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Original Article

Remote-Controlled Cooling System for Chrome Plating Cells Using Industrial IoT and MODBUS TCP/IP

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Abstract *- This project proposes an electronic control solution to improve thermal management during the electroplating process in chrome plating cells, using a cooling tower control system and an intelligent cooling process. Using RTD sensors to monitor temperature in real time, electronic solenoid valves to regulate coolant flow, an electronic card capable of communicating between devices, and control strategies to maintain stable temperatures in each cell, this system ensures precise and efficient control of thermal conditions throughout the chrome plating process, reducing response time by up to 96.67%). The integration of the ATMEGA 328P microcontroller, S7-1200 PLC and MODBUS TCP IP communication protocol, together with the visualization through a real-time monitoring peripheral, will allow operators to manage the system remotely, optimizing not only the coolant flow but also the product quality. In this way, the system not only ensures a more controlled and efficient process but also contributes to reducing operating costs and extending the useful life of the equipment in the event of manual operation deficiencies.*

Keywords *- Electroplating Process Optimization, Smart Cooling Control System, Temperature Monitoring with RTD Sensors, PLC and Microcontroller Integration, MODBUS TCP/IP Industrial Communication.*

1. Introduction

In the electrochemical industry, especially in pickling and chromium plating processes in chromium plating cells, cooling plays a crucial role in the quality and efficiency of the process. During the coating of metals with chromium, galvanometric cells experience a considerable increase in temperature due to chemical reactions and the applied electric current. If not properly controlled, this thermal increase can negatively affect both the coating performance on components and the service life of the cells. Uncontrolled temperature compromises the consistency and quality of the chrome plating and can lead to energy waste, critical damage to cell anodes, and high operating costs.

The pickling and chromium plating process in galvanometry cells requires precise management of thermal conditions to ensure coating quality and process stability. This intelligent electronic system offers an automatic, real-time solution, ensuring optimized resource use and better final product quality control. In addition, integration with a PLC and a microcontroller improves the system's reliability and scalability. This project proposes an electronic solution to improve thermal control during electroplating. Using RTD sensors to monitor temperature in real time, electronic solenoid valves to regulate coolant flow, and PID control strategies to maintain stable temperatures in each cell, this system ensures precise and efficient control of thermal conditions throughout the pickling and chromium plating process. This smart electronic cooling approach will not only improve the operational reliability of the electroplating process but also enable greater sustainability and competitiveness in the industry, transforming the cell chromium plating process into a more accurate, efficient, and cost-effective system.

2. Related Works

Like [1], where it evaluates the impact of Electrochemical Descaling Technology (EDT) on the corrosive behavior of carbon steel in industrial Circulating Cooling Water Systems (CCWS), comparing a system with EDT (E-CCWS) versus a conventional one with chemical treatment (C-CCWS). From the perspective of thermal efficiency and sustainability, EDT allows for the increase of the concentration of water in the system, significantly reducing water consumption, energy, and operating costs associated with the cooling process. Faced with the problem of corrosion or sulfation in coolant pipes, it is considered that [2] the control of scale formation is essential to maintain heat transfer efficiency and ensure the continuous operation of equipment such as exchangers and cooling towers. The progressive deposition of scales on the internal surfaces of the systems can cause significant thermal losses and blockages in the flow lines, compromising the overall performance of the cooling system. Regarding the design of cooling in cells, a method like [3] presents a line by subsections applied to the hot rolling process of silicon steel, with the objective of optimizing the thermal control of the rolls and, consequently, improving the geometrical quality of the strip, especially regarding the edge drop. The system is based on a segmented spray beam installed at the exit of the rolling mill, allowing localized thermal adjustment according to dynamic process parameters. Another study shows a similar cooling with different applications [4]. A passive thermal management system based on Phase Change Materials (PCM) is investigated to improve temperature control in electronic components subjected to critical operating conditions, such as those used in medical, industrial and military applications.

PCMs, known for their high latent heat capacity, are employed here as thermal storage elements that absorb and release heat during their phase transition, mitigating the risk of overheating. Similar systems are described in [5], where the study proposes a Closed Wet Cooling Tower (CWCT) integrated in a subway air extraction channel, optimizing space and energy efficiency. Through simulations in COMSOL and experimental validation, it was demonstrated that the thermal performance of this tower exceeds that of conventional models, being little affected by the heat dissipation of the environment, obtaining a thermal efficiency of up to 30.77% and cooling of 48.57%, with the ability to add units in series to cover the cooling demand by up to 29%.

Likewise, the hot and cold fluid recirculation system is similar to [6], where a flexible analysis method is performed to evaluate the thermal performance of cooling water recirculation systems, considering the influence of uncertain environmental and operating conditions. Based on psychrometric theory, 4000 dry and wet bulb temperature combinations were simulated to estimate the minimum tower outlet temperature. As one of the results, it was identified that the make-up water temperature range is the most influential factor in the flexible thermal regulation capability. Regarding the galvanometric cell design, a similarity is given in [7]. A parameter identification technique was developed based on the cell resistance waveform, allowing the system to estimate resistance and capacitance values.

A model was implemented in Simulink to simulate current and voltage waveforms, verifying that the model is stable, controllable and observable, although it presents low conditioning (errors$\leq$ 7 % in voltage and $\leq$ 10 % in current).

