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DESIGN AND DEVELOPMENT OF A PROGRAMMABLE LOGIC CONTROLLER BASED DATA ACQUISITION SYSTEM TO INCREASE EFFICIENCY IN GALVANOTECHNICAL PLATING BATHS

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Keywords
Electroplating, Plating, PLC, Efficiency.

Abstract

In industry, plating processes are used to improve the appearance of the material, to protect it against corrosion and to increase its durability. Different current pass through the brushes of the electrodes connected to the bars of the plating baths used in galvanotechnical plating, depending on the structure of the solution and other factors. This causes different amounts of wear on the brushes. As a result, the amount of current passing through the brushes changes and the quality of the plating decreases. In this study, a data acquisition system based on a programmable logic controller (PLC) was designed, and implemented to increase manufacturing efficiency on plating baths used in the flexible packaging industry and making galvanotechnical plating. The current passing through the busbars in the chrome plating bath were measured with the designed two shunt resistors, and the received electrical data was converted to 0-10 VDC value with an ENDA 242 signal converter and then transmitted to the Siemens brand S7-1200 PLC device. Through the program written on the PLC device, all the data was visualized with the Siemens brand KTP 400 PN device, which is a human machine interface (HMI), and audio and visual warnings were transmitted to the technicians for the necessary interventions. An ATmega328 microcontroller embedded system that measures pH, temperature, and level values, which are other variables of the plating bath, was added to the system and the variable data was transferred to the PLC. Thus, technicians were informed about the variables in the plating bath and system interventions were made by technicians, thus increasing the efficiency of the plating bath.

GALVANOTEKNİK KAPLAMA BANYOLARINDA VERİMLİLİĞİN ARTIRILMASI İÇİN PROGRAMLANABİLİR LOJİK DENETLEYİCİ TABANLI VERİ EDİNİM SİSTEMİNİN TASARIMI VE GELİŞTİRİLMESİ

Anahtar Kelimeler
Galvanoteknik, Kaplama, PLC, Verimlilik.

Öz

Endüstride kaplama işlemleri materyalin görüntüsünün iyileştirilmesi, korozyona karşı korunması ve dayanıklılığının artırılması için kullanılmaktadır. Galvanoteknik kaplamada kullanılan kaplama banyolarının baralarına bağlı elektrotların fırçalarından çözeltinin yapısına ve diğer etkenlere bağlı olarak farklı değerlerde akımlar geçmektedir. Bu durum fırçaların farklı miktarda aşınmasına neden olmaktadır. Bunun sonucunda fırçalardan geçen akım miktarları değişmekte ve kaplamanın kalitesi düşmektedir. Gerçekleştirilen bu çalışmada, esnek ambalaj sektöründe kullanılan ve galvanoteknik kaplama yapmakta olan kaplama banyolarının kalite ve verimliliğinin artırılması için programlanabilir lojik denetleyici (PLC) temelinde bir veri edinim sistemi tasarımı yapılmış, gerçekleştirilmiş ve sahada bir prototip cihaz ile uygulamaya konulmuştur. Krom kaplama banyosundaki baralardan geçen akımlar tasarlanan şönt dirençler ile ölçülmüş ve alınan elektriksel veriler ENDA 242 sinyal dönüştürücü ile 0-10 VDC değere çevrilip Siemens marka S7-1200 PLC cihazına iletilmiştir. PLC cihazına yazılan program vasıtası ile verilerin tamamı insan makine arayüzü (HMI) olan Siemens marka KTP 400 PN cihazı ile görselleştirilmiş ve gerekli müdahalelerin yapılması için sesli ve görsel uyarılar teknisyenlere iletilmiştir. Sisteme kaplama banyosunun diğer değişkenleri olan pH, sıcaklık ve seviye değerlerini ölçen bir ATmega328 mikrodenetleyicili gömülü sistem konularak değişken verileri PLC'ye transfer edilmiştir. Böylece kaplama banyosundaki değişkenlerden teknisyenlerin bilgi sahibi olması sağlanmış ve sistem müdahaleleri teknisyenler tarafından yapılarak kaplama banyosunun verimlilik artışı sağlanmıştır.

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DESIGN AND DEVELOPMENT OF A PROGRAMMABLE LOGIC CONTROLLER BASED DATA ACQUISITION SYSTEM TO INCREASE EFFICIENCY IN GALVANOTECHNICAL PLATING BATHS

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Highlights

- Variables of the solution used in galvanotechnic baths were obtained in a data acquisition system.
- The quality of the plating is improved by continuous monitoring of the cathode electrode current.
- Thanks to the data acquisition system, productivity increase was achieved.

Graphical Abstract

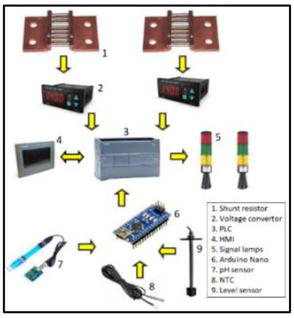

Figure. Galvanotechnical Plating Bath Data Acquisition System Elements and Data Flow

Purpose and Scope

In galvanotechnical baths, the unbalanced current passing from both sides of the cathode electrode prevents the plating from being at the desired level. The reason why this current is different is that the coals at the ends of the brushes on both sides wear out at different rates. Therefore, this situation causes different resistance values. In addition, it is important to constantly monitor the temperature, pH and level values of the plating bath solution and keep them at the desired values. When these values are at the desired values, the desired plating can be achieved. In order to minimize these problems, a data tracking system was developed in this study.

