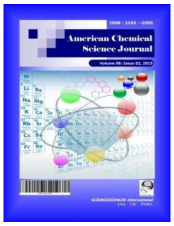

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A Microcontroller-based Design for Energy Efficient Nickel-chrome Plating Process

Olabode Oladipo Olakanmi[1], Ogundare Margaret Ojone[1,2], Adesina Olanrewaju Seun[1], Isadare Dayo Adeyemi[1,3], Akinluwade Kunle Joseph[1,3*], Taiwo Adeyinka Taofeek[1], Odejobi Olusegun Abel[1] and Adetunji Adelana Rasaki[1,3]

[1]Department of Engineering, Prototype Engineering Development Institute (PEDI), National Agency for Science and Engineering Infrastructure, NASENI, Ilesa, Nigeria.
[2]Department of Marine Science and Technology, School of Earth and Mineral Sciences, The Federal University of Technology Akure, Akure, Nigeria.
[3]Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author AKJ designed the study and wrote the protocol. Author OOO performed the electronics, control and simulation. Authors OMO, AOS and IDA performed the electrochemistry of plating. Author TAT managed literature searches. Authors OOA and AAR coordinated and interpreted results. All authors read and approved the final manuscript.

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ABSTRACT

This paper presents a microcontroller-based design system for automated Nickel-chrome plating process using time flow of current. Given fixed electroplating parameters, the amount of a substance discharged will be a function of time and current density. These oftentimes are traditionally read using a stop clock and ammeter on a rectifier. This conventional method lacks capacity for instantaneous measurement and is usually prone to error due to open circuit. The present study unveils an energy saving microcontroller-based design capable of monitoring the current flow and accurately determining the time in computing the instantaneous mass deposited on the cathode (work piece).

**Corresponding author: E-mail: jakinluwade@hotmail.com;*

Keywords: Microcontroller; nickel-chrome; energy-saving; current density; rectifier.

1. INTRODUCTION

Electroplating is an electrodeposition process for producing a dense, uniform, and adherent coating, usually of metal or alloys, upon a surface by the action of electric current [1]. This is done in other to achieve a desired set of properties for the work piece such as abrasion and wear resistance, corrosion protection, lubricity, aesthetics, etc.

Electroplating is an important industrial process today and products of electroplating are widely used in many industries, such as automobile, marine, air space, jewelry, machinery, electronics etc. The commercial importance of Nickel for example may be judged from the amount of nickel in the form of metal and salts consumed annually for electroplating, now roughly 100,000 metric tons worldwide, as well as its versatility from its many current applications [2,3,4].

The article to be plated is made the cathode (negative terminal). The anode could be sacrificial that is dissolvable anode or inert anode [5]. The sacrificial anodes are made of the desired metal that is to be deposited. The inert anode can only complete the electrical circuit, but cannot provide a source of fresh metal to replace what has been removed from the solution by deposition at the cathode. Electrolyte completes an electric circuit between two electrodes.

At the cathode, electrons are supplied to cations, which migrate to the anode. In its simplest form, the reaction in aqueous medium at the cathode follows the equation in equation (1) with a corresponding anode reaction:

$$M^{n^+} + ne^- \rightarrow M \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

At the anode, electrons are supplied to the anions, which migrate to the anode. The anode material can also be an inert anode. For the sacrificial anode, the anode reaction is given in equation (2):

$$M \longrightarrow M^{n+} + ne^- \ldots\ldots\ldots\ldots\ldots \quad 2$$

In this case, the electrode reaction is electro-dissolution that continuously supplies the metal ions.

Kumar et al. [6] investigated Structural modeling and analysis of an effluent treatment process for electroplating while Saravanan and Mohan [7] studies structure, current efficiency, and corrosion properties of brush elecetrodeposited Cr from Cr(III) dimethyl formamide bath.

Vanek [8] studies the benefits of plating localized areas with a portable plating system, via brush plating. Liang et al. [9] undertook structure characterization and tribological properties of thick chromium coating electrodeposited from a Cr(III) electrolyte.

Aydin et al. [10] investigated the potentiality of brush chromium plating process to replace conventional hard chromium plating and concluded that brush chromium plating is an environmental friendly alternative option for conventional chromium plating, and it has potentiality to be applied over steels to enhance wear resistance. Nevzat [11] studies the removal of copper(II), chromium(VI) and nickel(II) from metal plating effluent by electrocoagulation. He found out that after 40 minutes, with the exception of 98% Cr efficiency using Al-St electrode pair, all metal ions were removed with 100% efficiency using all other electrode pairs. Moura et al. [12] carried out feasibility studies of chromium electroplating process in stamping tooling and concluded that this improves the useful life of dies and their appropriate tools.

