Electroplating Plant Control System

Georgi Ruzhekov

***Abstract* — The system is designed to control a line for chrome plating of large machine elements. Chrome plating provides corrosion protection, increases surface hardness and improves the wear resistance of parts. All processes are controlled - transfer of parts, control of galvanizing current, temperature control of electrolyte solutions, safety and other auxiliary functions. The control system is based on a Programmable Logic Controller (PLC) and the necessary signal modules. Decentralized peripherals with wireless industrial PROFINET communication of mobile objects were also used. The control of the main drives is performed with inverters with PROFINET communication, and for those of the mobile objects - wireless PROFINET communication.**

The service staff uses two pcs. 12"touch operator panels - for the charging station and for service support. The operators also have a SCADA system, from which the installation can also be controlled, as well as set additional parameters.

***Index Terms* — Chrome plating, Industrial control system, PLC, SCADA**

I. Introduction

Electroplating is a process that produce a metal coating on solid material trough the reduction of cations of that metal using direct electric current. The part to be coated acts cathode of an electrolytic cell, the electrolyte is a solution of a salt of the material to be coated and the anode is inert conductive material. An external power source is used to operate this installation. The installation consists of 6 chrome-plated baths, one activation bath, 4 washing baths, storage positions, 3 cross manipulators that transport the stands with the details to and from the bathtub line and 2 portal manipulators that transport the stands with the details between the bathtubs, storage positions and transverse manipulators. The control system is built with a Siemens controller (CPU 1512C) [1] and the necessary signal modules. The communication with the mobile manipulators is done by PROFINET wireless communication. Two 12" touch operator panels and a SCADA system are used to connect with the operators. Industrial communications are used - PROFINET (wired and wireless) and PROFIBUS – Fig. 1.

According to the classification for the number of signals, this control system is middle class - it uses about 800 discrete and analog signals and about 3000 tags. The number of physical signals has been reduced many times with the use of communication networks.

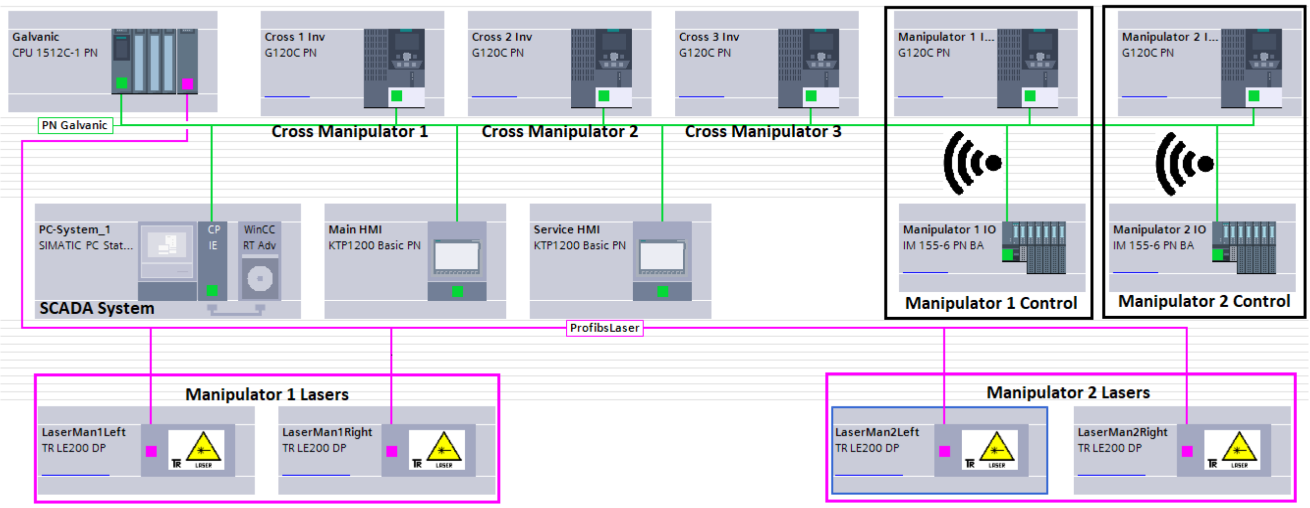

Fig. 1. Communication of the system

II. Basic Subsystems

The installation is large, consists of many movable and immovable objects, and most of them have sensors and actuators.