Design/methodology/approach

The values of the solution variables in the galvanotechnic bath, namely temperature, pH and level, were detected using sensors and these were brought to the Arduino Nano board containing an Atmega328 microcontroller. By using two shunt resistors, the current value passing through the cathode electrode was first transferred to a converter and then to the programmable logic controller (PLC) device. These data were evaluated with the PLC, which is the main data acquisition device of the system. These data were displayed on the human machine interface (HMI) device and the values of the boundary variables were entered. Additionally, a light and sound warning system was installed, providing operators with the opportunity to intervene in the system early.

Findings

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With the early warning system, when the current values passing through the cathode sides are not equal, system interventions have been made and production has become more efficient.

Practical implications

This study has been carried out in a way that can be applied in almost all galvanotechnical plating baths. Therefore, by applying them, early warning systems can be operated and product efficiency and quality will increase.

Originality

An original study was carried out by taking the temperature, pH, level, currents passing through the cathode sides and determining their limit values, which affect the plating in galvanotechnical plating baths.

1. Introduction

One of the areas of use of electricity in industry is plating technologies. It is widely used in plating to increase the durability of industrial materials, improve their appearance, and protect them against corrosion (Uğur and Ay, 2018). Today, plating processes are carried out using various methods such as electrolytic, hot dipping, liquid metal spraying plating metal cladding methods (Kelen, 2023). The most common electrochemical or galvanotechnical plating are chrome (Zhao et al., 2022) and zinc (Yu et al., 2020) plating. Other plating types are such as aluminum (Mwema et al., 2018), copper (Verma and Kumar, 2019), cobalt (Letchumanan et al., 2024), nickel (Saraloğlu Güler and Irgin, 2024), cadmium (Cihangir, 2023) and lead (Pradhan and Chakraborty, 2020), which are plating that are pure metals or their alloys.

Electrolytic metal plating is the process of creating a metallic film layer on metal or non-metallic materials using an electrochemical method (Belkin et al., 2020). The use of such coated materials in daily life is quite common (Basova et al., 2021). Silver and gold plating of watches, gold plating of glasses, and chrome plating of aircraft parts are among the examples that can be given. The main reason for plating metals is to improve their appearance and make their chemical and physical properties suitable for use (Akafuah, 2016).

The plating used in the flexible packaging industry is galvanotechnical plating, also known as electrochemical plating. This plating method is widely used due to the flexibility of production. For plating, gravure cylinders are used to create the desired image on the film packaging material (Tyagi et al., 2021). A gravure cylinder is obtained by copper electrolytic plating on the top of the iron body cylinder. Then, the desired design on the package is engraved on the copper-coated cylinder with engrave machines (Baustista et al., 2017). The main reason why this design image is processed on a copper-plated surface is that copper creates a suitable surface. The design processed with engrave machines is subjected to chrome plating in the next process. During the printed film production stage, a very thin chrome plating is applied to prevent damage to the cylinder on which the design has been processed, so as not to distort and cover the pattern on the surface (Bastarrachea et al., 2015). If chrome plating is not applied to the copper-plated cylinder, the design deteriorates very quickly, and visual quality problems occur. Similar processes are applied in copper and chrome plating baths. In these plating baths, the solution and the electric current passing through the solution are the two most important variables that affect the quality of the plating. There are also other variables such as pH, temperature, and level in the solution (Oliveira et al., 2021).

In the literature, it is possible to come across studies to develop and improve the plating quality of electrolytic copper and chrome plating baths, to reduce malfunctions that may occur in plating baths, to detect them in advance and to determine predictive maintenance times. In addition, studies have been carried out to improve hard chrome plating, silver plating baths, to optimize the solutions in nickel plating baths and to keep the variables in the plating baths at optimum levels. Kır and Apay (2020) optimized the plating parameters in hard chrome plating of structural steel using the Taguchi method. As a result of their studies, they emphasized the effects of current density, solution temperature, anode-cathode distance, pH value and plating time. Karaoğlan and Meriç (2019) improved the nickel ratio with the response surface method for nickel plating processes. They stated that the most important factor in this plating is the solution temperature. They determined the ratios of nickel sulfate ($NiSO_4$), nickel chloride ($NiCl_2$), boric acid (H_3BO_3), pH and brightener. In another study, Can and Akyalçın (2022) carried out studies on the corrosion prevention of multilayer plating. As a result of their work, they developed a plating that can minimize the effects that cause high levels of corrosion. Şimşek and Çetin (2022) examined the effects of current density and solution temperature in galvanized plating on the mechanical properties of the plating. They emphasized that the plating thickness increases linearly with temperature and current density in acidic baths. In a study conducted by Birlik and Azem (2018), they stated that the Wats bath is the best bath that can be used for electrodeposition and then touched upon the importance of current density, pH level, $NiSO_4$, $NiCl_2$, H_3BO_3 components and densities. In another study conducted together with these studies, Bağrıyanık (2020) examined the changes that chrome-plated materials used in vehicles are exposed to due to temperature. García Nieto (2020) developed a new method based on support vector machines model statistical machine learning for the prediction of hard chrome plating thickness. Venkateshaiah (2022) conducted a study to increase the use of developing automation technologies in plating.

