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MAINTENANCE, TESTING AND AUTOMATIC CONTROL OF THE CUP FILLING MASCHINE

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Abstract:
Industrial automation of the production process is based on the fusion of a CNC machine and an industrial robot. The industry of today requires skilled professionals and educators. Special attention is to be paid to the testing of the components and system operation and the maintenance of the system. Robots and automation are omnipresent nowadays and have also taken a significant role in education. The research presented here aims to overhaul the scaled model of the cup-filling machine to make it operate fully automated. The parts and subsystems of the cup-filling machine are explained in detail and their operation was tested. The cup-filling machine is fully automated using a programmable logic controller (PLC) SIEMENS S7 300. The machine can recognize two cup sizes and fills both types without overspilling. Filled cups are transported over a conveyor belt and classified according to their sizes PLCs have mainly replaced relays in industrial automation, bearing in mind that this way, scale-up is much more feasible, and alteration of control is done in PLC program code. This also has contributed to better maintenance and operation verification.

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1. INTRODUCTION

Automation has permeated every type of industry and many aspects of our daily activities. Human work is being continuously replaced by machines or automated agents [1-3]. The one niche that seems to be still mainly based on human work and manpower is maintenance. Managing complex systems such as processes, plants, or mechatronic ones can be very demanding.

Since the beginning of the 21st century, maintenance engineering has increasingly emphasized true reliability [4-5]. An asset-intensive business, such as manufacturing, relies on a reliability-centered engineering field to succeed. Reliability engineering has become a technology used to improve manufacturing capacity without capital investment [6].

The synthesis of a mechatronic control system is limited by computing power, real-time requirements, non-linearity of the process, limited speed and operating range of actuators, robustness, transparency of the solution, maintenance etc. [6-7]. The most important feature of the mechatronic system is the simultaneous (parallel) design of the mechatronic process and control. This means that the static and dynamic behavior of the process, the type and position of actuators and sensors in the system, are designed appropriately [8]. The goal of a lower level of control will enable safe, dynamic behavior with compensation of friction-type non-linearities, reduce the sensitivity of parameters and stabilize them [9-11]. Typical examples of tasks at this level

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are: damping of high-frequency oscillations, compensation of non-linear static characteristics, and compensation of friction effects, stabilization, and intermittent actuator control [12-14].

At the beginning of the industrial revolution, automated machines were controlled through relays interconnected by wires inside the control cabinet. It took a long time to detect a fault in the system, especially with complex control systems [15-17]. The lifetime of the relay contacts is limited, so they must be replaced over time. When replacing relays or other consumable parts, the machine had to stop and stop production. The control cabinet was only used for one specific process, and it was not easy to modify it according to the needs of the new system. According to what has been exposed so far, relay logic control has proven very inefficient [18]. These shortcomings were largely eliminated by the introduction of programmable logic controllers or PLCs in the control systems, which also contributed to improving quality, increased productivity and flexibility.

Devices installed in the field to automate technical processes, such as sensors, actuators, converters and drives, increasingly use communication networks to exchange information with higher-level controllers [19]. Factories of the future are based on flexible automation and computer-integrated manufacturing (CIM).

CNC (Computer Numerical Control) machines, industrial computers PLC (Programmable Logic Controller) and SBC (single board computer) and industrial robots form the basis of these production technologies [20-21]. The fact that the future factories will be computer-based means that the workforce will have a different composition than the traditional one [22]. First of all, it should be thinking of highly educated crews who will do the preparation, production monitoring and running-in so that the factory can function with as few people as possible. As a creator, man moves into designing, monitoring, planning and realizing all tasks related to concrete engineering.

PROFIBUS is one such communication network that can be used by all automation equipment, such as PLC, PC, HMI devices, as well as actuators and sensors to exchange data.