Using parametric identification with experimental data allowed for obtaining the time dependencies of the electrical parameters, and it was verified that the average active resistance correlates with the coating thickness, allowing accurate estimates of the coating growth during the process. The use of industrial protocols makes the system more robust and reliable, as well as in [8], where it addresses the proposed architecture with data acquisition through the Modbus TCP/IP protocol, standard in industrial environments, allowing the collection of operating parameters from the PLC. These data are sent to the cloud for storage and remote monitoring, and the online interaction between the DAIREL system and the HMI interface of the constant pressure plant is validated as a case study. Regarding the control strategies used, it is inferred in [9] where a PLC and IoT-based multichannel PID temperature control system was developed to overcome the limitations of traditional systems, such as lack of wireless communication, remote download, low thermal stability and poor interference immunity.

The system uses the MQTT protocol for remote data monitoring and control and remote offloading programs to the PLC via third-party cloud platforms. This architecture allows for simplified maintenance and remote access to key process variables. Experimental testing demonstrated steady-state thermal stability of ±0.1 °C using PID-controlled multichannel heaters. In addition, a cloud-based monitoring interface was integrated to provide real-time data (temperature, voltage, current) and instant notifications to mobile devices in case of alarm events, significantly improving responsiveness and operational management.

In terms of control type, this choice of controllers was made like [10] using data from the system itself with variable results where the performance of the Heat Exchange Recirculating Mash System (HERMS) system in craft brewing was evaluated using four temperature control strategies: P, P-logic, PI and PID. The objective was to optimize thermal accuracy during mashing, which is critical for enzymatic conversion and process efficiency.

The system was modeled using First Order + Delay (FOPD) and Second Order + Delay (SOPD) representations, tuning the gains using Skogestad's method. Simulations were performed in MATLAB Simulink. As a result, the P-logic controller achieved 0 % of overshoot, but at the cost of 100% of energy consumption, and the PI and PID controllers maintained the same thermal stability with only 30 % of input energy. And for another choice, like the controller type in [10], a greenhouse climate control by natural ventilation using PID controllers and feedback linearization techniques. A nonlinear model linking fan opening (main actuator) with indoor temperature was developed, addressing uncertainty in the airflow vs. opening ratio. The control design considers measurable disturbances and operational constraints, integrating PI control with linearizing feedback. Simulations and robustness analysis against parameter uncertainties show that the proposed approach maintains an adequate balance.

To conclude, the choice of a flow valve depending on the same design in [11] is taken as a reference to address technical problems such as unsteady flow in small openings and unequal force on the valve core. The single-seat control valve with stable flow regulation has been investigated and designed. The tapered surface of the outer edge of the valve core can cooperate with the valve seat when the valve seat operates stably, resulting in higher accuracy and stability in flow regulation. Mechanical and flow characteristics are analyzed. Fluid flow simulation analyzes the fluid's pressure, velocity, density, mass flow rate and volumetric flow rate under small and large openings of the single-seat control valve.

The relationship between the maximum pressure, maximum velocity, maximum density, mass flow rate and volume flow rate of the inlet and outlet with the opening is analyzed from small openings to large and small openings.

Thermal stress simulation analyzes the temperature, resulting heat flow, thermal stress, thermal deformation and safety factor, and material strength meets the requirements. The single-seat control valve was tested for valve body pressure, seat sealing, full stroke and switching time, drift and fluctuation, initial deflection, basic error and return difference, and dead zone. All test results meet the requirements.

The simulation results are compared and analyzed with the test results, and they match the test results. And also in [12] where PID control directly from the valve it is observed that an intelligent control valve system integrating a servomotor driven ball valve, IoT connectivity and PID control, allows precise flow tuning, fundamental for thermal applications where constant temperatures are required to be maintained, the finely tuned PID control allows precise flow modulation, making it ideal for systems where flow directly affects temperature, such as in cooling or heating processes. The solution is economical, precise and scalable for industrial temperature control applications.

3. Methodology

This paper presents the design and implementation of an intelligent electronic system for the remote control of the cooling in the electroplating cells during the pickling and chrome plating processes.

This would include the control of valves, the remote start-up of the cooling tower, and the customized regulation of the temperature in each cell individually.

Through the integration of PLC, a microcontroller and sensors, it will be possible to optimize the cooling process in a remote and automated way, guaranteeing the efficiency of the process, reducing operating costs and improving the quality of the final product. The main features of the control system are:

- Solenoid valve control to regulate refrigerant flow.
- Remote on/off control of the cooling tower.
- Control module through a monitoring peripheral.
- Independent monitoring and control of cooling temperature for each cell.
- Monitoring and warning system with alarms.
- Implementation of a robust control strategy and MODBUS TCP IP communication protocol for valve control.

The use of the PLC S7-1200 in conjunction with the ATMEGA 328P-AU base electronic card through MODBUS TCP IP communication allows the independent control of each valve.

The PLC input and output control simulation was done through simulations in TIA PORTAL V16, and the PCB design with ATMEGA 328P-AU was done in EAGLE 9.6.2 software; the programming of the card was done in ARDUINO IDE software.