When studies in the literature are considered, it can be seen that the pH value, temperature and level of the solution in the plating baths used in electrochemical plating are important. In addition, it is seen that the current value passing through the solution, which is the most important variable of electrochemical plating, is a very critical variable. Considering all this, it is important to monitor these four variables and intervene by technicians when necessary. In this design and application study carried out to achieve this aim, the design and development of a programmable logic controller-based (PLC) data acquisition system was carried out to increase the efficiency in galvanotechnical plating baths. The prototype system was used in a chrome plating bath. In addition, this system is designed to be expandable to other plating baths operating in the same factory environment in order to reduce production costs and increase efficiency.

In the "Introduction" section of this study, a general introductory literature information is given, and then the "Material" used in the second section is given. Then, the use of materials is explained in detail in the "Method" section. After that, in the fourth chapter, "Results and Discussion" is stated. Finally, the outputs of the studies are presented in the "Conclusions" section.

2. Material

2. 1. Plating

Plating processes are used to improve the appearance of metal and non-metal materials, increase their hardness, and protect them against corrosion. Plating processes are carried out in plating baths using various solutions (Brindha, 2021). Plating made with electric current are called galvanotechnical plating (Li, 2020). The basic units in plating are cathode, anode, electrolyte solution and plating bath. Electrical control systems are used to adjust the solution. Transformer rectifiers with control units are used to adjust the high value electric current passed through the solution. It is also seen that galvanotechnical plating is applied by plating non-metallic materials with a thin layer (Rajaramanan, 2021).

The plating technique used to coat metals is electrochemical plating. The basic principle of electrochemical plating is given in Figure 1. In plating, ions in solution are transported to the material to be coated due to the electric current acting on them (Wang, 2020). Hydrogen ions accumulate at the cathode electrode and sulfate ions accumulate at the anode electrode. These ions are electrically charged. Here, the fact that the solution creates an electric current causes the solution to be called an electrolyte. Considering water-soluble copper sulfate ($CuSO_4$), one molecule of $CuSO_4$ yields one copper and one sulfate ion. Copper ions collect in the solution on the cathode electrode and sulfate ions on the anode. The collection of copper ions on the cathode electrode is referred to as plating of the cathode electrode.

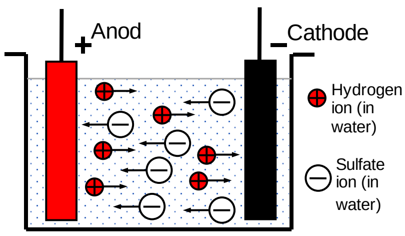
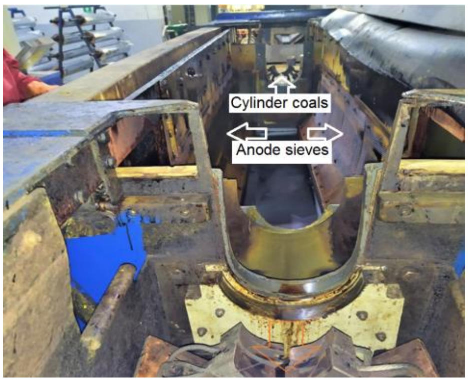


Figure 1. Electrochemical Plating.

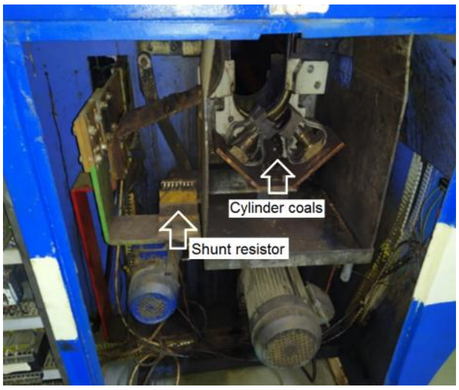
In galvanotechnical plating, the material to be coated is generally the cathode electrode. The anode electrode is made of the material on which the cathode electrode will be coated. Increasing the current density of the power supply connected to the anode and cathode electrodes in a controlled manner increases the anode ions in the solution and results in faster plating. While the voltage values of the power supplies used are 6-12 V, they have quite high current values. Additionally, anode corrosive halide chemicals are mixed into the solution to ensure the dissolution of the anode electrode. In the plating, the anode electrodes in metal structure are not pure and therefore cause the electrode potential to be different.

Copper and chrome plating baths are similar to each other in terms of operation. They keep an anode sieve in the bath section where the plating are made. While copper plating is being done, copper particles are placed on this anode sieve. In the chrome plating bath, nothing is placed on the anode sieve (Asamuah, 2021). In chrome plating, chromium in salt form is placed in solution. Anode sieves are mounted vertically, with the cathode cylinder to be coated in the middle. In both copper and chrome plating, the anode sieves are made of titanium plating. Therefore, no wear occurs on the anode sieves. The absence of wear increases the quality of the plating to be applied (Li, 2024).

In copper and chrome plating baths, the positive pole of the power supply is connected to the anode sieve. The current passes through the anode sieve and the solution, allowing the copper or chromium elements in the solution to reach the cylindrical cathode electrode to be coated. The material to be coated is placed on the cathode electrode, which has a cylindrical structure and can rotate around its own axis. The cathode electrode in this cylindrical structure is rotated by electric motors. As a result, the material to be coated rotates in the plating bath. The cathode cylinder electrode is connected to the negative end of the power supply with the help of current-transferring carbons at both ends of the cylinder. The same size of the coals here allows the same current to pass on both sides, and in this case, the thickness of the plating is the same on both sides. The different sizes of the coals cause the current passing from both sides to be different. As a result, the thickness of the plating on both sides of the cathode cylinder electrode is different. The plating is thick on the side where more current flows. This is an undesirable situation. The positions of the plating bath, coals and shunt resistors in this study are given in Figure 2. Plating bath consists of copper sulphate or chromic acid solutions, copper grains or chromium salts, titanium holding and working tanks, rectifier, titanium sieve, copper busbars, coals, and heating-cooling systems.