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A. Overhead manipulators

The overhead manipulators move stands with details for chrome plating between storage positions, chrome plating tubs, washing tubs and cross manipulators (Fig. 2). They have two degrees of freedom - horizontal and vertical movement.

Two motors and the corresponding gearboxes on both sides of the manipulator perform the horizontal movement. The two motors must move synchronously so as not to twist

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the manipulator. A frequency inverter controls the motors. The position of both sides of the manipulator is measured with laser distance sensors, which transmit the data via a PROFIBUS communication network. The positioning error must not exceed ± 5 mm. This accuracy must be achieved regardless of the weight of the load (0 to 2 t), with a speed of up to 0.5 m / s. The load must not be shaken when starting and stopping.

The vertical movement for lowering and raising the stands with details is performed with one motor, and the places of the vertical positions where the load must be established (upper, intermediate, and lower) are set with inductive sensors.

The control of this manipulator requires many signals - analog and discrete. Using cable connections between the manipulator and the controller is very difficult - it moves - its stroke is about 40 m. For this reason, the communication between the controller and the manipulator is chosen to be wireless. Frequency range 2.4GHz is used. The control panel of the manipulator is mounted directly on it. Decentralized peripherals and an inverter are used, which are connected to the controller via wireless communication. This approach saves a very large amount of cables that have to move with the manipulator. In this way, the interference that would be induced in these cables is eliminated.

Fig. 2. Overhead manipulator with details

B. *Laser distance sensors*

4 laser sensors are used [2] (Fig. 3.) - two for each manipulator (left and right side). In the range of sensors (50 m) their accuracy is better than ± 3 mm. PROFIBUS communication at a speed of 128 kb/s is used to connect to them. The laser sensors return the position in mm as well as diagnostic information. These parameters are used in the control system of the overhead manipulators. It is possible to use analog signals to transmit position data, but then it will not be possible to obtain the required accuracy.

Fig. 3. Laser distance sensor

C. *Cross manipulators*

3 cross manipulators are used in the installation. They are designed to transport stands with parts that need to be chrome-plated and return finished parts from the bathtub line to the place of loading and unloading, controlling their horizontal movement – Fig. 4. At the loading and unloading point, their vertical movement is allowed, which ensures the convenience of the service personnel for loading or unloading.

One engine is used for horizontal movement and is carried out at different speeds depending on the position of the manipulator on the track. For vertical movement, two motors are used, which raise and lower the stand with the parts synchronously on both sides. Frequency inverters are used to control the motors. The horizontal and vertical positions are determined using inductive sensors.

Fig. 4. Cross manipulator with details

D. *Frequency inverters*

Frequency inverters control the motors of the manipulators. They allow setting the speed, acceleration and deceleration of engine rotation. From a software point of view, each inverter is a technological object to which there is a group of functions, and which can be set the basic parameters. The communication to the inverters is via PROFIBUS, which greatly facilitates the wiring. The ability to set the acceleration and deceleration makes it possible to control the manipulators so that the swing of the load is minimal. Braking resistors are included and configured with the inverters, which makes it possible to set the braking deceleration. The resulting electrical energy during braking (the motor goes into generator mode) is dissipated on the braking resistor. This is especially important for manipulators to obtain accurate positioning and for cross manipulators to maintain a preset speed when lowering the load.

E. *Galvanic baths*

In them the chrome plating of the details is performed. Total number - 7, one is activation and the other 6 are for chrome plating. Each of the baths has a volume of about 20 m^3. One of the baths is activating - it performs electrochemical preparation of the details. In order to obtain a quality coating, it is necessary to keep the temperature of the electrolyte within set limits. Electric heaters are used for heating and tube coils are used for cooling, through which cold water is passed. In the process of galvanization, a very large amount of heat is released (50 – 100 kW), because of which is cooling is extremely important. A three-position controller carries out the control of the temperature regimes.

