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Development of an Industrial PID Regulation Solution for the Thermal Safety of a Multi-Wire Drawing Machine

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Abstract: Thermal control of multi-wire drawing processes is a strategic requirement in the automotive wiring industry, due to its direct influence on conductor quality, tool durability and operational continuity.[1, 2]This study, carried out as part of an industrial project at COFICAB MED, introduces an automated solution based on PID regulation to control the temperature of the lubricating emulsion used in the cooling of the wire drawing machine. The proposed architecture is based on a Siemens S7-1200 PLC programmed under TIA Portal, using PT100 sensors connected to a 4–20 mA transmitter and controlling a Belimo motorized valve in closed loop. The integration of an HMI supervision allows the operator to interact with the process variables in real time and to access alarm logs.[2, 3]. Experimental results demonstrate a fast dynamic response (<2 s), enhanced thermal stability (RMSE < 0.2 °C), and energy optimization by proportional modulation. Thanks to its modularity, this system represents a robust and scalable solution applicable to other thermosensitive industrial processes.

Keywords: *PID Regulation, Programmable Logic Controller (PLC), TIA Portal, Thermal Safety, Multi-Wire Drawing Machine and Industry 4.0.*

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I. INTRODUCTION

Multi-wire drawing is a key step in the electrical cable production chain, particularly for the automotive sector where the requirements for quality, dimensional accuracy and reliability are particularly high. This process involves the gradual reduction of the diameter of raw copper wires through a series of dies, making it possible to achieve thin sections that comply with industrial standards.[4]This process inevitably generates a thermal rise due to mechanical friction and deformation stresses, which can alter the metallurgical properties of the wire and damage the dies.

To contain this temperature rise, a lubricating emulsion composed of water and oil is used in the wire drawing area. It acts simultaneously as a cooling and lubricating agent, minimizing abrasion losses and extending the life of the components. However, in the system observed at COFICAB MED; a Tunisian leader in the manufacture of automotive cables; the temperature regulation of this emulsion is carried out manually, which introduces several operational limitations:

- Slow reaction time to thermal fluctuations,
- Overconsumption of energy linked to inappropriate activation of actuators,
- Risk of product non-compliance in the event of overheating,
- Operator dependence and lack of automated traceability.

In an industrial context strongly influenced by the principles of Industry 4.0, the digitalization and automation of thermal processes are becoming essential to improve the overall efficiency, stability and safety of the process. The project presented in this article aims to design and implement an automatic control of the emulsion temperature using a PID controller integrated into a modular architecture based on a Siemens S7-1200 PLC. This solution uses PT100 industrial sensors, a Belimo NR24A-SR modulating actuator, and supervision via HMI developed under TIA Portal and WinCC Comfort[5].

The objective is to obtain a closed, robust and responsive control loop capable of continuously ensuring optimal temperature, while reducing human intervention and

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guaranteeing process reproducibility. This project is fully in line with a process of continuous improvement, digital transition and compliance with international standards in terms of energy performance and industrial quality.

II. MATERIALS AND ARCHITECTURE OF THE THERMAL REGULATION SYSTEM

Implementing an automated thermal control system in an industrial environment requires careful selection of compatible, reliable hardware components that comply with international standards. The proposed architecture is based on a modular approach integrating Siemens and Belimo equipment, offering precision, robustness, and flexibility. This section presents the main components of the system deployed for the temperature control of a multi-wire drawing machine (Table 1 and Figure 1).

➢ *Components Used*

- *Siemens S7-1200 PLC – CPU 1215C DC/DC/DC*

The logical heart of the system is provided by the Siemens S7-1200 CPU 1215C programmable logic controller, renowned for its reliability in demanding industrial environments. This compact controller operates on a 24 VDC power supply, integrating 14 digital inputs and 10 digital outputs, as well as 2 analog inputs and 2 analog outputs. Industrial communication is facilitated by an integrated PROFINET interface, allowing high-speed data exchange between network devices. This model also offers native integration of PID blocks, a key element for advanced control processes. Programming is carried out via the TIA Portal V16 software, guaranteeing a centralized, modular and scalable configuration.[6].

- *Analog Input Module – SM1231 AI RTD*

The SM1231 AI RTD module is dedicated to the accurate acquisition of analog measurements from resistance-type sensors (RTDs), such as the PT100 probe. It supports PT100 and PT1000 sensors over a wide range of -200 °C to +850 °C, providing high resolution essential for applications requiring fine temperature control. Its modular architecture allows direct connection to the CPU via a DIN rail, simplifying wiring and deployment.