(a)



(b)

Figure 2. Plating a) Bath and b) Coals and Shunt Resistor.

While preparing the copper plating bath, copper salt is used in the solution (Ayyıldız, 2021). The plating tank is filled ½ with deionized water or distilled water that has had its ions removed. The purity and conductivity value of water is known by pH measurement. The conductivity of the deionized water used should not exceed 10 u (Siemens) and the pH value should be between 6.5–7.5. An amount of 210-230 g/l salt is added to the solution in 50 and 100 kg amounts by mixing. 0.5-1.0 ml/l hydrogen peroxide (H_2O_2) is added to the solution and stirred for 1 h. Then, 96% purity sulfuric acid (H_2SO_4) is slowly added to the solution. While these processes are carried out, the solution is in constant circulation. Attention should be paid to the heat generated when H_2SO_4 is added to the solution. Dilution is made for one day to remove the heat created by the H_2SO_4 acid. After these processes, the temperature of the solution in the plating bath reaches 40°C and copper particles are placed in the anode basket. Meanwhile, the solution is kept in constant circulation and filtered with a carbon filter for 12 hours. Then, plating is done with 0.3-0.5 A/dm^2 for 6-10 h.

In order to achieve the desired plating, some criteria in the solution and system must be taken into consideration. It is desired that the plating is hard, its surface is smooth, and the thickness is in the desired amount. It is not desired to have plating holes, pits and distortions on the coated surface. Current density is of great importance in creating the desired plating. While the current density in copper plating baths is 20-25 A/dm^2, depending on the design of the plating bath, it should be 50 A/dm^2 for chrome plating. As the current density in the solution increases, the crystal formation rate increases, and the plating becomes thinner. If the current density increases excessively, the metal ions coming out of the cathode cannot fully match the ions in the solution, causing the plating surface to become black and spongy.

Another variable that improves plating quality is solution density and mixing. If the formation of crystals in the solution is rapid, the adhesion to the surface to be coated will be thin and strong. Stirring the solution prevents local dilution at the cathode. In addition, filtering the solution at regular intervals increases the plating quality (Haifeng, 2020). Another variable that affects plating quality is temperature (Kır and Apay, 2020; Şimşek and Çetin, 2022). It is ideal for the solution temperature to be 30°C in copper plating baths and 60°C in chrome baths. Since high temperature values increase diffusion, the rate of formation of crystals increases and small crystalline structures appear in the plating. Another disadvantage is that it reduces the polarization of the cathode. Other variable in the quality of the plating is the pH value of the solution. Depending on the type of plating, the solution must have a certain pH value. It is important to monitor all these variables with a control system and make necessary interventions.

2.2. Programmable Logic Controller and Human Machine Interface Touch Screen

PLC is widely used in industrial automation systems to capture variables in plating baths and other processes and to process data and create control signals. PLCs evaluate the analog and digital signals coming to their inputs depending on the programs written and produce analog or digital outputs. The elements connected to their inputs can be changed with various expansion modules. Some of the temperature sensors can be connected directly to their inputs. They also need standard current and voltage values for their inputs. Their outputs can be relay or transistor. A Siemens brand S7 1214C DC/DC/DC model PLC was used to capture the variables in this plating bath. The supply voltage of this PLC is 24 V DC. Its output is DC transistor output. The input units contain analog and digital inputs. It has 14 digital inputs and 10 digital outputs. Two of the inputs were used as analog inputs in the system with a 6ES7 222-1BH32-0XB0 module. Again, expansion modules can be installed on this PLC to increase the number of inputs and outputs. Since the number of outputs in the PLC was not sufficient for the plating baths in the factory where the application was made, an additional 6ES7 231-4HF32-0XB0 output expansion module was used. PLC makes analog digital conversion (ADC) conversions with 10 bits and provides 500 mA output current. Profinet communication interface and TIA portal (Totally Integrated Automation Portal) software are used for programming.

Siemens brand KTP 400 PN model HMI panel, which is a human machine interface (HMI), was used to visualize the variables taken by PLC of the galvanotechnical plating bath, to display warnings, to write alarms and to determine warning limits. There are 4 function keys on this device and their programming is done with TIA portal software. The screen size of the device is 4.3 inches, thin-film-transistor (TFT) screen, resolution 480 × 272 px, user memory is 10 MB, protection class is IP65, and the device depth is 43 mm.

2.3. Atmega328 Microcontroller

The ATmega328 microcontroller on the Arduino Nano CH340 microcontroller board was used to read the values of the variables affecting the quality of the plating in the galvanotechnical plating bath. This microcontroller has 14 digital Input/Output pins, 6 of which can be used as pulse width modulation (PWM). It also has 8 analog inputs. There is a 16 MHz crystal oscillator on the Arduino Nano CH340 board to operate the microcontroller. This was preferred because the inlet and outlet numbers are sufficient to obtain the variables in the plating bath.

