Technology improvement of chromium on steel parts electrodeposition using complex command and control systems

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Abstract. The paper aims to provide improved technological process of electrochemical deposition of chromium on steel for decorative parts for corrosion protection but also to improve mechanical properties. The proposed idea is perfectly suited to be grafted onto existing electrodeposition installations, but it can be applied successfully in the development of new such plants. Complex command and control systems are designed to operate in high aggressive environmental conditions specific to these types of installations. The theoretical part completes the experimental results obtained on a laboratory facility.

1. Introduction
Chromium electroplating on metal parts represents one of the most complex processes of electrodeposition. Starting from chromium deposition in decorative purposes, going to deposition for protection of parts working in harsh environments and reaching the deposition of chromium with role to improve the mechanical properties of the parts strongly stressed, all enroll in the generic name of chromium plating: decorative, protective or hard [1]. Electrolytic deposition of other metal materials (gold, silver, copper, nickel, zinc, cadmium, etc.) are particular cases of this electroplating procedure. In addition, only for chromium there is a porous type of electroplating. Therefore, this technology intended to be the most complex.

In this article, we will analyze only the electroplating process itself. Preparatory operations (washing, degreasing, etching) and the final ones (final washing, drying and packing) will not be analyzed in this article. Electrodeposition process control is suitable for automatic or semiautomatic lines served by mechanized systems.

If for the transportation of parts from one vat to another can be used successfully only a PLC, for the electroplating vat the system of control for the requested immersion time of the parts underwent treatment and control of current intensity will be more complex.

This article is not a technical project. It shows the logical method of improving the technological process of electrochemical deposition of chromium and testing the theory through simulation on a laboratory plant [2].

2. The principle on the proposed method
We start from the basic relation of the electroplating process (Faraday’s law):
The results obtained by applying this formula represent the theoretical values for a trial in 100% yield. For the real process, the mass corresponding to the calculated time will be lower.

This inconvenience is relatively easy to fix. Through quantitative determinations of accuracy, we measure the actual deposited mass. This value is compared to the theoretical one and the current efficiency of the plant is calculated. Given this performance, the necessary corrections on the value of hold time will be made, so through the new calculated value to obtain the desired coating thickness.

The calculation formulas underlying the implemented software implemented on the computer that monitors the electroplating process are [3]:

- The calculation of theoretical mass

\[
m = \frac{A \cdot I \cdot t}{Z \cdot F} \quad \text{[g]} \tag{1}
\]

where:
- \(A\) – atomic mass of the metal [g]
- \(I\) – the intensity of the electrolysis current [A]
- \(t\) – electrolysis time [s]
- \(z\) – metal valence
- \(F\) – Faraday\’s number \([F = 96500 \text{C mol}^{-1}]\)

- Theoretical required time for depositing

\[
t = \frac{m_t \cdot z \cdot F}{A \cdot I} \quad \text{[s]} \tag{3}
\]

- Current efficiency

\[
\eta = \frac{m_r}{m_t} \times 100 \quad \text{[\%]} \tag{4}
\]

where:
- \(m_r\) – actual mass [g]
- \(m_t\) – theoretical mass [g]

The logic of the calculation program is:
- Entering the type of metal material used for coating (Au, Ag, Ni, Cr, Zn, Cd, Pb, etc.);
- Entering the thickness of the metal material layer required to be deposited;
- Entering the surface to be coated by electrodeposition;

\[
t = \frac{S \cdot \delta \cdot \rho \cdot z \cdot F \cdot \eta}{A \cdot I} \quad \text{[s]} \tag{5}
\]

Technological parameter values vary greatly depending on the type of metal coating. In Table 1 are summarized core values:

| Protective coating | Electrolyte components | Quantity [g/l] | T \[^{0}\text{C}\] | Anode s | Current density [A/dm\(^2\)] | Observations |
|--------------------|------------------------|----------------|----------------|---------|-----------------------------|--------------|
| 0                  | 1                      | 2              | 3              | 4       | 5                           | 6            |
The advantage of this program is that besides the fact that it monitors the process in real time, it works with a database (atomic mass of deposited metal, valence, density of deposited material) from which automatically sets its values. The operator will enter only three values: the type of metal material used for coating, the thickness of the metal material to be deposited and the surface to be deposited. For objects with complex surfaces, the space scan can be used. In this case the obtained value obtained is transmitted automatically in the program.

