of operator panel elements information model

The tree-like organization of the description of the operator panel elements structure provides the possibility of creating various elements of the operator panel and ensures the simplicity of displaying information about it. Let's consider several examples of creating the elements structure of the operator panel.

In Fig. 3 shown an example of a description of the model of an element such as a toggle switch without fixation used to form commands for the *X*-axis movement. The equivalent model of a toggle switch without fixation is assembled from two push buttons without fixation. To display the toggle switch on the operator panel, a "image" is used, which is part of the element model, and the rectangular areas "*X+*", "*X–*" are used to emulate pressing the toggle switch in the corresponding direction and form the states of the corresponding parameters "Select *X+*", "Select X–". In the model of this element, the state "1" for the corresponding parameter is formed throughout the entire time the toggle switch is held; when it is no longer affected, the state of the corresponding parameter "Select *X+*", "Select X–" is set to "0".

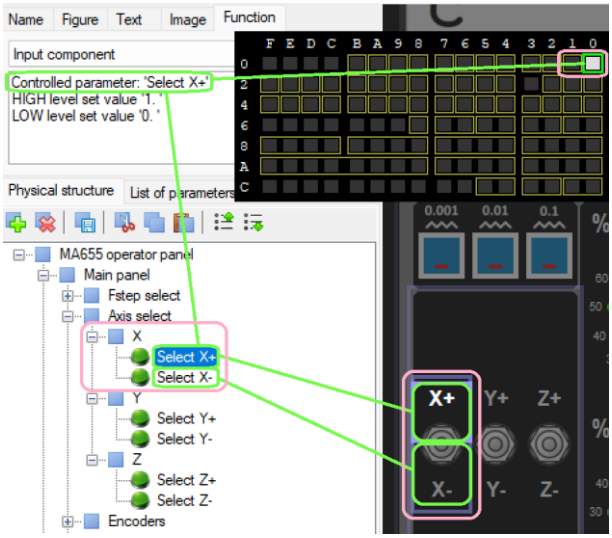

Figure 3: The model of a toggle switch without fixation

Another type of functional block will be shown on the example of a group of buttons that control the parameters of stepping (Fig. 4). One of the possible solutions for switching to the stepping mode is the use of special function buttons on the operator panel.

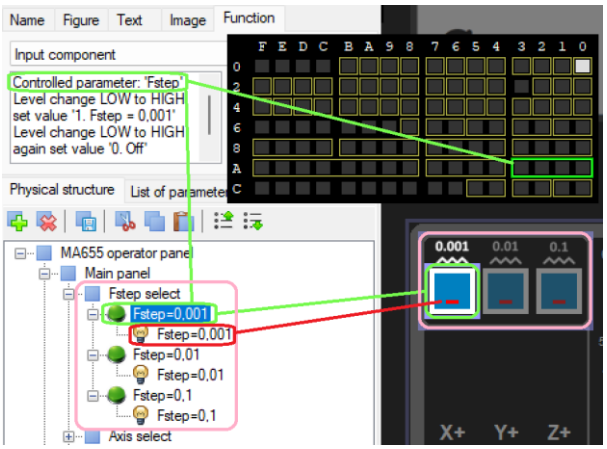

Figure 4: A complex model of element for the mode setting/switching/cancellation

At the same time, it should be noted that such a solution implies the possibility, after the completion of control in the mode of stepping movements, to return to the mode of movement from the operator panel with the parameters set before such a switch. This is achieved by pressing the selection button again by setting the stepping motion parameter "*Fstep*" to the state "0". Thus, pressing any of the

buttons of the specified group should lead to the establishment of the appropriate status code. Pressing any other button from this group should result in the establishment of a new status code that differs from the previous one. Pressing the same button again should set the state to "0", which corresponds to the command to cancel the stepping mode.

In Fig. 5 shown the complex model of the control and indication element of the spindle speed parameter. The real design of such a module can be created based on the use of an incremental encoder as an input device and a set of LEDs as indication devices. Just like with a toggle switch, to display the input device on the field of the operator panel, an "image" depicting a knob is used, and the functional model is an assembly of two "buttons" that provide an imitation of the encoder rotation events in the direction of decreasing or increasing the parameter. The number of generated states in this case is limited both by the capacity of the dedicated counter in the address space and by the physical ability to place the required number of LEDs to display the set state.