A profile of the change of the galvanizing current over time has been developed for each type of part. It is set in relative units depending on the galvanizing area. The system supports 500 types of parts, each of which sets the size and number of parts to be processed. Operators set the type of parts and their number, from which the galvanizing current curve is calculated.

Controllable rectifiers are used. The output voltage is up to 12 V and the current up to 15000 A. Their voltage is controlled, and the current is the resulting value and mainly depends on the area of the parts and solution temperature. Some of the rectifiers are controlled by discrete signals to increase and decrease the voltage, they are of the integrating type - they use a speed controller. The other group of rectifiers is controlled with a voltage of 0 ÷ 10V and they are controlled by position controllers. The rectifiers return as analog feedback signals for voltage and current, as well as discrete for their state.

F. Process control system

Coordinates the work of the whole system depending on the current state of the subsystems and the assignments received from the operators. **The main processes are:**

- Start of detail processing - the operators set the type of parts and their number, which are attached to a stand and start the operation. It is performed at the loading and unloading position.
- Obtaining ready-made details - after the processing of the details is completed, the system arranges the stands with ready-made details at the warehouse positions. Operators set which of the stands to be delivered to the loading and unloading position.
- Manual control of the manipulators to perform ancillary activities.

The system controls:

- Cross manipulators for carrying stands ready for processing or delivering finished parts;
- Bridge manipulators for moving the stands with details between the bathtubs (activation, chrome plating and washing) and the storage positions. The operation of the manipulators is optimized, as both manipulators can perform most of the functions of the other.
- Starting the processes in the baths.
- Control of the cooling and heating processes of the baths, control of the mixers.
- Emergency monitoring.

G. Main database

They are stored as data structures in the non-volatile memory of the controller. In this way, the system remains operational even in the event of a failure in the SCADA system, which runs on a standard computer. The entry or change in the data is done through the SCADA system. Supported:

- data for the processed details - up to 500 pieces, as for each detail are recorded dimensions, number of activation current curve, number of chromium current curve, time corrections, washing times, etc. parameters.
- It is possible to search in the database for details by number and name.
- Current curves - 100 pieces.
- Technological parameters - 20 pcs.
- The system maintains real-time data for each stand - details it carries, current position, current operation, next operation.
- Data on the manipulators - current position and speed, distance between the manipulators, position in height and number of the stand to be transported.
- Data on galvanic baths - the presence of a stand, the current implementation of galvanizing, electrolyte temperatures and its control, electrolyte level.

Stands for carrying details. The system maintains a real-time database of 50 stands, each of which supports:

- Active / Inactive
- Position number
- Part number that is attached and the number of these details
- Ongoing process

III. SCADA

The system has a SCADA system from which all processes can be controlled. It is based on WinCC Advanced and is part of the engineering station of the system. The software is developed in the environment of TIA Portal V17 [1]. In addition to the SCADA system, there are two 12“ touch operator panels - one for the place of loading / unloading and the other - on the electrical panels and is designed to perform service operations.

All elements of the SCADA system and the operator panels are animated, all the necessary data for the operators are displayed.

A. Main screen

The entire installation is shown on the main screen (Fig. 5.). In this way, operators have a complete view of the processes that take place in the installation:

- All positions
- Stand with or without elements, if there are in the respective position, elements of the stand - name and number.
- Overhead manipulators, their position horizontally and in height, what they carry, distances, speeds. Their position is animated, i.e. they move in real time.
- Galvanic baths - temperature of the galvanic solution, cooling or heating included, mixers included, remaining time of the process, voltage and current of the rectifier.
- Cross manipulators - their current positions are animated. It shows what they wear and their position in height.
- Positions can be allowed or banned. If a position is forbidden, the manipulators will not leave stands with elements in this position.