2. MATERIALS AND METHODS

This paper presents the overhaul and alteration of the scaled model of the cup-filling machine. The fully automated operation of the machine is obtained by adding a PLC to it and programming it in accordance with specifications. After the design and development process, a functional machine, an automatic cup-filling machine is constructed, which is a scaled-down model of an industrial machine. A control algorithm is developed to provide proper operation of the machine. A machine's control unit and specific components are replaced with programmable logic controller SIEMENS S7 300. A detailed description of the mounting, installation, procedures for wiring and programming of PLC as well as a simulation of PLC program by using the PLC SIM software, is given in this scientific paper. The program is translated and transferred to the control unit, and then applied to the machine.

The methods applied here include: analysis, synthesis, abstraction, concretization, specification, deconstruction, definition, division, deduction, analogy, and experiment.

The machine is equipped with sensors to transport cups to the point where these are filled. Cups are differentiated by height, i.e. volume.

The sensors used here are the proximity sensors - to detect if the cup is on the belt and whether it is in place to be filled. Also, sensors detecting the cup's height are used to discern between the two types of cups, either of volume V_1 = 0.1 l or of V_2 = 0.2 l.

The pump installed here provides the constant volume flow rate Q, which is Q = 0.7 l/s. Since the pump is at the same level as the nozzle, there is no need to compensate for the gravity. Filling times for both cup sizes/ volumes, either V_1 = 0.1 l or V_2 = 0.2 l, are calculated by the following equations, (1) and (2).

$$T_1 = \frac{V_1}{Q} = \frac{0.1\ \mathrm{l}}{0.7\frac{l}{\mathrm{min}}} = \frac{6}{0.7} s \approx 8.57\ \mathrm{s} \approx 9\ \mathrm{s} \qquad (1)$$

$$T_2 = \frac{V_2}{Q} = \frac{0.2\ \mathrm{l}}{0.7\frac{l}{\mathrm{min}}} = \frac{12}{0.7} s \approx 17.14\ \mathrm{s} < 19\ \mathrm{s} \qquad (2)$$

Finally, the machine is tested and put into use. It was determined empirically (references in [2]) that 19 s is enough to fill the cup of 0.2 l and not to overspill it. Smaller cups are sorted to one side and larger ones to another side. The proper operation is asserted in practice. The machine is constructed for educational purposes and works with students, but it might also be used in industry with few specific adaptations.

3. AUTOMATION OF THE CUP FILLING MACHINE BY CHANGING THE CONTROL METHOD

To make a control unit using relay technology, more components are necessary, such as more complex connections and a larger number of conductors. Changing the mode of operation refers to a physical change in the control cabinet, which in this case, is very difficult to implement, considering that the cabinet is made for the designed specification (Fig. 1).

Fig. 1. Machine's control cabinet in relay logic technology

The machine is controlled by installed and wired components, i.e. contractors and time relays (Fig. 2). The possibilities of individual components are limited by their construction, so the contractors have three ordinarily open (NO) and three customarily closed (NC) contacts each.

Fig. 2. The time relay

The time relay determines the time of one tap according to the set time; two-time relays are needed for two-time intervals.

Instructions for setting the time (Fig. 3):

- ✓ Potentiometer for the adjustment of asymmetrical input,
- ✓ Adjusting time delay,
- ✓ Selecting function,
- ✓ LED indicator,
- ✓ Potentiometer for upper voltage adjustment,
- ✓ Potentiometer for under voltage adjustment.

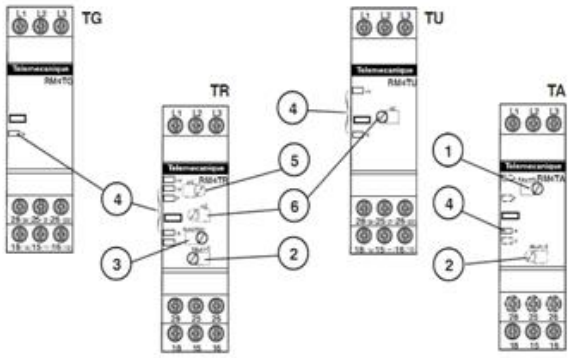

Fig. 3. The instructions for setting time

Each control change refers to the physical addition of a new contactor and the binding or rewiring of elements according to a new scheme. In contrast, each change of the time interval requires the mechanical movement of the switching buttons, which is a very complex process in which downtimes can be very long so that production costs can grow significantly.