Table 1. Materials used

Type	Model	Quantity
Microcontroller	ATMEGA 328P-AU	1
PLC	S7-1200	1
RTD	Pt100, Class A, 3-wire	6
Flow Valves	TFV4-304	6
Contactor	CHINT NC1 0910	2
Contactor	CHINT NC1 3210	1
Peripheral	TFT 4.3” TFT	1
Gateway	BE7200	2
Transformer	380V-220V 300W	1
Power Supply	24V-5A	2
Ethernet cable	RJ45 Extension	2

To understand more about its operation, the logic is shown in (See Figure 1) where the system waits for control activation, which will have a blocking of drives by an emergency stop with 2 internal contacts, waiting for temperature control by the RTD module the system will start its operation manually or automatically depending on the working conditions in temperatures from 45 to 55 ° C, in a manual mode the activation of valves will be open and close (ON-OFF control), also if configured to work automatically valve activation will have the PID control strategy using the control tuning ZIEGLER-NICHOLS, such processing and action will be given by the control card based on ATMEGA 328P-AU, similarly will be blocked by increases and decreases in temperature, or settings in manual mode that affect the proper functioning of the system.

For the electrical control part, there is a change in its activation system, which currently addresses the detailed problem.

This expects the timing and activation by sequence; all this will be replaced with the change of contactors and the integration of PLC S7-1200.

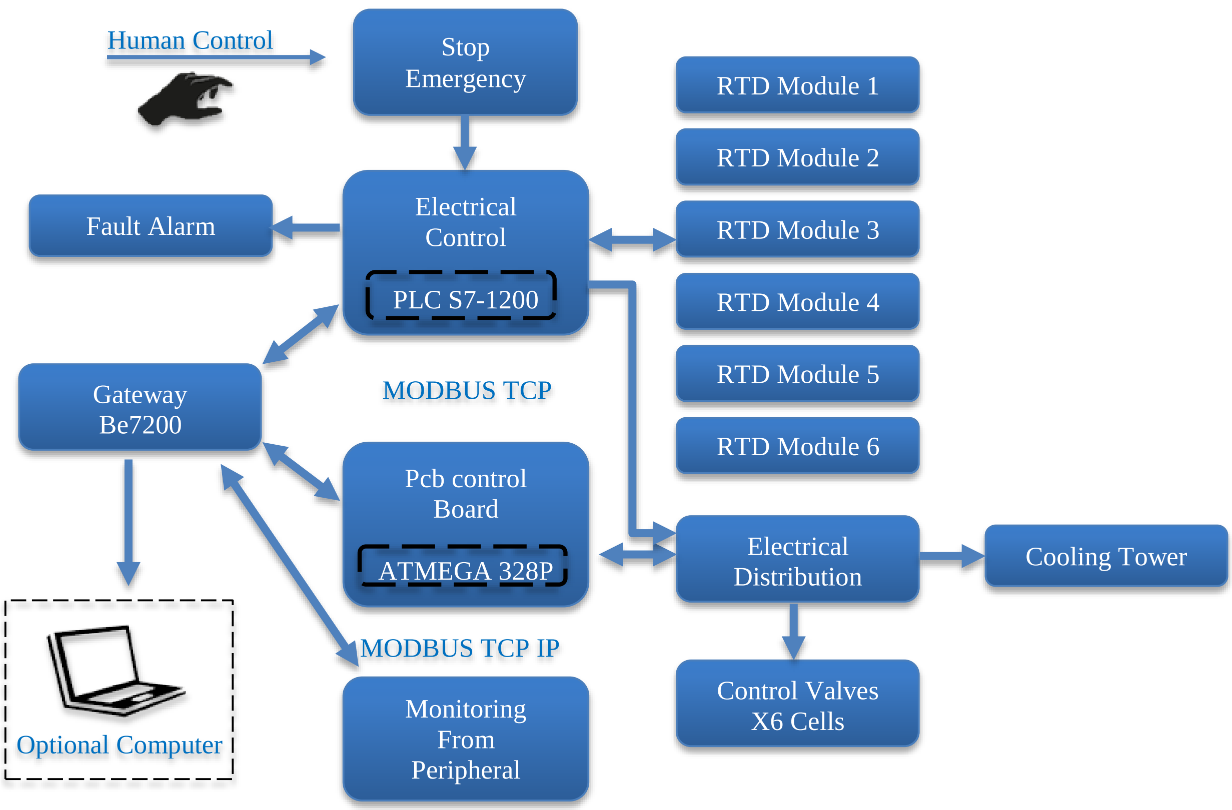


Fig. 1 Block diagram of the system

4. Developed System

The purpose of the system is to automate temperature control in chrome plating cells through the use of RTD type temperature sensors, proportional valve control and a control architecture based on a Modbus TCP/IP industrial network (See Figure 2). This solution seeks to avoid overheating due to late manual intervention, increasing the efficiency and safety of the process.

The operation of the system starts from the activation of the activation protection of the control devices which is conditioned with an emergency button, this allows the activation of the relays in electrical part corresponding to the control of valves and peripheral power with the PCB control board, as for safety before an emergency part this has the possibility that an error in the system deactivates the valves.