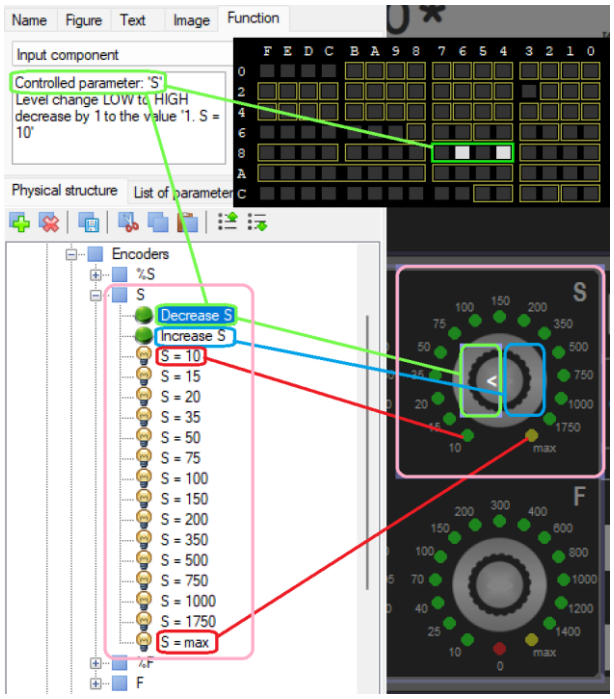

Figure 5: A complex model of the control and indication element of the spindle speed parameter

In this example, a 4-bit parameter is allocated in the address space of the operator panel to store data about the specified state of the spindle speed parameter "*S*", which allows describing 16 states. This is consistent with the possibility of placing the corresponding number of LEDs. It should be noted that the state of such a device on the operator panel can be formed not only by the panel itself, in the process of the operator acting on it, but also by commands coming from the CNC system. In this case, the CNC system sets the display state for this block based on an analysis of the interaction of various equipment nodes and the state of the CNC itself.

In Fig. 6 shown an example of a complex model of a tool change control element for setting and indicating the number of used tool.

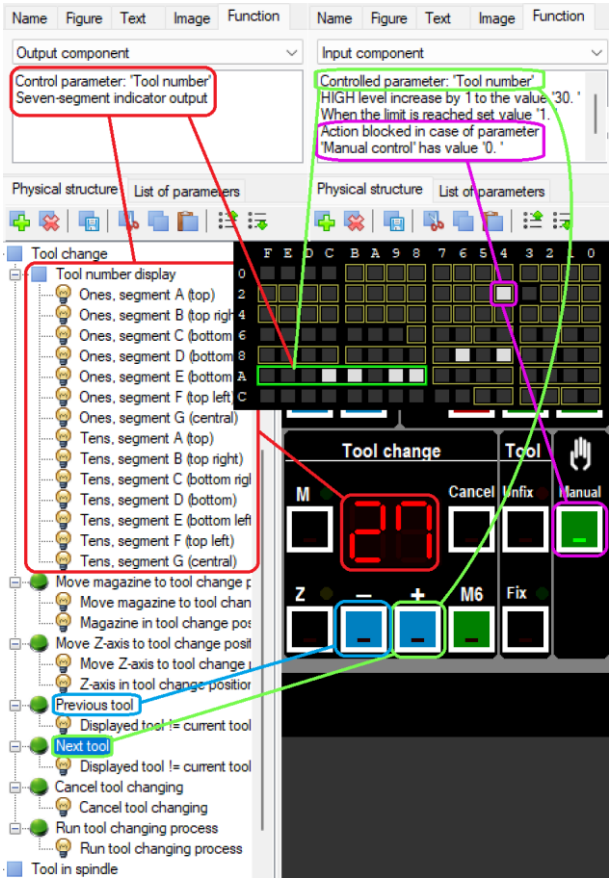

Figure 6: A complex model of a tool change control element

This example considers the possibility of creating a node in which the number of the tool specified for installation is formed by successively increasing/decreasing the value of its number when pressing the corresponding buttons "increase the tool number", and "decrease the tool number". Display of the generated number is carried out using a seven-segment indicator, which allows displaying numbers from "00" to "99". The rules for processing device state variation for clicking the corresponding buttons are specified in the description of functions by selecting from the list of possible transformations. A fairly simple set of rules allows organizing a cyclic stack for specifying a tool number, taking into account the limited capacity of the tool magazine of the corresponding machine. A seven-segment digital indicator is used to display the number of the tool and its model is assembled as a composite unit from the simplest basic display elements. The function "Output to a seven-segment indicator" provides decoding of the status code of the control parameter "Tool number" and for each indicator element, in

accordance with its location in the display unit, determines the necessity to turn it on. In turn, the indication of a change in the number of a given tool on the buttons themselves is controlled by a command from the CNC. In the example shown, the indicators are active on both the "–" and "+" buttons in case the number of tools actually installed on the machine does not match the number of tools displayed on the panel, which indicates the necessity to install the tool. The cancel button is used to stop the automatic change process if necessary or to reset the tool number setting. In this case, there is no indication on the "–" and "+" buttons, and the number of the tool actually installed on the machine is set on the indicator.