By replacing the relay technology with a PLC control unit, it is much easier to potentially replace or supplement the functions of the machine by simply changing the program code, the wiring is reduced to a much smaller number of conductors, the timer setting is done programmatically by entering values in seconds, due to the smaller number of moving parts such as contacts is the number of cancellations.

4. TRANSLATION OF A BLOCK DIAGRAM INTO A LADDER DIAGRAM

STEP 7 is an engineering tool for SIMATIC controllers that run on the standard Microsoft Windows platform.

Translation of a block diagram means writing program code based on a block diagram in one of the standard programming languages for PLC programming:

- ✓ Ladder logic diagrams (LAD),
- ✓ Function block diagrams (FBD),
- ✓ Structured text (ST),
- ✓ Instruction list (IL) or, as is named here, Statement list (STL).

The simulation software PLCSIM is integrated into STEP 7 Professional, which is used for testing the user program offline. The LAD and FBD programming languages are used by connecting predefined blocks that represent logic circuits. To write programs using these two programming languages, it is necessary to know the basic symbols of automation and their functions. The STL programming language is often chosen by those who previously had contact points with any type of programming.

The basic procedure is applied, in processing the data of the automation system:

- ✓ Development of a new project,
- ✓ Hardware configuration,
- ✓ Configuration of the communication network,
- ✓ Assigning names to signals,
- ✓ Writing the driver program.

When creating a project, the first step is assigning the name and determining a storage location. After a unit is added, the hardware settings are specified. Based on the request, a communication rail is placed and modules are added. If necessary, the module parameters or the IP addresses of the signal modules are adjusted and additional communication expansion rails can be added.

A project may contain several units. Configuring the communication network creates connections between units that enable data exchange. Before writing the driver program, the signals are given symbolic names. A driver is made up of separate parts called blocks. Blocks are programmed using the mentioned programming languages, and thus the sequence of execution of blocks can be determined.

The online help of SIMATIC Manager provides the user with all the necessary information during programming, so the user does not need a manual, significantly speeding up the program's creation time. In order to use the help, it is necessary to have Microsoft Internet Explorer installed. The name of the help topic can be selected using the Help command or by simply pressing the F1 key on the keyboard.

There is a command in the form of a question mark on the toolbar. Using that command user can also get the corresponding help.

Selecting the desired module from the catalogue of modules using the Drag&Drop method could be located in the desired place. When installing the modules, it is necessary to take care of the arrangement of the correct filling of the slots. Some slots are predefined for certain modules so that others cannot enter that slot. For example, the third slot is reserved for the communication module and nothing else can be installed besides it. If it is not needed, the slot remains empty.

To find the desired module, it is necessary to go through the map structure. When the mouse is clicked on the selected module, its most important features necessary for creating the program are displayed. The selected module is transferred to the slot with factory settings and the program automatically assigns IP addresses.

The user can subsequently change the module settings as needed. Double-clicking the mouse on the selected module or selecting the Edit Object Properties function opens a dialogue window for changing parameters (Fig. 4). The zoomed-in detail is shown in Fig. 5.