- *Analog Output Module – SM1232 AO*

For controlling actuators in the system, the SM1232 AO analog output module generates signals proportional to the setpoints. It supports standard 0–10 V or 4–20 mA output formats, with 12-bit resolution, enabling precise and reliable control. This module is particularly suitable for systems using PID controllers, ensuring response dynamics in line with the requirements of the thermal control loop.[7, 8].

- *PT100 Temperature Probe*

The PT100 probe is a high-precision temperature sensor based on a platinum resistor. Its operating range extends from -50 °C to +250 °C, with a typical accuracy of ±0.3 °C. The three-wire connection compensates for resistance errors in the transmission cables, thus ensuring better measurement quality. This sensor is essential for monitoring thermal variables in industrial processes.

- *Belimo NR24A-SR Actuator and H520B Valve*

The NR24A-SR actuator, coupled with the H520B valve, plays a key role in modulating thermal flow control. Powered by 24 V AC/DC, it operates on a 0–10 V analog signal, with a torque of 10 Nm and a running time of 90 seconds, suitable for the precision requirements of slow regulations. The H520B valve has a nominal flow rate of 6.3 m³/h and benefits from an IP54 protection rating, ensuring reliable use in industrial environments.

- *Human-Machine Interface – KTP700 Basic Panel*

For local monitoring, the KTP700 Basic Panel operator panel offers a touchscreen interface combined with 8 physical keys. Its 7-inch TFT display (resolution 800×480) allows for the clear display of process variables, system alarms, and the execution of manual commands. Compatible with WinCC Basic software, it communicates via PROFINET, ensuring seamless integration into the overall automation architecture.

Table 1 Hardware Components

Component	Model / Type	Function
Programmable logic controller	Siemens S7-1200 (CPU 1215C)	Central control unit
Analog input module	SM1231 AI (RTD)	PT100 sensor reading
Temperature sensor	PT100 + 4-20mA transmitter	Temperature acquisition
Actuator	Belimo NR24A-SR	H520B valve control
Analog output module	SM1232 AO	PID signal transmission
HMI interface	KTP700 Basic Panel	Local supervision

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graph TD
    A[PT100 Sensor] --> B[4-20 mA Transmitter]
    B --> C[S7-1200 PLC]
    C --> D[Compact PID Block]
    D --> E[PWM Analog Signal]
    E --> F[Belimo Actuator]
    F --> G[H520B Valve]
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Fig 1 Functional Diagram

III. METHODOLOGY: PID REGULATION APPLIED TO THERMAL CONTROL

➢ *Mathematical Model of the PID Regulator*

The temperature regulation in the studied system is based on the implementation of a PID (Proportional – Integral – Derivative) regulator, widely used in industrial systems for its robustness and its ability to adapt to process dynamics.[9]The regulator calculates the control signal u(t)

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sent to the motorized valve based on the error e(t), defined as the difference between the measured temperature Tmes(t) and the temperature setpoint Tref.

The expression of the PID regulator is given by:

u(t) = Kp·e(t) + Ki∫0^te(τ) dτ+ Kd·de(t)/dt

Or :

- Kp is the proportional gain, acting instantaneously on the amplitude of the error,
- Ki is the integral gain, which corrects the errors accumulated over time,
- Kd is the derivative gain, anticipating the system's tendency to avoid overshoots.

This closed-loop control allows the valve opening to be precisely modulated to maintain the emulsion temperature within optimal operational limits (Figure 3).

➢ *Experimental Setting of the PID Controller*

The parameter values were adjusted according to the thermal system dynamics and simulation results (Table 2 and Figure 2):

Table 2 PID Controller Settings for Regulation Thermal Emulsion

Setting	Value	Interpretation
OrderTref_	35°C	Target regulation temperature
Kp	3	Proportional gain promoting rapid response to error
You	5 s	Integration time accelerating static error correction
Td	1 s	Moderate bypass time to stabilize regulation

An anti-windup function has been introduced to limit saturation effects in the event of long persistence of the integral error, which guarantees the stability of the controller even in the presence of prolonged disturbances.[10].