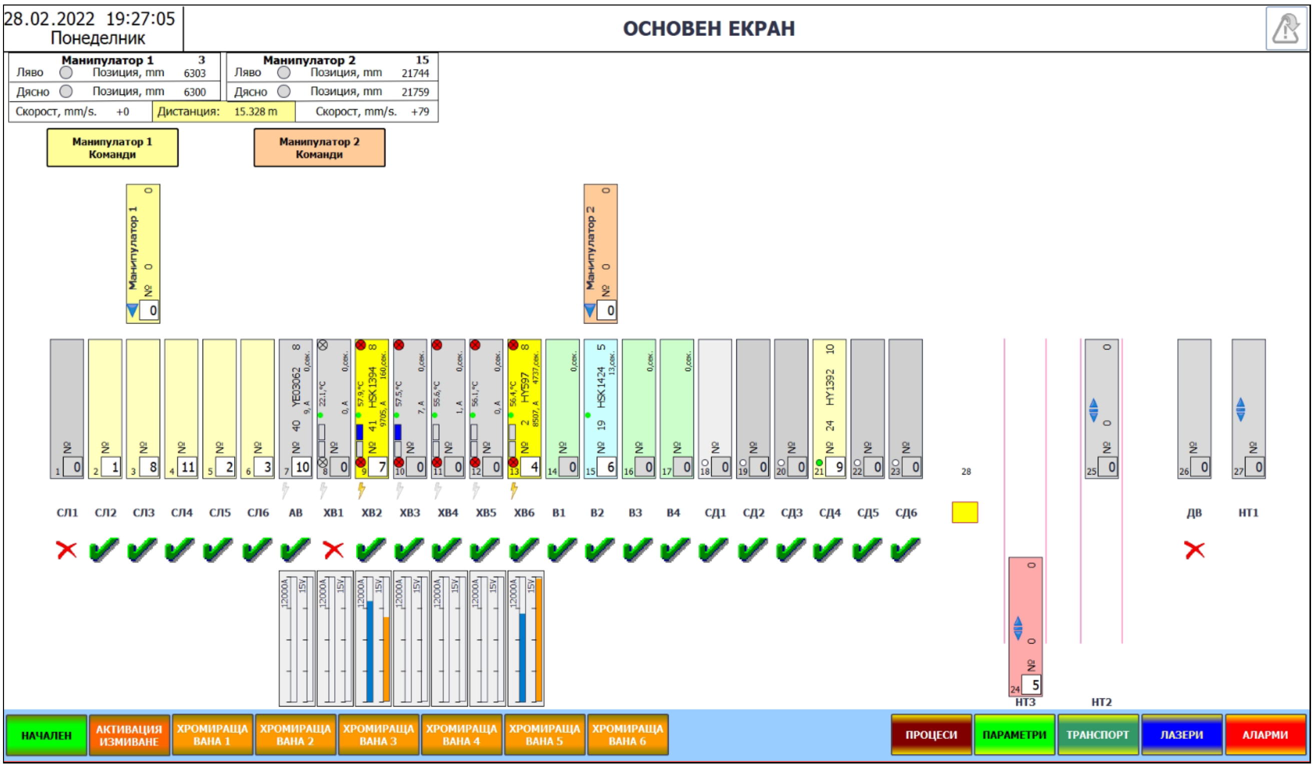

Fig. 5. SCADA – Main screenFrom this screen, a stand with ready-made elements can be called up and delivered from a set cross manipulator to the corresponding unloading position

From the main screen, additional screens can be opened for each manipulator (Fig. 6). Through which the manipulators can be used for auxiliary operations - to move from the starting position to the end position with or without a stand. Extremely convenient function for operators.

Fig. 6. Additional screen for auxiliary operation

B. *Process screen*

In Fig. 7 a screen showing the processes that take place at each position. The number of the stand, what is on it and the ongoing operations are displayed.

The Fig. 8 the dialog system for control the processes of loading unprocessed parts, as well as for unloading finished parts. The operators set what details are attached to the respective stand and start the operation. The system checks for the correctness of the entered data and starts the operation. In this case, the cross manipulator takes the stand to the bath line from where overhead manipulator 2 takes it and transports it to the activation bath or to a storage position, where it waits before being transported to the activation bath.