Subsequently, the chrome plating cells have temperature sensor reading modules, where a rigorous selection was made due to its direct application in sulfuric acid, choosing the RTD sensor type Pt100, Class A, 3 wires, encapsulated in PTFE coated, with thread for thermowell, range -50 °C to 200 °C, additionally the module responsible for the reading of these RTD activates a relay at a setpoint temperature of 45 to 55°C and analog signal of 0-10V, The signal is received by the control card with ATMEGA 328P and the PLC S7-1200 is responsible for the activation and interlocking of the cooling system of the cooling tower, in addition to activating the corresponding control output to the electronic card and valve power supply, as well as the ignition of the cooling tower sequentially to avoid cavitation in peripheral pumps and generate load alarms for vacuum activation of the same.

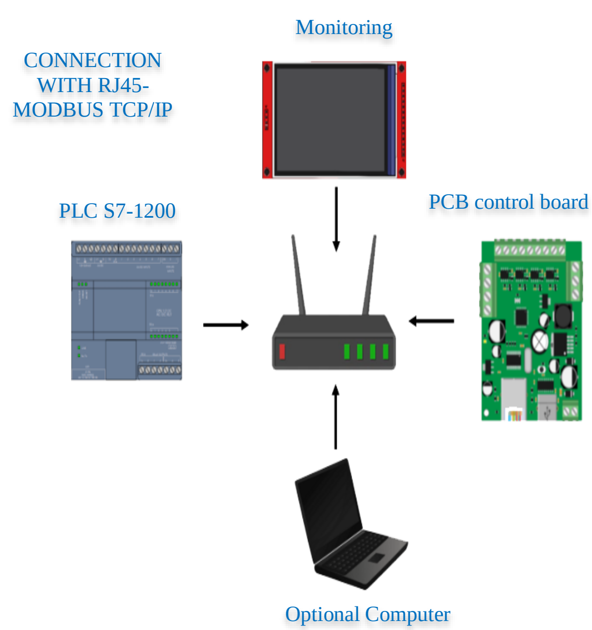


Fig. 2 MODBUS TCP/IP system

For the manual or automatic activation of the flow valves, the activation must be done from the monitoring peripheral linked to the MODBUS TCP/IP network, allowing the visualization of data such as temperature in each cell in an individualized way configured by windows, cooling tower activation, alarm activation and resetting of the same.

As for the design of the device's main control PCB, it will feature MODBUS TCP/IP communication via the ENC28J60 IC for ETHERNET connectivity (see Figure 3). Using a gateway, it will be possible to connect to the S7-1200 PLC via its integrated RJ45 port. Additionally, the card will have a STEP-DOWN voltage reducer with LM2596 at 12VDC regulation from 24VDC from the main power supply (see Figure 4).

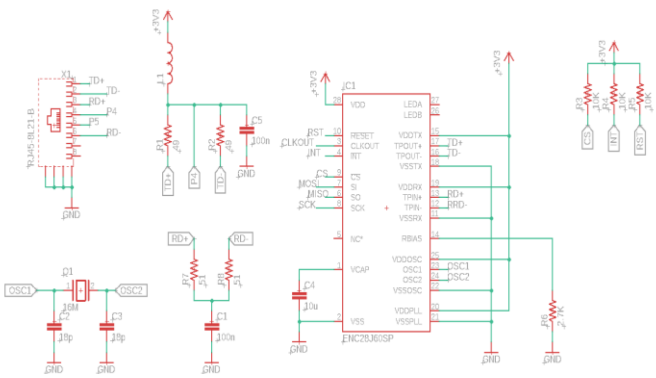


Fig. 3 MODBUS communication with ENC28J26

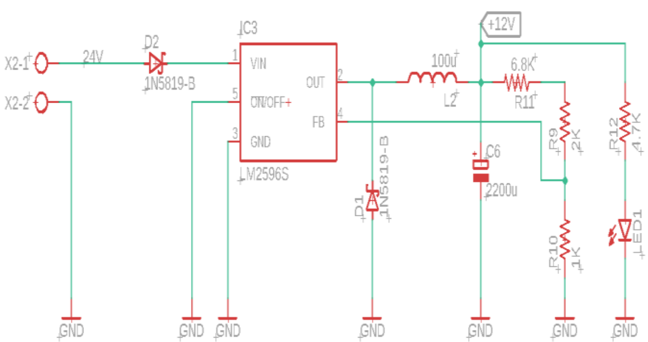


Fig. 4 Main 12V voltage

The ATMEGA 328P is integrated as the main microcontroller for reading ADC variables through its PC0 ports. Signal conditioning is provided by LM358D operational amplifiers for optimal reading in its ADCs from 0-10VDC analog signals from the RTD modules already installed, with protection against voltage surges (see Figure 5). For valve control, the control card will send the analog output signal through the analog ports of the ATMEGA 328P, which, through an integration configuration with the LM358D opamp, achieves the variable analog voltage of 0-10VDC necessary for the modulation of refrigerant control valve regulation (see Figure 6).