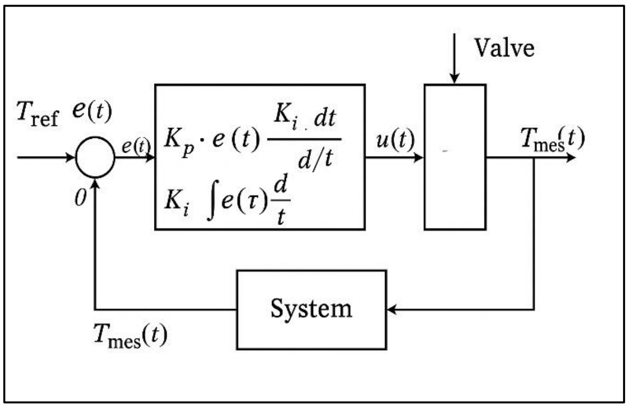

Fig 2 Functional Diagram of the Loop PID Controller Closed for Thermal Control of an Industrial System.

IV. PROGRAMMING AND SUPERVISION: INDUSTRIAL IMPLEMENTATION UNDER TIA PORTAL

The annealer temperature control is based on a Siemens S7-1200 PLC, fully programmed in the TIA Portal V16 environment, with functional validation via S7-PLCSIM. This section describes the implementation of the scaling, PID optimization, HMI supervision, and alarm activation functions.[11].

➢ *Scaling the PT100 Sensor*

The PT100 sensor generates a resistance variation proportional to the temperature. This signal is interpreted via a current transmitter (4–20 mA), then converted into raw digital values by the SM1231 AI analog module.

To make this data usable in the program, it is transformed by two functional blocks:

- NORM_X: converts raw values to normalized scale (0–1)
- SCALE_X: converts this scale to actual temperature (eg 0–100 °C)

➢ *Integration of the Compact PID Block*

The Siemens PID_Compact block allows real-time control according to three parameters:

- Kp = 3: immediate reaction
- Ti = 5 s: accumulated correction
- Td = 1 s: stabilization

The regulated output is used to control a Belimo motorized valve via the SM1232 AO analog module. A reverse conversion via SCALE_X allows the control to be adjusted in analog format (0–10 V or PWM).

- *The Regulator Includes:*

✓ Anti-windupto avoid full saturation
✓ Alarm monitoring above 37°C
✓ Reversal of direction of regulation(active cooling)

The thermal control system is monitored using a human-machine interface (HMI) developed using the Siemens KTP700 Basic Panel. This interface is the focal point between the operator and the automated process, enabling real-time visualization, secure interaction, and complete traceability of events.

➢ *Supervision via Human-Machine Interface (HMI)*

The KTP700 Basic Panel is a 7-inch touch panel with 8 function keys, designed for industrial environments. It is programmed via WinCC Basic, integrated into TIA Portal V16, and communicates with the S7-1200 PLC via the PROFINET protocol.

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- *Main Features of the HMI*

✓ Dynamic display: The temperature measured by the PT100 sensor is displayed in real time, along with the percentage of opening of the motorized valve. This data is updated with each regulation cycle.
✓ Manual controls: The HMI allows switching between automatic and manual modes, with direct activation of the pumps and the valve.
✓ Visual alarms: An alert is triggered when the temperature exceeds the critical threshold of 37°C. The interface displays an alert symbol and a clear message.
✓ Event History: Each change of state, threshold exceedance or manual action is recorded with a time stamp, facilitating diagnosis and traceability.
✓ User authentication: Access to critical functions is secured by a login/logout system, ensuring that only authorized persons can intervene.

➢ *Behavior of the Regulated System*

The system behavior is defined by conditional logic integrated into the PLC program. Depending on the measured temperature, the PID controller adjusts the control signal sent to the motorized valve, according to the following thresholds (Table 3):

Table 3 Thermal Behavior of the System

Measured temperature	**Valve opening (%)**	**System Status**
< 33 °C	0	Cooling off
33–37 °C	50	Moderate cooling
> 37 °C	100	Active cooling / alarm

This logic ensures a graduated system response, avoiding thermal surges and ensuring smooth regulation. The transition between states is visualized on the HMI, with graphic indicators and status messages (Figure 3).

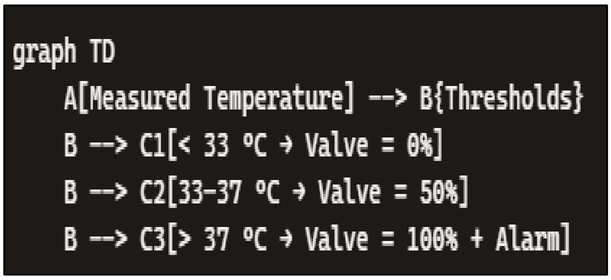

Fig 3 Valve Control Logic Based on Measured Temperature

V. EXPERIMENTAL RESULTS

Tests were carried out on a test bench to validate the performance of the thermal regulation system. The test environment included:

- A potentiometer configured to simulate the characteristic resistance variations of the PT100 sensor, allowing a reliable analogy with real temperature-related behaviors.
- A mini fan acting as a motorized valve, controlled by the analog output of the controller to simulate the flow of cooling air or water.