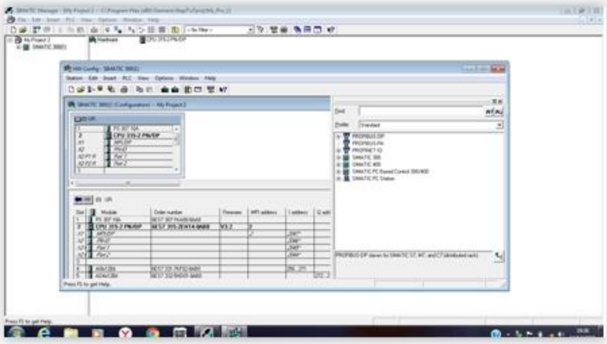

Fig. 4. The hardware configuration in the HW Config window

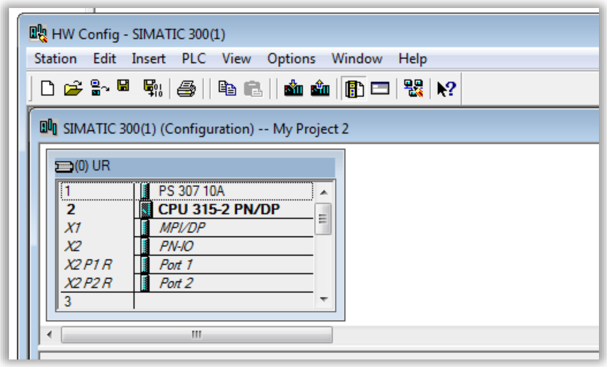

Fig. 5. Zoomed-in detail of the hardware configuration in the HW Config window

If the PLC unit works independently, there is no need for a network that is only necessary if there is an extension (Fig. 6; zoomed-in Fig. 7).

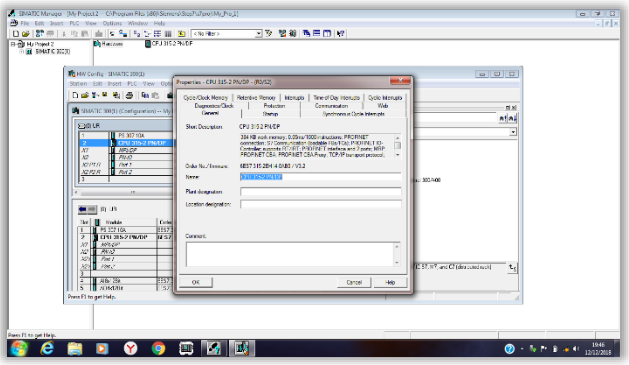

Fig. 6. The appearance of the window for changing module parameters

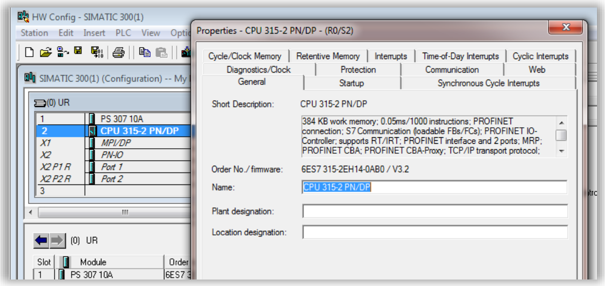

Fig. 7. Zoomed in detail of the window for changing module parameters

An algorithm of a PLC program is shown in Fig. 8.