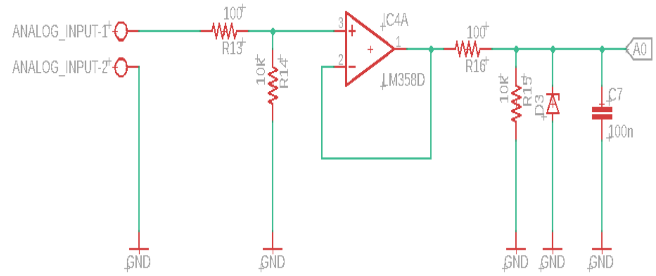


Fig. 5 0-10VDC to 0-5VDC input signal conditioning

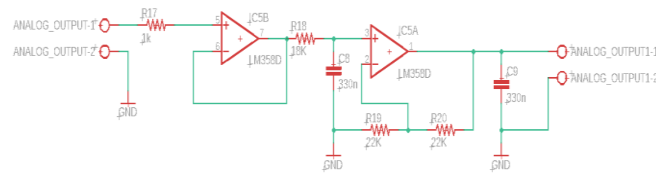


Fig. 6 0-5VDC PWM to 0-10VDC output signal conditioning

The design of the peripheral monitoring module was performed in the same way, integrating the ENC28J60 IC for ETHERNET connectivity and an ATMEGA 328P microcontroller for programming the corresponding 4.3” TFT. The design of the monitoring panel was made to have sub-windows where each chrome plating cell with its respective temperature control is displayed independently (See Figure 7).

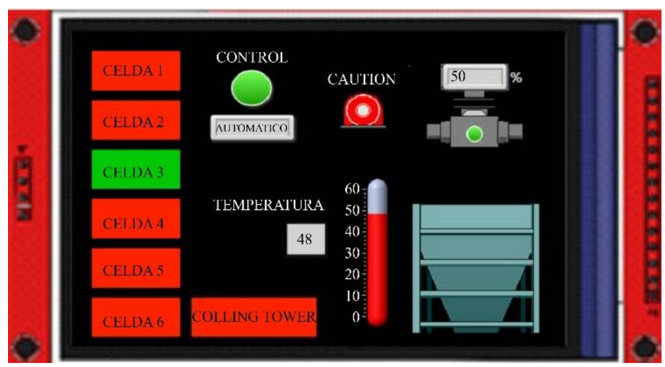


Fig. 7 Peripheral monitoring module

The programming of the control card and monitoring peripheral with ATMEGA 328P was done in ARDUINO IDE software in C++ language, likewise, the PLC S7-1200 in TIA PORTAL V16 and the electrical distribution logic was done in CADESIMU. The operation in each stage of the system is as follows:

4.1. Operating Logic in Control Card with ATMEGA 328P

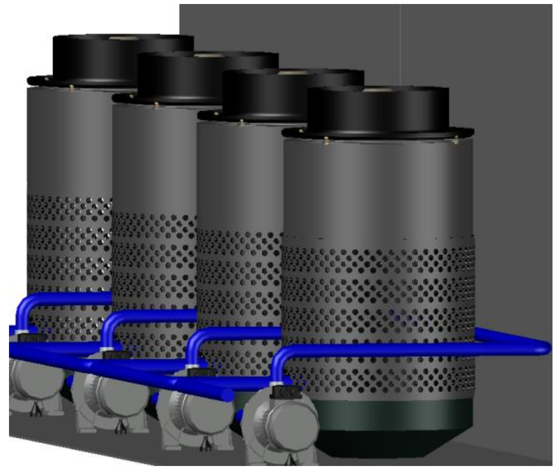
- 0-5VDC 1Khz to 0-10VDC analog PWM signal drive for independent flow valve control per chrome plating cell (6 in total).
- Analog 0-10VDC voltage reading from chrome plating cell RTD modules, logic and conditioning of this signal is performed to send a discrete signal via MODBUS TCP/IP

to the S7-1200 PLC to enable cooling tower and manual or automatic control.
- Configurations from monitoring the peripheral via MODBUS TCP/IP to perform these modifications in the electrical distribution stage of the cooling system.

4.2. PLC S7-1200 Operating Logic
- Actuation of distribution relays depending on the discrete signal from the control card with ATMEGA 328P via MODBUS TCP/IP, the signal is received for the action of manual or automatic control change relays in the electrical distribution stage, cooling tower control, over temperature alarms, and control status pilots.
- A discrete 0-24VDC signal is received from the RTD modules of each chrome plating cell to display alerts programmed in the module for cell temperature increase or decrease.
- Enable the main contractor to power the system at 380VAC 3-phase.

4.3. 380VAC- 220VAC Electrical Distribution Logic
- The 380VAC 3-phase voltage will be distributed to the RTD module (see Figure 8) and the cooling tower motors (see Figure 9); these motors will be activated sequentially depending on the programming and timing logic in the S7-1200 PLC.
- A voltage phasimeter will be installed at the beginning of each contactor to corroborate the correct voltage input and avoid failures due to rotation reversal before the next preventive maintenance or change of contactors for these motors.
- The 220VAC voltage will be obtained from the transformer, which will reduce the 380VAC voltage to the indicated one, to feed the 24VDC power supply and the PLC S7-1200, with the sole purpose of isolating electrical noise produced by motors. And to feed control relays and contactors, the distribution of phase R of the three-phase line plus neutral will be used.