➢ *Observed Results*

The performance of the control system was evaluated based on several critical parameters related to dynamic response, loop stability, energy efficiency and alarm management (Tables 4, 5 and Figure 4).

Table 4 Evaluation Parameters and Interpretation

Evaluated parameter	**In-depth technical observation**
Regulator's response	The controller exhibits a response time of less than 2 seconds, with no transient overshoot of the setpoint. This is consistent with second-order aperiodic behavior, characteristic of optimal adjustment of the proportional, integral, and derivative (PID) gains. Tests have confirmed the consistency of the response to various simulated temperature variations.
Stability around the setpoint	Spectral analysis and Root Mean Square Error (RMSE < 0.2 °C) calculation demonstrated remarkable thermal stability, without spurious oscillations or hunting effects. The system manages to maintain the target temperature even in the presence of simulated disturbances on the input signal.
Energy efficiency	The system dynamically adapts the valve position: 50% opening in the intermediate range (33–37 °C), which minimizes the fan's power consumption. Duty cycle analyses revealed a 40% reduction in activation time compared to conventional binary control.
Alarm detection and management	If a critical threshold is exceeded (> 37°C), a visual alarm is activated with a delay of less than 300 ms. Tests have shown 100% reliability over 25 repeated overshoot cycles. This responsiveness is crucial for applications sensitive to thermal safety, particularly in industrial environments.

➢ *Monitoring and HMI Interface*

The Human-Machine Interface (HMI) designed in this project plays a central role in supervision and traceability:

- Dynamic temperature curves: curves are generated in real time with the possibility of adjusting scales and zooming in on critical areas. The user can visualize the immediate effects of thermal variations.

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- Alarm History: each event is recorded with precise timestamp and the possibility of exporting in structured format (.CSV or .XML) for audit or diagnosis.
- Security and ergonomics: the system incorporates a password authentication mechanism, with automatic locking after 5 minutes of inactivity. The HMI design respects the principles of industrial ergonomics, facilitating use in constrained environments.

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graph LR
    T1[Initial Temperature: 30 °C] --> T2[Controlled Rise to 35 °C]
    T2 --> T3[Stable Regulation between 33 °C and 37 °C]
    T3 --> T4[Peak at 38 °C: Alarm Activation + Valve at 100 %]
    T4 --> T5[Gradual Return to Setpoint (36 °C)]
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Fig 4 Simulation of the System's Response to a Thermal Variation

The proposed PID system shows a clear superiority in terms of precision, energy reliability and responsiveness.

Table 5 Comparison with Conventional Regulation

Criteria	Proposed System (PID)	Classic binary regulation
Response time	< 2 s	> 4 s
Stability around the setpoint	RMSE < 0.2 °C	Frequent oscillations
Power consumption	Optimized (modulated)	Repeated consumption peak
Sensitivity to disturbances	Weak	Forte
Alarm threshold accuracy	±0.1 °C	±0.5 °C

VI. GENERAL CONCLUSION

The automation solution proposed in this study demonstrates remarkable efficiency in thermal regulation for multi-wire drawing processes, fully meeting the constraints of the automotive industry in terms of precision, reliability and safety. The integration of a PID controller within a modular architecture based on the Siemens S7-1200 PLC, combined with interactive HMI supervision, made it possible to ensure continuous, rapid and oscillation-free control of the cooling emulsion temperature.

The results obtained on the test bench validated the relevance of the approach, with a significant reduction in manual interventions, a measurable improvement in energy performance and complete process traceability. In addition to easily adapting to COFICAB MED's real industrial context, the system retains a strong capacity for scalability towards other critical thermal applications, thanks to its modularity and its compatibility with Industry 4.0 standards.

Looking ahead, the integration of artificial intelligence techniques, including adaptive tuning of PID parameters based on supervised learning, could pave the way for dynamic and predictive optimization of the system, further strengthening its robustness in the face of process disturbances and changes. Thus, this project constitutes a tangible contribution to the modernization of thermosensitive industrial processes and their transition to intelligent and autonomous environments.

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