C. *Detail parameters screen*

The setting of the parameters of the parts for galvanization is done by a dialog system. It is connected to the database of details and allows you to enter and / or edit the parameters - serial number, name of the part, dimensions, technological program, activation program, current program, correction of chrome times. The part surface and the maximum number of parts that can be chrome-plated at the same time are automatically calculated.

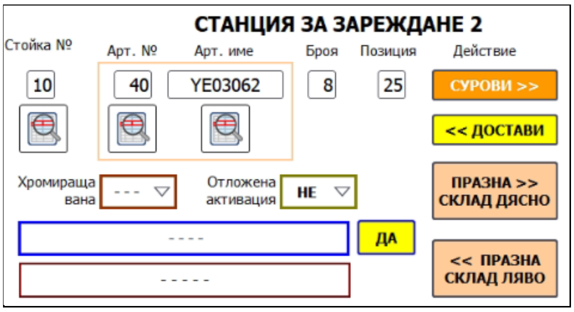

Fig. 8. Loading and unloading dialog system of Load station 2

The parameters of the technological and current programs are also set through a dialog system. Current curves are set in relative units (A/dm^2). When chrome plating is started, the current curve is calculated depending on the area of the chrome plating parts.

The dialog systems for the part parameters and current curves are shown in Fig. 9.

An information subsystem has also been developed, which allows for detailed tracking of each stand. It is asked whether it is available, at what position it is currently, what details are attached to it, some basic parameters of these details and the current operation on them. An opportunity has been created to change the current operation. This gives additional flexibility to the system, as operators can change the technological process if necessary (Fig. 10).

Позиция		ТИП ПОЗИЦИЯ	Партиден №	Стойка №	Арт. №	Арт. име	Броя	ПРОЦЕС
1	✗	Складова отляво	0	0	0		0	- - - - -
2	✓	Складова отляво	0	1	0		0	- - - - -
3	✓	Складова отляво	0	8	0		0	- - - - -
4	✓	Складова отляво	0	11	0		0	- - - - -
5	✓	Складова отляво	0	2	0		0	- - - - -
6	✓	Складова отляво	0	3	0		0	- - - - -
7	✓	Активираща вана	0	0	0		0	- - - - -
8	✗	Хромираща вана 1	0	0	0		0	- - - - -
9	✓	Хромираща вана 2	0	0	0		0	- - - - -
10	✓	Хромираща вана 3	0	0	0		0	- - - - -
11	✓	Хромираща вана 4	0	0	0		0	- - - - -
12	✓	Хромираща вана 5	1711	10	40	YE03062	8	Хромиране
13	✓	Хромираща вана 6	1710	4	2	HY597	8	Хромиране
14	✓	Измиване 1	1708	7	41	HSK1394	8	Край измиване 1
15	✓	Измиване 2	0	0	0		0	- - - - -
16	✓	Измиване 3	0	0	0		0	- - - - -
17	✓	Измиване 4	0	0	0		0	- - - - -
18	✓	Складова, сурови и готови	0	0	0		0	- - - - -
19	✓	Складова, сурови и готови	1712	5	27	MYP29	2	Сурови на склад
20	✓	Складова, сурови и готови	0	0	0		0	- - - - -
21	✓	Складова, сурови и готови	0	0	0		0	- - - - -
22	✓	Складова, сурови и готови	0	0	0		0	- - - - -
23	✓	Складова, сурови и готови	0	0	0		0	- - - - -
24	✓	Напречен транспорт 3	0	9	0		0	- - - - -
25	✓	Напречен транспорт 2	0	0	0		0	- - - - -
26	✗	Дехромираща вана	0	0	0		0	- - - - -
27	✓	Напречен транспорт 1	0	0	0		0	- - - - -