2.4. Shunt Resistor, Signal Converter, pH, Temperature, and Level Sensors

Shunt resistors are one of the most effective ways to measure the current values of high-current circuits. 2 shunt resistors were used to measure the current value passing through the electrical busbars in the plating bath. The values of the shunt resistors in the system are 0.024 mΩ and 2500 A capacity. There is a voltage drop of 0-60 mV on it. Thus, less power loss is ensured. The voltage value falling on the shunt resistor is quite low. Its value cannot be transmitted directly to the PLC. Therefore, this voltage value must be converted to 0-10 VDC value that the PLC can read. One of the devices that does this is the ENDA brand EPA 242 model device. Using this device, the current value passing through the busbars was first converted into voltage in shunt resistors, and this value was converted to 0-10 VDC value with a converter and transferred to the PLC. 0-10 VDC current was measured to 0-2500 A with the software in the PLC.

In galvanotechnical plating baths, the pH value of the solution affects the quality of the plating, and its continuous measurement is important. The pH sensor used in the measurement of this variable is a chemical sensor and produces a voltage value depending on the pH value with 2 electrodes in its structure. The generated voltage value is transferred to the output of the transmitter card as 0-5 V DC. The supply voltage of this sensor is 5 V DC, its dimensions are 43 mm × 32 mm, its operating temperature is 0-60°C, its sensitivity is 0.1 pH (25°C), and its connector is BNC type.

A negative temperature coefficient (NTC) temperature sensor was used to detect the temperature of the solution in the system. This sensor is easily available from the market. The resistance value of NTC decreases as the temperature increases and the measurement range is -30 to 105°C, the cable length is 300 mm, the probe length is 5 × 25 mm, the resistance is 10 kΩ ±%1 and the output has 2 wires.

A float type potentiometer level sensor was used to determine the level of the solution. The level sensor has an internal resistance is 190 Ω, a float type polyurethane, measurement length is 30 cm. Its operating voltage is 12-24 VDC, and operating temperature is 0-70°C and protection class is IP88. Also, its body structure is plastic - polyvinyl chloride (PVC).

3. Method

In this study, a data acquisition system was developed to increase the quality and efficiency of the plating made in galvanotechnical plating baths. The developed data acquisition system elements and the data flow between them are given in Figure 3. This design was built on a chrome galvanotechnical plating bath as a prototype application, and audible and visual warnings were sent to technicians when the data of this plating bath went beyond the specified limits. In order to improve the quality of the plating made in the chrome plating bath, it is important to constantly measure the variables of the plating bath: current, temperature, pH and level. To achieve this purpose, the current values passing through the brushes on both sides of the coated cylinder in the system were measured with two 0.024 mΩ shunt resistors specially designed for this system. Since the voltage drop in these shunt resistors is low, the voltage value was converted to 0-10 V DC value with the ENDA brand EPA 242 model voltage boost converter and transmitted to the Siemens brand S7 1214C DC/DC/DC model PLC device. A pH electrode and a transmitter that converts the voltage value produced by it to the standard 0-5 V DC value were used to determine the pH value of the solution in the chrome plating bath. A commercially available NTC with 10 kΩ resistance with error rate of ±1% was used to detect the temperature value. Additionally, the solution level was detected with a float sensor of 190 Ω. The pH, temperature and level variables of the solution were transmitted to the Arduino Nano ATmega328 microcontroller so that they could be transmitted to the PLC device. Incoming data was evaluated with ATmega328 and converted into real pH, temperature, and level information. In order to send this information to the PLC device, the PWM pins of the ATmega328 microcontroller are transmitted analogously to the PLC device through an electronic circuit placed between the PLC and the ATmega328. The PWM and ADC resolutions of the ATmega328 microcontroller are 8 bits. The variables collected in the PLC device were transmitted to the HMI device and the limit values of the variables could be entered with this device. When the limit value exceeds the lower and upper limits of the variable value, the technician is notified with an audible and visual warning system.

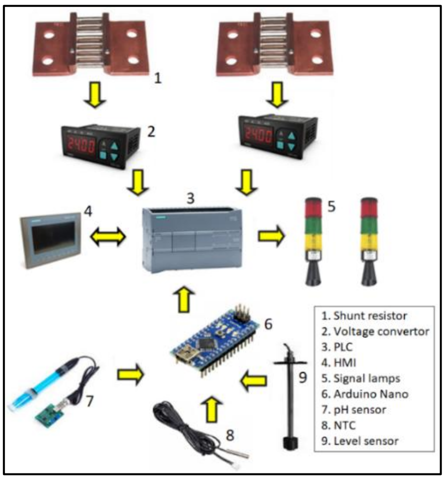


Figure 3. Galvanotechnical Plating Bath Data Acquisition System Elements and Data Flow.

The electrodes and other electrical devices in the chrome plating bath are given in Figure 4. One of the most important elements of the plating bath is AC-DC rectifiers. The electric current coming out of the positive pole of the rectifier is divided into 2 anode and screen electrodes. This current passes through the solution and reaches the cylinder where the plating is made. It passes through the carbon brushes on both sides of this rotating cylinder and reaches the negative pole of the rectifier. Thus, the plating is done. The current value passed through the solution is adjusted according to the size of the cylinder, the amount of plating and the desired plating hardness.

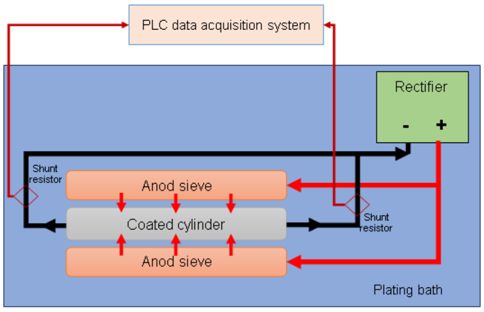


Figure 4. Plating Bath Electric Current Passage.