Fig. 8 RTD module



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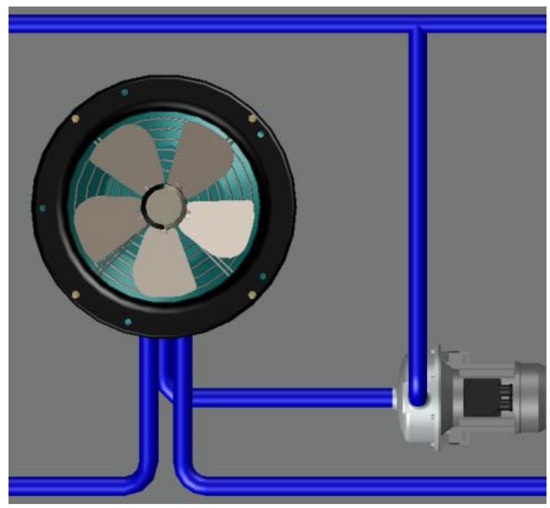


(b)

Fig. 9 Cooling tower

As for the control tuning of the flow valves, ZIEGLER NICHOLS control theory open loop test with STEP impulse command to generate the following characteristic curve in relation to time (See Figure 9).

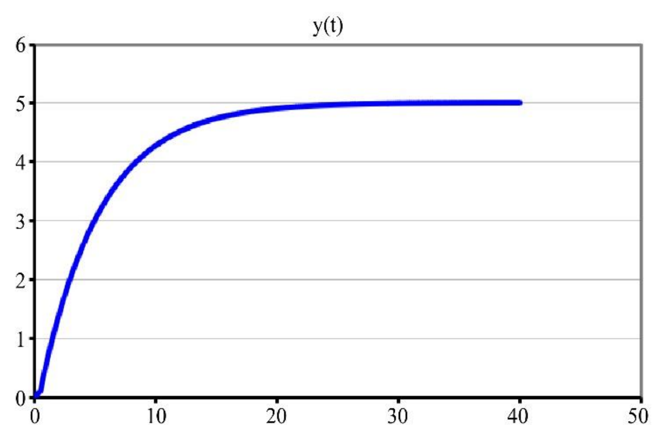


Fig. 10 System reaction curve

According to the values found in the reaction curve, tuning with values KP, TI, and TD, obtains the following characteristic curve for temperature control in the chrome plating cell (see Figure 10). The implementation of the electronic cooling system requires proper handling by the chrome plating operator properly trained for the handling of these components, likewise the electrical part for manual operation will be available from the peripheral module to use it when the RTD sensor calibration or update variables in the PLC S7-1200 is required, It should be noted that the cooling system of the cooling tower must be done sequentially, avoiding pump cavitation and operation without water coming from the water tank, corroborating the correct operation in each turret (See Figure 12).

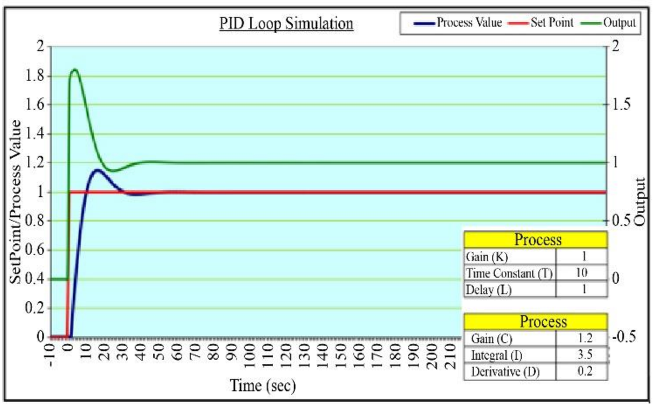


Fig. 11 Variable controlled with PID tuning

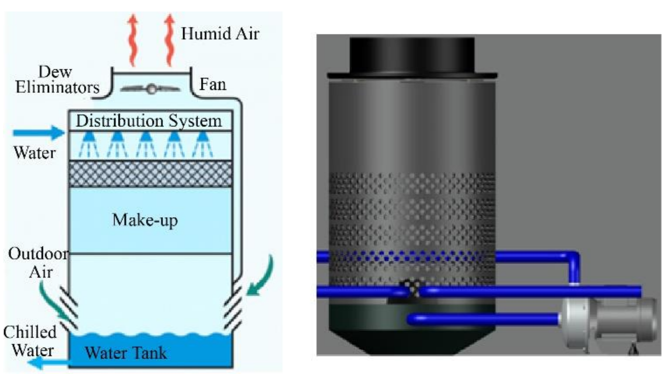


Fig. 12 Operation of cooling turrets

Before actual implementation tests, simulations are performed, which took seven days to obtain data for each chrome cell, depending on the sizes and purpose, to modify the corresponding analog output signal in the flow valves. Next, the system's electrical panel was installed in the rectifier electrical room, which has the following block diagram of operation (see Figure 13). The conductor connections to the peripheral module located in the chrome plating plant were also made using pipes. To complete the installation, power tests were performed for each device to be controlled, The voltage of 220VAC and 24VDC for powering control devices and 380VAC 3-phase for the power stage, together with the amperage as constant total energy consumption in the cooling tower, being 25A, and free passage of the coolant in valves for coolant control, both used in manual mode. The tests were performed from the operation of the peripheral module in manual mode for the ignition of the cooling tower, sequentially activating each turret, likewise proceeding to the activation of each valve to verify the correct flow modulation, depending on the setpoint of the RTD module of each chrome plating cell, the operator in charge of this work performs the respective cooling. The manual control mode was subsequently executed, once the chrome plating cells reached a temperature range between 45 and 55 °C, in pickling or chrome plating of components, the system is enabled with setpoint values of 50°C obtaining an optimal cooling control for tests performed in the chrome plating cell No. 6 (See Figure 13).