Fig. 7. All process that take place at each position

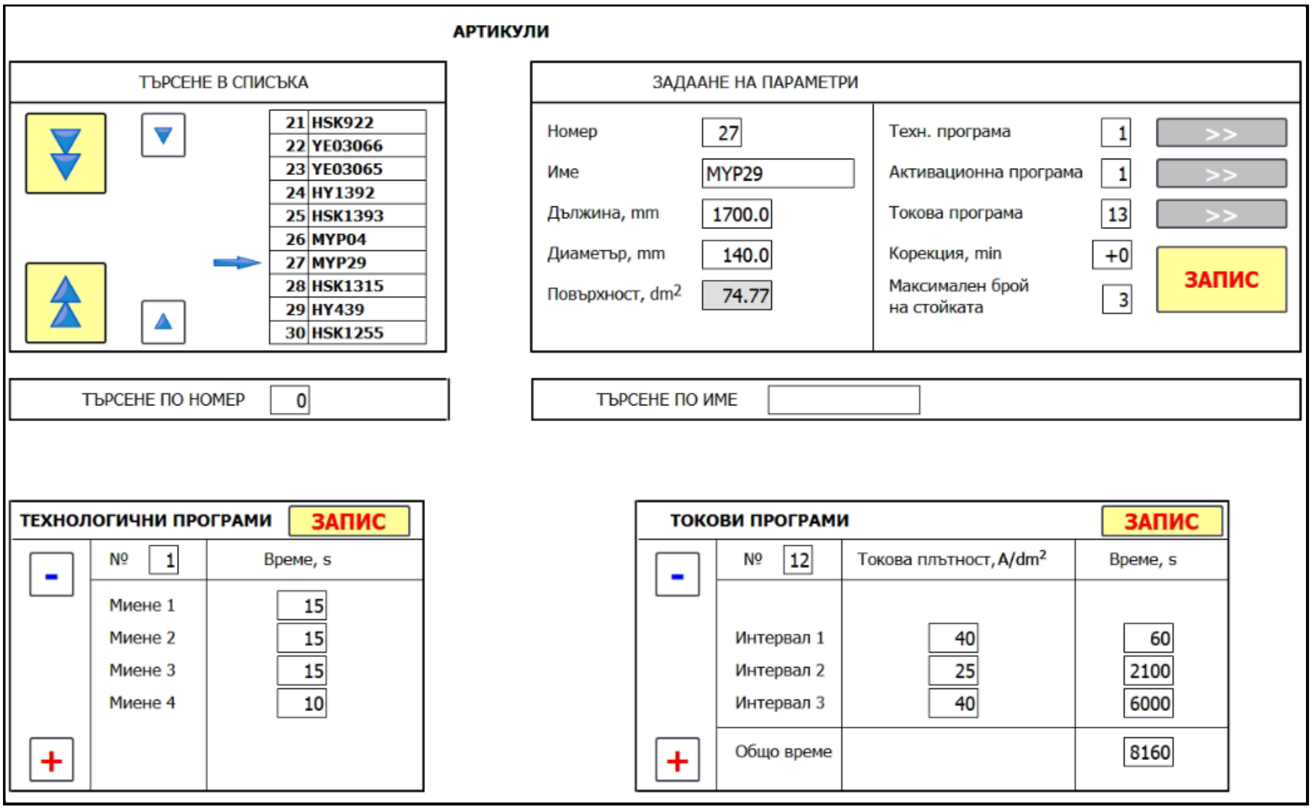

Fig. 9. Dialog system

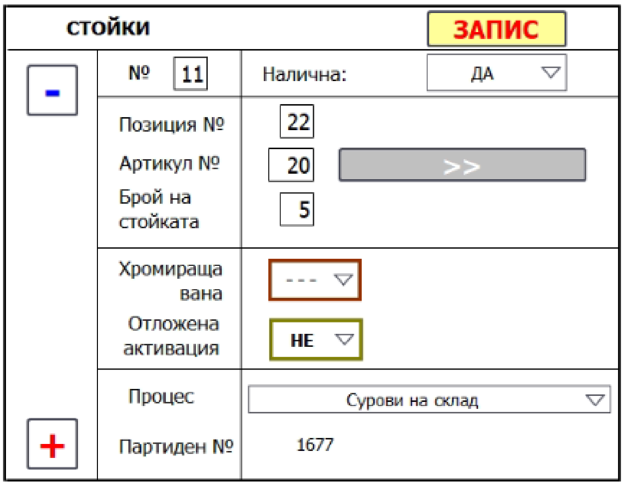

Fig. 10. Stand information subsystem

D. Manipulator positioning system:

A system for setting the positions of the manipulators has been developed (Fig. 11). The procedure involves manually moving each manipulator (possibly two people) to each of the positions. The set position is selected with the mouse and the distance data from the laser distance sensors are recorded in the respective data block. Subsequently, it is possible to make small adjustments by setting the distance values directly in mm.

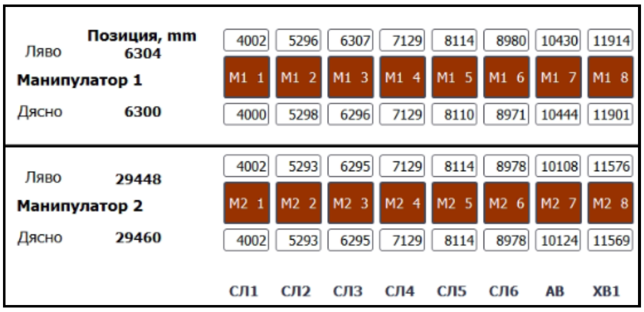

Fig. 11. A small part of the screen for setting the position of the manipulators

This procedure is particularly dangerous and improper operation can cause serious damage to the installation. For this reason, it is performed only by authorized persons, only when necessary, and is password protected.

All settings related to speed, acceleration and other motion parameters are also password protected.

E. Visualization of the operation of chrome-plated baths

In Fig. 12 the screen of one of the chrome baths is shown. Normally, chrome-plated baths operate in automatic mode, but it is possible to set the voltage manually or turn off the rectifier. Operators can monitor the galvanizing process - the times of the individual intervals of the current curve, voltage and galvanizing current.