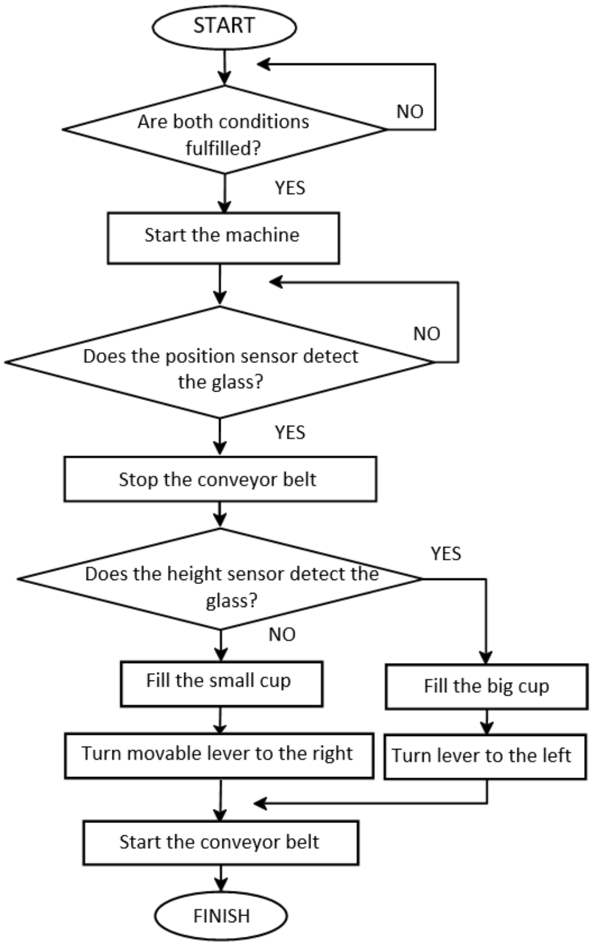

Fig. 8. The algorithm of a PLC program

5. MAINTENANCE AND CHECKING OF I/O CONNECTIONS OF THE MECHATRONIC SYSTEM

Connecting an I/O device to the appropriate module is a routine operation. After creating the program and testing it in offline and online mode, the connection is made by a technical person who does not have to have advanced knowledge of how PLCs work and program. The connection is created according to the scheme created based on the printout of the program code. When connecting larger systems with tens, hundreds or even thousands of inputs and outputs, it is advisable to mark each cable, element, and row terminal so that the operator can find it more easily in the event of failure of a part of the system.

In smaller systems, such as the charger, labeling the conductors and elements is unnecessary (Fig. 9). This is obtained because the wiring is reduced to just several necessary cables.

Fig. 9. The labelling of the conductors

Checking the connections between elements and modules can be done visually, if possible (by following the connection point of the conductor from element to element), or with an instrument that can test the conductor's continuity.

Usually, a multi-meter is used either to measure the resistance of conductors or to detect a connection between two terminals (Fig. 10). For the same conductor, it shows electrical resistance of 0 Ω (a continuous tone on the buzzer); for open leads or a break in the circuit or the conductor, it shows OL MΩ (indicating this with no tone).

Machine performance testing is set to check the mechanical assembly and user program compliance. Instead of simulating signals, the PLC receives accurate signals from the components that are installed on the machine.

Testing the cup-filling machine includes: starting the conveyor belt - turning on the filler on the main switch, taking into account that the conveyor belt should be stationary, waiting for the compressor to force the pressure in the bottle to 2 bar (the "air pressure" light should turn on), fill the liquid container with water (the level sensor should react, and turn on the "liquid level" light) which causes that the conveyor belt moves (Fig. 11).

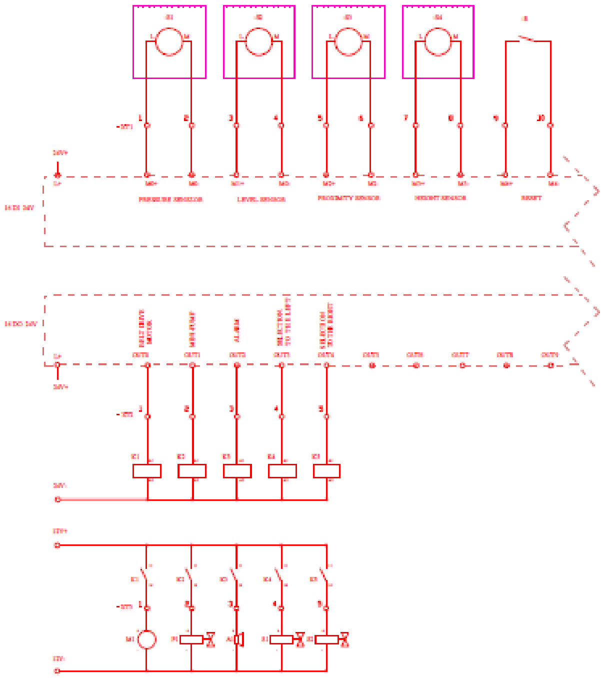

Fig. 10. The connection scheme

Fig. 11. Conveyor belt starting - input and output signals

Fig. 12 shows activated PLC inputs I 0.0 and I 0.1 (pressure sensor and level sensor) and activated output Q 0.0 (conveyor belt motor).