The current value to be passed through the cylinder in the plating bath is calculated with the following equation.

$$I = L \times C \times J \times F \qquad (1)$$

Here, I is the current to be passed through the cylinder to be coated (A), L is the length of the cylinder to be coated (dm), C is the circumference of the cylinder to be coated (dm), J is the current density (A/dm^2) and F is the immersion rate of the cylinder into the solution. If the cylinder to be coated is completely submerged in the solution, the immersion ratio is taken as 1, if it is half submerged, the immersion ratio is taken as ½. In order for the plating to reach the desired thickness in the plating bath, the time the material to be coated remains in solution is determined by the equation below.

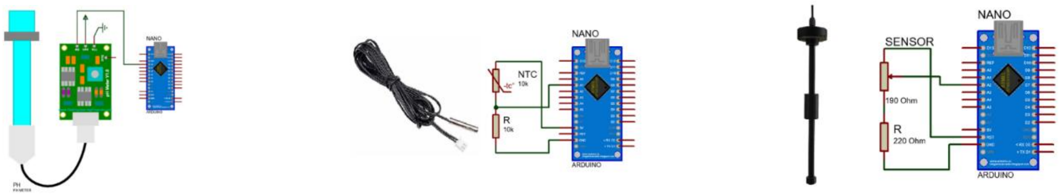
$$t = 75.3 \times L \times C \times d \times 60/I \qquad (2)$$

Here, d is the desired plating thickness (mm) and t is the required time (min). For example, if the cylinder length is 8.8 dm, its circumference is 0.96 dm, the desired plating thickness is 0.15 mm and the plating bath current is 1600 A, then the time needed is 36 min. is available.

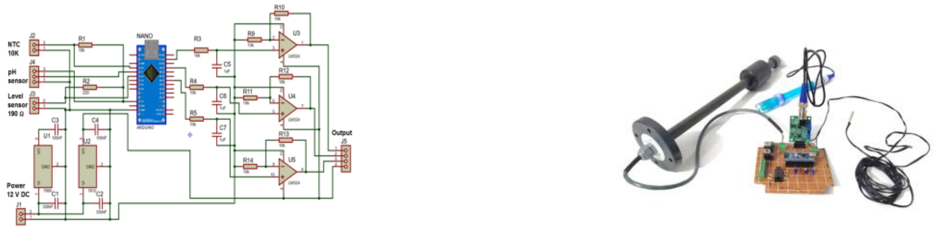
The operation of the S7 1214C DC/DC/DC PLC device, which is the basic control unit of the system, was carried out with a 24 V DC power supply. The digital outputs of the PLC were used for the lamp and buzzer. After the voltages of the shunt resistors were increased with the ENDA device, 0-10 V DC was entered into the analog inputs of the PLC. Since there are two analog inputs on this PLC, an additional analog input module was added to the system to make the system ready for other plating baths. The highest voltage of 2500 A was passed through the shunt resistor. According to this current value, the shunt resistor produced 60 mV. The data of these current-sensing shunt resistors installed on the right and left busbars of each plating bath were converted to current values with the PLC program, and audible and visual warnings were generated when they were below or above the limit values entered with the HMI device.

When the current drawn by the plating bath is 1500 A, it is expected that the current value of 750 A will pass through the two busbars due to the equal resistance value of the system. If 1200 A passed from one busbar and 300 A from the other busbar, the difference between them became quite large and the alarm mode of the system was enabled. The red signal lamp on the side where the current flows the most and the green signal lamp on the side where the current flows low worked. When the operator received these alarms, he checked the electrical equipment of the system and made the necessary cleaning and arrangements in the plating bath. If there is a difference of 600 A between the current value passing through the busbars, a yellow signal lamp is turned on the side where the current flows most, and a green signal lamp is turned on the side where the current flows less, and an audible warning is also activated.

Figure 5 shows the methods used to measure pH, temperature, and level values with the Arduino Nano ATmega328 board. The voltage level taken from the electrodes of the pH sensor used was entered into the microcontroller card as 0-5 V DC via the transmitter card to which this sensor was connected, as shown in Figure 5a. The microcontroller connection of 10 kΩ NTC is made with a voltage divider 10 kΩ resistor as shown in Figure 5b. It was carried out as shown in Figure 5c, using a 220 Ω voltage divider resistor in the microcontroller connection of the 190 Ω level sensor with float. The data processed by ATmega328 was transmitted to the analog inputs of the PLC device using the LM324 operational amplifier with the circuit as shown in Figure 5d. The reason for using opamp here is to deliver the standard voltage value to the PLC. 7805 and 7812 linear regulators are used in the system to feed the sensors and transmitter. Sensor inputs are made with the help of connectors to make connections easy. An output is provided for connections to the PLC. The physical connections of the sensors are given in Figure 5e.



(a) (b) (c)



(d) (e)

Figure 5. ATmega328 a) pH, b) NTC, c) Level Sensors, d) Electronic Circuit and e) Physical Appearance.