On the right side of the screen (Fig. 13) are the settings for switching on the mixers, heating, cooling and setting the temperatures.

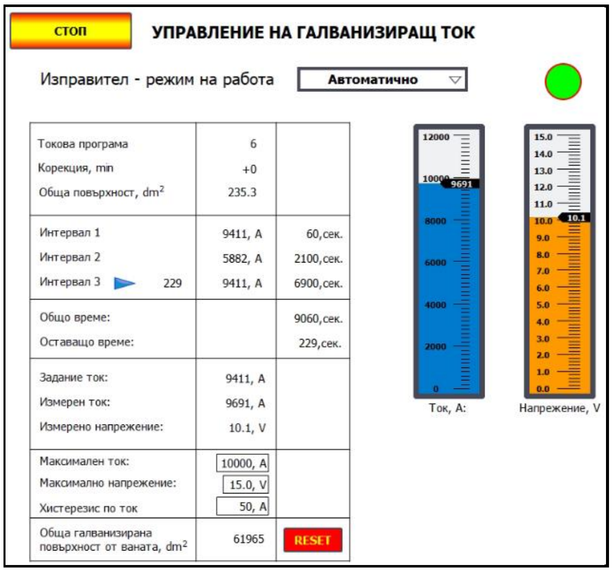

Fig. 12. Galvanization current

Fig. 13. Temperature control

IV. Stages of System Development

The system is very complex, expensive equipment is controlled and it is necessary to pay special attention to work safety. The main requirement is to prove the operability of the control system before it is connected to the installation to be operated. Factory Automation Test (FAT) [3], [4], [5] is used for this.

The FAT helps assure both parties that the new equipment complies with all contractual specifications. Moreover, it helps address any functional issues before the equipment arrives at the client's installation site. Rectifying manufacturing issues while the system is still with the manufacturer helps control aspects of the project, such as timeline and budget. The FAT is a cost-effective solution and is preferable to addressing issues post-deployment.

The Factory Acceptance Test is a process that evaluates the equipment during and after the assembly process by verifying that it is built and operating in accordance with design specifications. FAT ensures that the components and controls are working properly according to the functionality of the equipment itself.