Fig. 13 shows the response of the sensor, which manifests in the activation of the PLC input I 0.2 (position sensor), the stop of the conveyor belt, the deactivation of the output Q 0.0 (conveyor belt motor) and the activation of the output Q 0.1 (pump) in a time interval of 9 sec.

Fig. 14 shows the response of the sensors, i.e. activation of PLC inputs I 0.2 and I 0.3 (position sensor and height sensor), stop of the conveyor belt, i.e. deactivation of output Q 0.0 (conveyor belt motor) and activation of output Q 0.1 (pump) in a time interval of 19 sec.

Fig.12. Activated PLC inputs

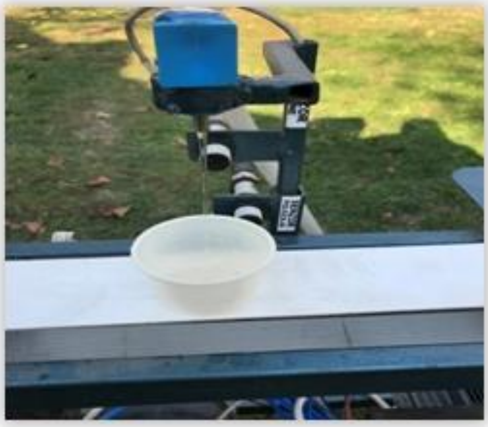

Fig. 13. Cup stop 0.1 l - photo of the machine

After being filled, cups are transported over a mini conveyor belt. At the end of the belt, cups are sorted concerning their size (volume).

CUPS SORTING - at each stop and filling, the selector for 0.1 l cups should be on the right and for 0.2 l cups on the left.

Fig. 14. Cup stop 0.2l - photo of the machine

Fig. 15 shows the response of the sensors, that is, the activation of the PLC inputs I 0.2 and I 0.3 (position sensor and height sensor), the stop of the conveyor belt, the deactivation of the output Q 0.0 (conveyor belt motor) and the activation of the output Q 0.1 (pump) during the time interval of 19 sec and activation of output Q 0.3 (selection to the left). Sorting glasses to the right side is presented in Fig. 16.

Fig. 15. The responses of the sensors detecting cup's position and height for filling the 0.2 l cup

Fig. 16. Sorting glasses to the right side

6. RESULTS AND DISCUSSION

This paper shows the maintenance and automation control of the machine for filling cups. The plan was to construct a smaller filling machine that has the ability to recognize two sizes of glasses and sort them after filling. The machine is composed of a combination of new and recycled used parts, predominately aimed for educational purposes. The first concept of the solution was designed without PLC controller, and in this research, a program for PLC is developed. The task of this machine is to fill glasses of different volumes of 0.2 l and 0.1 l. It has a liquid tank, pressure and level sensors, a compressor, and a button for automatic on and off. The conditions that must be met in terms of operation are as follows: air pressure must be above 2 bar, conveyor belt width 10 cm, circulation pump with constant flow, machine charger operating at 220 V, power of the electric motor of 12 W, cup sorting using a pneumatic piston, protection against loss of air pressure, protection against improper sorting, light alarm, and after signaling the lack of liquid, the level should be enough to fill one glass. The machine is tested, and its maintenance is described in detail. This model (Fig. 17) might be used with some enhancements for industrial production.

Fig. 17. The completed cup-filling machine with PLC and sensors

7. CONCLUSION

With the development of computer-aided technologies and their implementation in control units, today, a much more compact and safer operation management of any automatic control system with a much longer service life compared to some older models. With appearance and functionality, ease of expansion to a vast number of inputs, outputs, sensors, actuators and programming tasks, and simplicity of changing programming tasks, PLC programmable logic controllers have taken over automation and management in all branches of industry. Smaller ones have replaced the former huge control cabinets with relays, the expansion of functionality is done by changing the program code, the detection of errors occurred is mainly done before compiling and also programmatically, a large selection of user interface layouts and many more possibilities and advantages have been brought by new and modern management systems.

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