4. Results and Discussion

With this study, the currents passing over the coals of the brushes on both sides of the cathode cylinder in the plating baths were detected with shunt resistors. The pH, temperature, and level information of the solution, which also affects the quality of the plating, was detected and first transmitted to the ATmega328 card for processing, and from there to the PLC device with the designed and implemented electronic circuit. Thus, the variables in a plating bath can be detected and visualized with the HMI device. In this HMI device, the plating bath was operated according to the criteria determined according to the properties of the plating. Changing these alarm values on the HMI screen according to the status of the system can be done with the written program. Additionally, information about alarm situations can be obtained using the HMI device. Thanks to this flow information, equal current flow is ensured on both sides of the cylinder in the plating bath, and deformation of the plating, plating of different thicknesses, pits on the plating surfaces and the formation of plating dust are prevented. As a result, unnecessary use of consumables is prevented, and capacity reduction is prevented. In addition, plating costs have been reduced by reducing the use of spare parts. Figure 6 shows the alarm status in the chrome plating bath used as a prototype trial. The current value of 1270.6 A, which is the current value that the plating device will draw at full capacity as written on the label, is digitalized, and displayed on both the HMI device and the ENDA device.

(a) (b) (c) (d)

Figure 6. Chrome Plating Machine: a) HMI Screen, b) Alarm Lights, C) Machine Information and D) ENDA Current Visual.

Current difference limits are determined at two levels on the system. These limits have been determined in line with expert opinions based on the operators' experience during use. During the trials, these threshold values were entered into the system as 300 A and 600 A. While the 300 A value warning has secondary priority, the 600 A difference warning is defined as the first priority warning. When one of these warnings occurred, operators maintained the plating bath for the next plating process. Operators have been informed about the cleaning of the busbar and coals. At the moment when the current imbalance occurred, the temperatures of the brushes were measured with a thermal camera as shown in Figure 7. It has been determined that brush coals deteriorate at temperatures of 140-160°C. This situation caused current imbalances in the system. Thermal camera images are in Fahrenheit. Here, the temperature of one adapter is 241°F = 161°C, while the temperature of the other is 145°F = 62°C. This current imbalance caused the adapter, coal and other components to fail. The adapter gear melted due to excessive heat. Accordingly, the plating bath did not work because there was no rotational movement in the cylinder.

(a) (b) (a) (b)

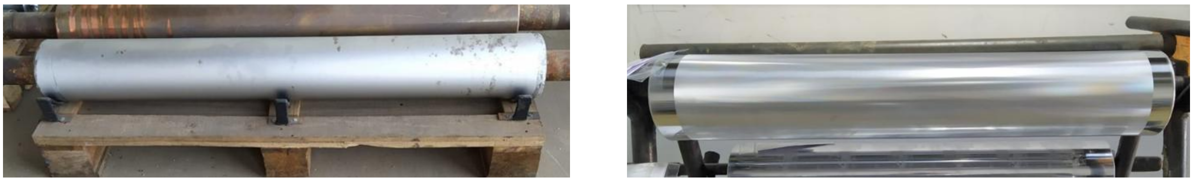
Figure 7. Chrome Plating Bath Error Status: a) Adapter, and b) Thermal Camera Images.

Since current imbalance causes overheating, gaps have formed between bronze and aluminum parts because metals with different expansion coefficients expand at different rates. Dirt and solution residues filling the gaps made it difficult for current to flow and caused the system to fail more quickly. Example part distortions are shown in Figure 8.

(a) (b) (c) (d)

Figure 8. Deteriorations in Plating Bath Because of Heating Caused By Current Imbalance: A) Melted Adapter Gear, B) Taper Distortion, C) Adapter and D) Coals.

The temperature of the solution could be monitored instantly with temperature measurements made on the system. It has been observed that the data acquisition system designed and used as a prototype gives an alarm when the specified limit values are exceeded. The temperature of the solution, which is brought to the desired value by the resistances of the plating bath, rises above the desired value by heating the solution in the current. In this case, the system's own coolers come into play. The system gave an alarm when the temperature in the chrome plating bath dropped to 50°C. In this case, the operator intervened in the system for the next plating and the system was allowed to reach 60°C again. The plating formed in these two cases are given in Figure 9.



(a) (b)

Figure 9. Chrome Plating: a) 50°C and b) 60°C.

At the solution temperature of 50°C, it was observed that the gloss of the material coated on the cylinder was low, the plating was soft and there were roughnesses on it. After the system alarms, when the operator intervened in the system for the next plating, it was observed that the coated material on the cylinder had the desired hardness, brightness, and smoothness values while the solution temperature was 60°C.

Continuous monitoring of the pH level of the solution was carried out with the sensor used. With the developed data acquisition, it was possible to monitor how the acid and salts placed in the solution caused a change in the amount of solution on a weekly basis and at what intervals the values changed. In addition, continuous detection of the change in the amount of solution was easily achieved with the help of the float system. In the system, the solution in the reserve tank is transferred by pump to the plating section where the anode sieve and cylinder are located. As a result of the process, it is transferred back to the reserve tank. This can be ensured to be between the maximum and minimum values by operator intervention in the system with the developed system warnings.

In the findings regarding current imbalance, it has been seen that many factors cause current imbalance. It has been observed that one of the main reasons is the deformation, contamination, and oxidation of the surfaces of the shafts and adapters used in the cylinder assembly, which come into contact with the plating cylinders, that is, through which electric current passes. Since it is difficult for electric current to pass through this type of surface, he preferred the other current branch. When the entire electric current passes through a single branch, overheating occurs in the busbars through which the current passes. Another important reason for the current imbalance is the coals that enable the transmission of electric current on which the cylinder adapters used in cylinder assembly sit. These coals in both cathode bars became worn and deformed after a certain operating period, due to environmental and usage conditions. For this reason, the current chose the other easier path and heating occurred in the equipment and busbars through which excessive current passed.