The FAT is a customized testing procedure for different types of systems and the tests are executed before the final installation at the plant. The FAT is not a requirement but recommended to be carried out, according to the standard IEC 61511, if the application software of the logic solver is fairly complex or if the architecture of the safety instrumented system is using redundant arrangements. FAT must be conducted in a thorough and forthright manner. A poor or rushed FAT can lead to missed nonconformities, which can only then be corrected after the equipment is installed—which in turn can wreak havoc on a project schedule.

For this reason, the development of the system is carried out at the following stages:

1. Based on the available documentation for mechanical and electrical parameters of the equipment, an electrical scheme of the power unit has been developed and the necessary components for the protection and switching equipment and frequency inverters have been choice.

2. Controller, signal modules and communication equipment are choice.

3. SCADA and HMI platforms are choice.

4. Development of a software simulator of the system:

- Approximate models of the individual elements of the installation have been developed and implemented in the TIA Portal environment - they work on the same controller as the control algorithms. The sampling times of all elements of the installation are selected.
- Control algorithms have been developed.
- Conducting tests entirely in simulation mode - simulated processor and simulated elements of the installation. All hardware switches, buttons, locks and sensors are also simulated.
- Conducting full simulation tests and approval by the Contracting Authority.

5. Development of a hardware-software simulator of the system:

- The real controller and signal modules are used.
- Connected to switching equipment, inverters and communication system.
- Instead of the electric motors of the installation, motors that are not coupled to the mechanical part are included.
- Some of the models of the objects are preserved.
- Full testing of this simulator and wireless communications.

6. Connecting the system to the real manipulators and conducting tests. At this stage, it is necessary to adjust a few parameters, mainly related to the parameters of the movement of the manipulators, settings of some regulators, adding additional functions, the need for which is established when starting actual production.

This organization of the development of the system allowed for the installation and commissioning of the system within two weeks.

V. Conclusion

This article is a brief description of the developed and implemented plant control system for chrome plating of large machine elements. The structure of the control system is shown. A Siemens controller CPU 1512C and the necessary signal modules are used, the communication is based on PROFINET and PROFIBUS and the control system of the mobile manipulators is based on decentralized peripherals and wireless PROFINET communication. It uses about 800 discrete and analog signals and about 3000 tags. The number of physical signals has been reduced many times with the use of communication networks.

The system controls more than 50 fundamental processes simultaneously and coordinates their work.

Laser distance sensors are used to determine the position of the manipulators.

The individual subsystems, databases and the software system for process control are considered.

The SCADA system and some of the main screens are briefly shown. Some of the basic functions and their implementation are explained. It is shown how the basic data for the processed details, the technological parameters, the current curves, as well as the data for positioning of the manipulators are entered. The ability of the operators to monitor the course of the technological process and, if necessary, to intervene in some of the stages is provided.

For the convenience of the operators, two 12“touch panels are installed - one on the loading and unloading station and another on the electrical panels, which is used to diagnose the system.

The simultaneous use of SCADA and operator panels enables the operation of the system to continue even in case of damage to the computer of the SCADA system or in case of damage to any of the displays.

The stages of development of the control system, which are in accordance with the requirements of Factory Automation Test (FAT), are shown. It has been shown that thanks to these stages of system development, it is possible to develop the system independently of the elements of the installation, to perform tests with the control system in advance and to eliminate errors. In this way, the actual implementation of the system took place in just two weeks.

References

[1] https://support.industry.siemens.com/.

[2] http://www.tr-electronic.de

[3] Black, Rex (August 2009). Managing the Testing Process: Practical Tools and Techniques for Managing Hardware and Software Testing. Hoboken, NJ: Wiley. ISBN 0-470-40415-9.

[4] SO/IEC/IEEE International Standard - Systems and software engineering. ISO/IEC/IEEE. 2010. pp. vol., no., pp.1–418.

[5] "Factory Acceptance Test (FAT)". Tuv.com. Archived from the original on February 4, 2013. Retrieved September 18, 2012