3. The method simulation on a laboratory plant
To verify this theory we did a simulation on a laboratory plant. In real situations monitoring and control system is grafted on real plant. It will make the necessary corrections and will be introduced in the database. If the computer monitors several types of electrodeposition (Ni, Au, Ag, Zn, Cd, etc.) database will be completed with the appropriate values of these metallic elements [4,5].

The practical verification of the previous exposed theory involves two stages.

The first step involves theory converting into a software that runs on the computer that monitors the technological process, and the second one consists in testing of steel samples in a laboratory plant.

The mathematical calculation was compiled with WinCC software. Here's the routine for calculating the keeping time in the electrodeposition vat [7].

Initial data: the deposited material - chromium; deposited layer thickness - 1 μm.

Keeping time in vat – 2134 s

Program calculation time maintenance
#include "apdefap.h"
void OnLButtonDown(char* lpszPictureName, char* lpszObjectName, char* lpszPropertyName, UINT nFlags, int x, int y)
{
  double surface, thickness,time_maintenance;
  double density[20]; //table with used material density
  double valence_element[20];
  double mass_atomic[20];
  double nr_faraday=96500;
  double intensity=5;
  double efficiency=0.15;
  density[0]=0.00719;
  valence_element[0]=3;
  mass_atomic[0]=51.9661;
  if (strcmp(GetTagChar("type_material"),"crom")==0)
  {
    surface=GetTagDouble("surface");
  

thickness=GetTagDouble("thickness");

time_maintenance=(surface*density[0]*thickness*valence_element[0]*nr_faraday*efficiency)/(mass_atomic[0]*intensity);
SetTagDouble("time_maintenance",time_maintenance); //Return-Type: BOOL

The synoptic that appears to the operator has an easy and complete protocol (Figure 1).

![Synoptic](image1)

**Figure 1.** Synoptic of data entry by operator.

The second stage of theory verification consisted in chrome plating of steel samples in a laboratory plant.

![Laboratory plant](image2)

**Figure 2.** Laboratory plant for electroplating.
Baseline characteristics of the samples are tabulated in Table 2 and hold times in electrodeposition process vats in Table 3.

### Table 2. Characteristics of the steel samples in initial phase.

| No. sample | Dimension [mm] | Mass [g] | Roughness [µm] |
|------------|----------------|----------|----------------|
|            | Diameter       | Height   |                |
| 1          | 15,10          | 30,00    | 41,97          | 12,5           |
| 2          | 15,14          | 29,90    | 42,15          | 12,5           |
| 3          | 15,09          | 30,00    | 41,87          | 12,5           |
| 4          | 15,10          | 30,10    | 42,10          | 12,5           |
| 5          | 15,07          | 30,15    | 41,88          | 12,5           |
| 6          | 15,19          | 30,15    | 42,33          | 12,5           |

### Table 3. Hold times samples.

| Hold time [s] | 1   | 2   | 3   | 4   | 5   | 6   |
|---------------|-----|-----|-----|-----|-----|-----|
| Organic degreasing | 60  | 60  | 60  | 60  | 60  | 60  |
| Chemical degreasing | 300 | 300 | 300 | 300 | 300 | 300 |
| Washing       | 60  | 60  | 60  | 60  | 60  | 60  |
| Etching       | 180 | 180 | 180 | 180 | 180 | 180 |
| Washing       | 60  | 60  | 60  | 60  | 60  | 60  |
| Chrome        | -   | 900 | 1800| 2700| 3600| 9000|
| Washing       | 60  | 60  | 60  | 60  | 60  | 60  |
| Ascent        | 40  | 40  | 40  | 40  | 40  | 40  |

![Figure 3. Sample aspect after chrome.](image)

### 3. Obtained results

After chrome, samples modified their initial mass, except sample 1, which is blank. The first was the quantitative determination. The results obtained from the weighing are presented in Table 4.
Chrome samples were metallographic prepared and analyzed quantitatively by equipment from the laboratory BIOMAT Research Centre of the Faculty of Materials Science and Engineering from the University Polytechnica of Bucharest.