Fig. 13 Component reaction at proper temperature and current

The following tests were performed by raising the set point of the RTD module to one outside the appropriate operating range as 60 °, which meets the emergency warning feature, also when the temperature is excessive rectifier as a method of protection depending on the set point of the RTD module blocks the current sent to the chrome plating cell (See Figure 14). The system was tested for 15 days after installation, finding small deficiencies in terms of electrical noise control in the distribution board, as it was in a place prone to electromagnetism of transformers in electrical room, changing its location next to cooling tower and implementing a snubber network to suppress voltage spikes generated by power contactors. Once the changes were made, the operation was corroborated during 20 days of testing, which were satisfactory. This implementation was carried out in a metal mechanic workshop specialized in chrome plating of hydraulic parts of yellow line equipment located in the industrial area of Cerro Colorado, Arequipa. The optimization of the electronic system has a satisfactory result, since the control is directly from the peripheral module to a previous one which had to be done manually from the rectifier room, improvements in the quality of the product to be chromed and reduction of the activation time of the cooling tower in automatic mode improving the stability of the process.

Fig. 14 Temperature-current protection at zero

5. Tests and Results

To evaluate the effectiveness of the electronic cooling control system, such as process optimization and control times, the values obtained before and after implementation are mentioned, such as the reaction time for the activation of the cooling tower which was acquired by the operator indicating that in a usual situation it took 5 min to open and turn on the cooling system, For unusual cases it took him 30 min to perform these actions, time increase due to adverse situations such as snack time or shift change and optimal cooling control performed with manual and electric valves depending on the correct opening of the same to maintain the proper temperature of each chrome plating cell. A comparison of these values and the calculation of the improvement of the system is made, obtaining satisfactory results in terms of the reduction of the activation time of the cooling system and optimization in the correction of errors due to porosities in hydraulic components generated by overheating or excessive cooling in the chrome plating cells.

$$Improvement\ \%: \left(\frac{T.Manual - T.Automatic}{T.Manual}\right)\ x\ 100$$

- Average Scenario:
  $$Improvement\ \%: \left(\frac{5-1}{5}\right)\ x\ 100 = 80\%$$

- Worst Case Scenario:
  $$Improvement\ \%: \left(\frac{30-1}{30}\right)\ x\ 100 \approx 96.67\%$$

Table 2. Improved cooling system activation time

Control	Scenario	Activation Time	Manual Mode vs Improvement
Manual	Average	5 min	-
Manual	Worst case	30 min	-
Automatic	Implemented	1 min	80% to 96.67%

After implementation, a reduction in response time of up to 96.67% is obtained, prevention of overheating, reduced risk of damage to components in chrome plating cells, the implementation makes the system does not depend on an operator to perform the critical task in terms of cooling, achieving optimization and control of the process.

The efficiency and comparative of the control in flow valves and keys is given by the following values indicated by the operator, the time of 10 min on average to perform control and optimal regulation of flow to chrome plating cells, dead time due to excessive cooling in cells by a bad control and deficiency in the handling of these manual keys generating process delay of up to 40 min to return to obtain the proper temperature compared to the improvement of 0.5sec in terms of control and regulation of flow, zero dead time due to the effectiveness of the control.

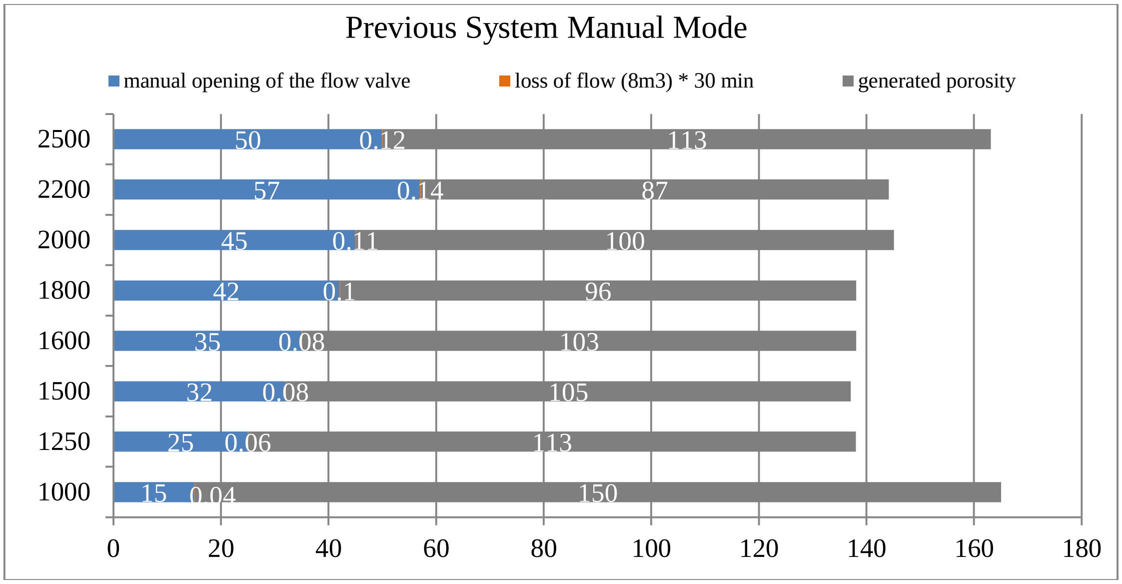
Table 3. Manual and automatic efficiency values