Thus, the proposed scheme of the information model of the operator panel elements (Fig. 2) allows modeling the elements and blocks of the operator panel for CNC equipment that are diverse in complexity and functionality. On the basis of the proposed information model, software for designing and a program for emulating the functioning of operator panels has been created.

4. Interactive Design Software for Control Panels

Based on the model described above, software for interactive design and a program for emulating the operation of operator panels have been created. The interface of the program is shown in Fig. 7. The working area of the screen is divided into two areas: the main part is the project display area and the left side panel is the project tree display area and setting the parameters, functions, and properties of the elements being designed.

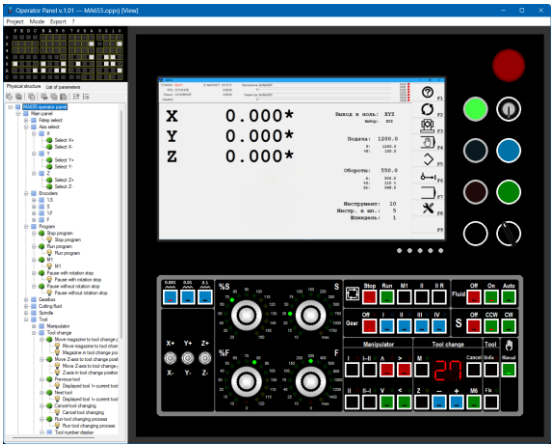

Figure 7: The interface of the software for the interactive design of the equipment control panel

The software allows designing the operator panel by assembling a layout solution based on the use of previously developed elements and nodes of the operator panel or the development of new nodes. The creation of new specialized elements of the operator panel is carried out by creating a structural information description of the node model (Fig. 2) using basic elements, functions, and parameters in a particular project.

In the emulation mode, it is possible to perform an offline test of the operator panel operation algorithms. It is possible to perform a complete simulation of the operation of the operator panel and control of technological equipment with CNC by connecting a computer with this software to the CNC system.

In the process of interactive design of the operator panel, changes are made to the layout, indication methods, and algorithms for the operation of the panel elements and their interaction with the CNC. The convenience of the operator's perception of the control of CNC equipment is checked using a panel of the appropriate layout. After completion of all design and debugging procedures, the software provides the ability to generate output reports in the form of an operator panel controller configuration file, a CNC system configuration file, an operator panel geometry interface file, and a graphical file of panel design.

5. Interactive Design Application of CNC Equipment Operator Panels

The proposed model and software based on it were applied in the design of operator panels for various CNC equipment. Performing equipment modernization and creating special equipment for different technologies is characterized by significant differences in the structure and functionality of such equipment. This circumstance leads to the fact that for the optimal provision of the corresponding functionality of the equipment, the operator panels must undergo significant changes.

In Fig. 8 shown the operator panel of a 3-axis milling machine with an automatic tool changer and an automatic transmission in the spindle drive. In the project, in addition to the possibility of performing a tool change using the M-functions, it was necessary to create a remote control that allows using the control buttons to perform individual stages and the entire procedure for changing a tool.

In Fig. 9 shown examples of operator panels for different types of specialized equipment. In a special machine, for the continuous winding of fiberglass pipes (Fig. 9, *a*) the process parameters are set in the text of the control program, which ensures the coordination of the movement of several actuators at once. The operator is given the opportunity to adjust the intensity of the process by setting "%*F*" and "%*S*" and performing temporary technological shutdowns to service various devices for supplying glass fiber to the winding zone.

In a special machine for the bends winding (Fig. 9, *b*) the winding process of the pre-

impregnated woven tape is carried out. The machine is intended for the mass production of products for a limited number of programs. In the project of this machine, it was necessary to implement the possibility of selecting programs from a fixed limited list, performing machine zeroing, and adjusting workpiece coordinate system offsets using only the controls of the CNC operator panel.

Figure 8: CNC control panel for modernization of the milling machine MA655SM30

Figure 9: Operator panels for special CNC equipment: (a) operator panel for special machine for the continuous winding of fiberglass pipes; (b) operator panel for special for the bends winding machine [26]

In addition to being used in the production process, the developed software for the interactive design of operator panels for CNC equipment is used at the O.M. Beketov National University of Urban Economy in Kharkiv in the training of specialists in the field of automation. The necessity to conduct training sessions in the conditions of the COVID-19 pandemic, and especially in martial law, necessitates the search or development of special software tools that replace practical and laboratory work with real equipment for the study and research of virtual objects created using digital twin technology.

6. Conclusions

In this paper, an information model of the operator panel elements is proposed. It combines a geometric, logical, and functional description. This has allowed to creation of software for the interactive design of the operator panel, which includes solving the problems of panel layout and logical control functions, debugging operating modes, testing the convenience of controlling CNC equipment in panel emulation mode, and automating the generation of output reports. In addition, this software can be used for online learning if it is not possible to work with real equipment.

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