Chrome test results obtained by metallographic analysis are presented in the following table.

**Table 4. Properties steel samples in final phase**

| No. sample | Initial mass [g] | Final mass [g] | Chromium deposited mass [g] |
|------------|------------------|----------------|-----------------------------|
| 1          | 41,97            | 41,97          | 0,00                        |
| 2          | 42,15            | 42,16          | 0,01                        |
| 3          | 41,87            | 41,90          | 0,03                        |
| 4          | 42,10            | 42,14          | 0,04                        |
| 5          | 41,88            | 41,93          | 0,05                        |
| 6          | 42,33            | 42,45          | 0,12                        |

**Table 5. Properties steel samples in final phase**

| No. sample | Deposition properties | Medium thickness layer [μm] | Continuity | Adhesion |
|------------|-----------------------|----------------------------|------------|----------|
| 2          | grey white, glossy    | 0,892                      | good       | good     |
| 3          | grey white, glossy    | 2,085                      | good       | good     |
| 4          | grey white, glossy    | 3,025                      | good       | good     |
| 5          | grey white, glossy    | 3,321                      | good       | good     |
| 6          | grey white, glossy    | 9,307                      | good       | good     |

**Figure 4. Micrographics sample 2.**

**Figure 5. Micrographics sample 3.**
Data from the analysis reports are summarized in Table 6, based on them resulted the histogram in Figure 9.
Table 6.

| No. sample | Thickness deposited layer [μm] |  |
|------------|--------------------------------|---|
|            | minim                           | maxim | average |
| 2          | 0.719355                        | 1.10108 | 0.892833 |
| 3          | 1.78984                         | 2.4896  | 2.08504  |
| 4          | 2.57204                         | 3.65992 | 3.02584  |
| 5          | 2.88286                         | 3.97075 | 3.32112  |
| 6          | 8.7914                          | 9.9584  | 9.30799  |

Figure 9. Results Histogram resulting from the analysis reports.

The dependence of the deposited layer thickness, measured by microscope, according to the holding time in the chromium plating bath is shown in the graph of Figure 10.

Figure 10. Thickness variation of the deposited layer by time.

As shown in Figure 10, the actual values are very close to the theoretical. Extrapolating the results, we obtain the graph in Figure 11.
For hard chrome plating is recommended to use electrodes with a form close to the part to be subjected to improvement treatment, this in order to increase the electrodeposition process efficiency. In this case they are working with great intensity currents. The hard chrome plating involves a diffusion layer as thick as possible.

4. Conclusions
The obtained results confirmed that the logic of calculation is perfectly feasible for applying real electrodeposition processes.

Using this type of process driving, it minimizes the time required to change the technological parameters. For the same type of coating, it may be introduced a variety of sizes of parts, it can be applied layers with different thicknesses depending on requirements, however adjusting rapidly from the virtual Control Panel that is the computer with its interfaces.

Using the WinCC software implemented on a PC that communicates with a PLC makes it possible to read process variables by monitoring and storing the results in a database will ultimately lead to increased plant performance by adjusting these parameters to theoretical ideal values.

This created software is designed to improve the quality of produced products and the efficiency of the metal deposition plant.

Starting from a classical electrodeposition line, mechanized, a complex process command was created with the WinCC software. He allows, however, by extrapolation, to adapt to any electroplating process that uses electrolysis vats served by a mechanized parts transmission system.

5. References
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