Parameter	Manual	Automatic
Flow control and regulation time	10 min	0.5 sec
Dead time due to excessive cooling	≈ 20 min	0
Total potential delay	30 min	0.5 sec

$$Efficiency\%: \left(1 - \frac{T.New}{T.Oldant}\right)\ x\ 100$$

According to the comparisons, the success rate of the electronic control system in automatic mode is 99.97%, making it a feasible system for production in the galvanometric process implemented directly to the chrome plating cells.

97%, being a feasible system for production in the galvanometric process implemented directly to the chrome plating cells, in addition to these factors there is the reduction of porosity in components because the sulfuric acid is reused and contain metal particles from previous chrome plating or pickling, then shows the reduction of these porosities in components of 1000 to 2500cm2 for industrial hard chrome plating with density of 30A/dm2 to 750amp, along with the flow used in the system in manual and automatic mode (See Figure 15).



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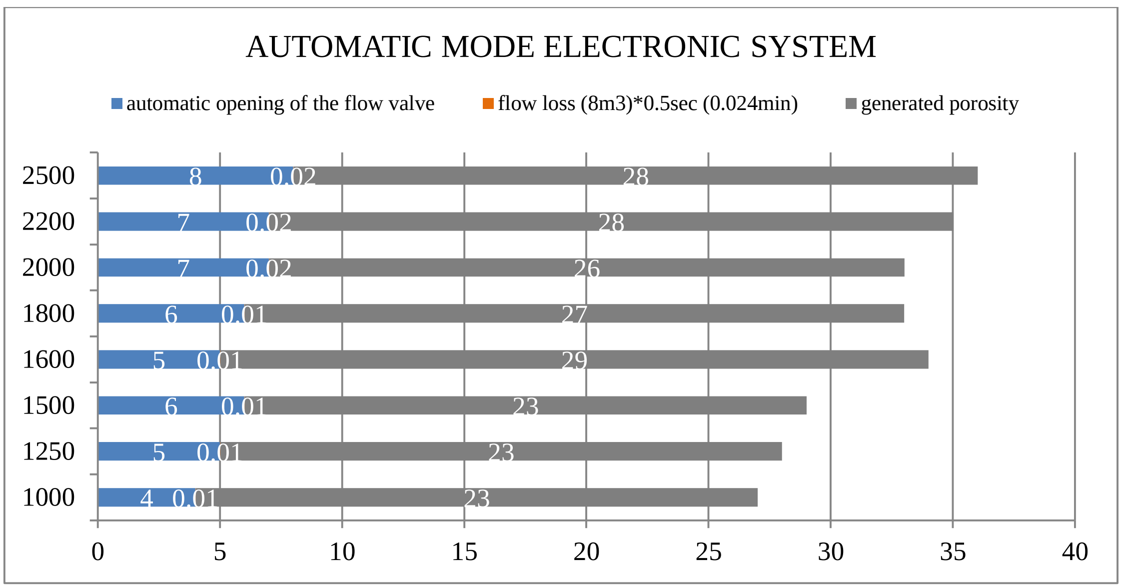

(b)

Fig. 15 Porosity generated before and after implementation.

In addition, a calculation is included to obtain energy savings based on the times proposed in a real 3-hour hard chrome plating application.

$$P_{cooling\ tower} = 380VAC\ x\ 25 = 9.5kW$$

$$E_{consumed1} = 9.5kW\ x\ 3\ hrs = 28.5kWh$$

Based on an intermittent operation of 1 min, the smart control will be used 30% of the time.

$$E_{consumed\ 2} = 28.5kW\ x\ 0.3 = 8.55kWh$$

$$E_{consumed\ 1} - E_{consumed\ 2} = 28.5kW - 8.55kW = 19.55kWh$$

A total energy saving of 19.55 kW is obtained during 3 hours of continuous use with the implementation of the system.

6. Conclusion

The present study demonstrated the feasibility and effectiveness of an advanced electronic system for thermal management in electroplating processes, specifically in chrome plating cells. Through the integration of an ATMEGA 328P microcontroller for the control of analog actuators, a Siemens S7-1200 PLC as the central logic unit, and an industrial network architecture based on the MODBUS

TCP/IP protocol, it was possible to establish an individual and distributed control platform. The system incorporates high-precision RTD sensors for continuous temperature monitoring and solenoid valves with 0-10V analog modulation for dynamic regulation of the refrigerant flow rate, based on thermal control algorithms performed by the control card. The results obtained in controlled tests show an improvement in the thermal stability of the process, achieving a reduction in response time of up to 96.67% compared to manual regulation systems. In addition, implementing a visualization panel from the monitoring peripheral allows the supervision of multiple cells, which optimizes operational decision-making in real time. It is concluded that the present study validates the proposed system as not only a significant improvement in the thermal performance of the chrome plating process but also represents an efficient strategy in terms of reducing operating costs, mitigating failures due to human intervention and extending equipment life through more accurate, reliable and automated control.

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