In electric current imbalance, the magnitude and consequences of the imbalance vary depending on the state and degree of adverse conditions that cause the imbalance. For example, in field studies, it was determined that the current difference was less due to the corrosion of the coals and more due to deformation and pollution on the adapter and shaft surfaces. In addition, operational assembly errors can be detected thanks to this designed system, as a current difference will occur if there is an error in the assembly of the cylinder placed in the plating bath.

Some arrangements have been made in the plating process section in order to prevent undesirable situations by measuring and evaluating electrical currents and revealing their causes. The system ensures regular cleaning and maintenance of the cones, shafts, and adapters, which are the assembly parts of the cylinders to be coated and through which the electric current passes. By drawing attention to the meticulousness of the cylinder assembly process, non-contact in the electric current paths was prevented. Deformed coals were replaced at the required interval, adapter shaft cone and other machine equipment that were beyond repair were renewed. The busbars and anode screens through which electric current passes were dismantled and their cleaning and maintenance could be done by evaluating the results of the developed warning system.

With the work carried out to eliminate electrical current imbalances, undesirable situations have been reduced to minimum levels, and the costs resulting from the breakdown of cylinder assembly equipment, spare parts and consumables have been reduced. Quality problems caused by current imbalance are prevented. Machine downtimes caused by undesirable current imbalance situations are minimized, thus preventing loss of production capacity.

In order to keep the plating solution temperature at the optimum level, the resistance heating system that heats the solution and the water-cooled coil system that balances the heat must be active and working as it should. It has been determined that it would be more convenient to use a proportional-integral-derivative (PID) controlled heating system rather than an on-off resistance system to ensure a more accurate temperature operation. Studies and investigations can be carried out by changing the temperature of the water circulating in the cooling coils for both the optimum effect on the system and energy efficiency.

In the studies and examinations carried out, it has been determined that the pH value generally remains constant during the plating process and does not affect the plating as long as it remains within the oscillations of around ±0.3. In summary, it has been observed that the pH value is less affected by operating conditions. To fully measure this effect, measurements can be made from several points.

pH measurement of the system can be used actively and effectively during the preparation of the solution in the plating bath, when sulfuric acid, chromic acid and pure water are added. Situations such as adding undesirably excessive amounts of water during the washing process with pure water during the plating process and changing the content balance of the solution over time can be detected by pH measurement. As a result of this determination, the pH balance in the system can be adjusted. Thus, the quality of the plating in the plating bath can be increased.

Although measuring the amount of solution has the least direct effect on quality, it has indirect effects. Because of temperature, the plating solution evaporates and decreases over time. Additionally, solution losses may occur due to leaks in the machine reserve and plating tank. These situations may cause undesirable situations in the short or long term, and in the long term, the content and amount of the solution may deteriorate due to evaporation and during the washing process with pure water. In addition, it is a common situation that the cooling water mixes with the solution due to the puncture of the coils. Since the amount of solution increases rapidly in this case of mixing, this situation can be detected early by level measurement.

On the realized measurement system, current imbalance error status is shown on the HMI panel as duration and number of errors. In addition to this feature, more detailed and historical tracking of both current imbalance status, measurement data and system error conditions can be added to the system. Data can be transferred to the computer system via Ethernet or wireless communication and can be saved from the PLC to a memory card with the memory card to be added.

5. Conclusions

In this study, a data acquisition system was developed based on PLC to monitor the variables of the plating baths used in a factory and to give warnings to the operator. The current values passing through the brushes on both sides of the cathode electrode in the solution were detected by a designed and produced shunt resistor and transmitted to the PLC device with an ENDA brand converter. The pH, temperature and level variables of the solution were detected by sensors and converted into analog signals that could be transmitted to the PLC with the Arduino Nano Atmega328 microcontroller. The data in the system is visualized on the HMI screen. The minimum and maximum ranges of the plating bath variables can be entered with the buttons of the HMI screen. The designed system was tested as a prototype in a plating bath. For the plating to have the desired quality, it was important that the temperature value was 30°C in the copper plating bath and 60°C in the chrome plating bath. If these temperatures were lower than the desired values, it was observed that the plating was incomplete and hazy. If the temperature values were higher than the desired values, the plating hardness was not at the desired level and soft plating were observed. With the warnings in the developed system, the operator is enabled to intervene in the system. This ensures that the system has fewer malfunctions, less consumables are used, and fewer defective products come out of the machine. As a result, the efficiency of the system is increased. The designed system only involves data acquisition. According to this data, it has been determined that improvements can be continued by creating control algorithms that can intervene in the system and placing the necessary actuators in the system.

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Conflict of interest

There is no conflict of interest in this study.

Ethics consent

Ethical consent is not required for the study.

Nomenclatures

ADC	Analog Digital Conversion	C	Circumference of Cylinder to be Coated (dm)
$CuSO_4$	Copper Sulfate		
HMI	Human Machine Interface	d	Desired Plating Thickness (mm)
H_2SO_4	Sulfuric Acid	F	Immersion Rate of Cylinder into Solution
NTC	Negative Temperature Coefficient	I	Current (A)
PID	Proportional-Integral-Derivative	J	Current density (A/dm^2)
PLC	Programmable Logic Control	L	Length of Cylinder to be Coated (dm)
PVC	Polyvinyl Chloride	t	Required Time (min)
PWM	Pulse Width Modulation		
TIA	Totally Integrated Automation Portal		
TFT	Thin-Film-Transistor		

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