Prajakta and Suraj [13] investigated Resistance Spot Welding of CRCA Steel sheets using surface modified electrodes. This study revealed that Ni plating with 35 microns thickness and Cr plating with 25 microns thickness requires less current to weld spots of higher strengths compared to non plated electrodes. This was due to increase in resistance of the weld system due to plating which requires less current as resistance of the weld system is increased.

In previous research work on automated plating machine, attention has been on the biological and pharmaceutical products such as tablets coating [14,15,16].

However, there seems to be dearth of information on the design of an automated nickel and chrome plating machine for energy efficiency. Therefore this research work is aimed at addressing this problem by devising a microcontroller-based design for energy efficient nickel-chrome plating process. This study improves the energy efficiency of an electrochemical process using a microcontroller-based design.

2. MATERIALS

The following are the materials/soft resources used for this work:

- Nickel and Chrome voltameter
- MikroC PRO for embedded systems applications development
- ISIS Proteus Schematic Capture Design and Simulation Suite

3. METHODOLOGY

Given fixed electroplating parameters, the amount of substances discharged at the anode is a function of time and current density. Considering Faraday's law of electrolysis, that is, the mass deposited at the cathode and the mass dissolved at the anode is directly proportional to the product of the current and time and may be calculated from the expression:

$$M = ZaIt \qquad (3)$$

Where **M** is mass deposited at the cathode in grams, ***I*** is current in amperes, ***t*** is time that the current flows in hours and ***a*** is current efficiency ratio. Proportionality constant ***Z*** equals 0.3233 for Chrome and 1.095 for Nickel.

The work flow is as follows: a current sensor senses the electroplating current and converts it to analog voltage. This analog voltage is digitized and interpreted by a microcontroller for the corresponding current equivalent. This is done simultaneously with the time tracking algorithm in the microcontroller using its internal timer/counter to get the real time. The product of current and time with constants (current efficiency (a) and electrochemical equivalence (*z*) are computed and display on Liquid Crystal Display (LCD). The amount of mass discharged is a function of current and time provided the electroplating parameters are kept constant.

3.1 Description of the System Block Diagram

Fig. 1 shows the block diagram of the system.

Alternating current is controlled by the power controller (ON/OFF controller) and AC is rectified to Direct Current (DC) source by the rectifier. The electroplating current is converted to analog voltage through Hall Effect-Based Linear Current Sensor IC (ACS712). The 10 bit internal ADC of the microcontroller converts the analog voltage signal to digital voltage levels giving 1024 ADC states (for 10 bits system, 2^{10} = 1024 states). Input buttons (Ni/Cr) is for selecting Nickel or Chrome deposition. Rest button is for system reset and Startkey is for starting the electrodeposition instantly. LCD displays the electroplating current, time in real-time and instantaneous mass deposition. Anode and cathode (work piece) are in the electrolyte making the circuit a complete loop.

3.2 System Schematics

Fig. 2 shows the schematics of the system. Voltage controlled current source was selected with transconductance value of 1.0 to simulate electrodeposition current. This current is converted to analog voltage by ACS712 current sensor and digitized by the internal ADC of the microcontroller. Microcontroller interfaced with LCD displays the current value on the screen.

3.3 Specifications of Microcontroller, Current Sensor and LCD

8-bit microcontroller PIC 16F887 from Microchip was used as the controller of the system with the following required specifications:

- Operating frequency 0-20 MHz
- Power supply voltage 2.0-5.5V
- A/D converter (10-bit resolution)
- 3 independent timers/counters

Linear Current Sensor which is Hall Effect-Based from Allego micro systems IC was selected (ACS712). It has the following specifications:

- 185 mV/A output sensitivity
- 5 µs output rise time in response to step input current
- 1.2 mΩ internal conductor resistance
- Output voltage proportional to current

16 by 4 alphanumeric LCD with HD44780 compatible interface connection to microcontroller was selected.

3.4 Time Measurement Technique

8-bit TMR0 Timer/Counter of the PIC16F887 was used for tracking the time of current flow. 1.024 seconds was achieved as described below:

8-bit timer has 256 counting states (2^8 = 256 states) which cause interrupt upon its overflow. Counter increment (Cinc), i.e transition from one state to another is calculated as follows:

Counter increment (Cinc) = (4 Prescaler)/(MCU clock frequency)................... 4

where: Precaler is the frequency reducer
Cinc = (4*32) ÷ (4000000)
Cinc = 32 mS

Counter overflow is calculated as follows;

Counter overflow = (Number of the counter states – TMR0)*Cinc............. 5

= (256-96)*0.000032
Counter overflow = 5.12 mS
TMR0 Interrupt will occur every 5.12 mS
When TMR0 Interrupt occurs for 200 times, then, 200×5.12 mS= 1.024 S

Constant 200 was compared with count variable in the embedded software for tracking the system time every 1.024 seconds in the interrupt service routine (ISR) of the microcontroller.

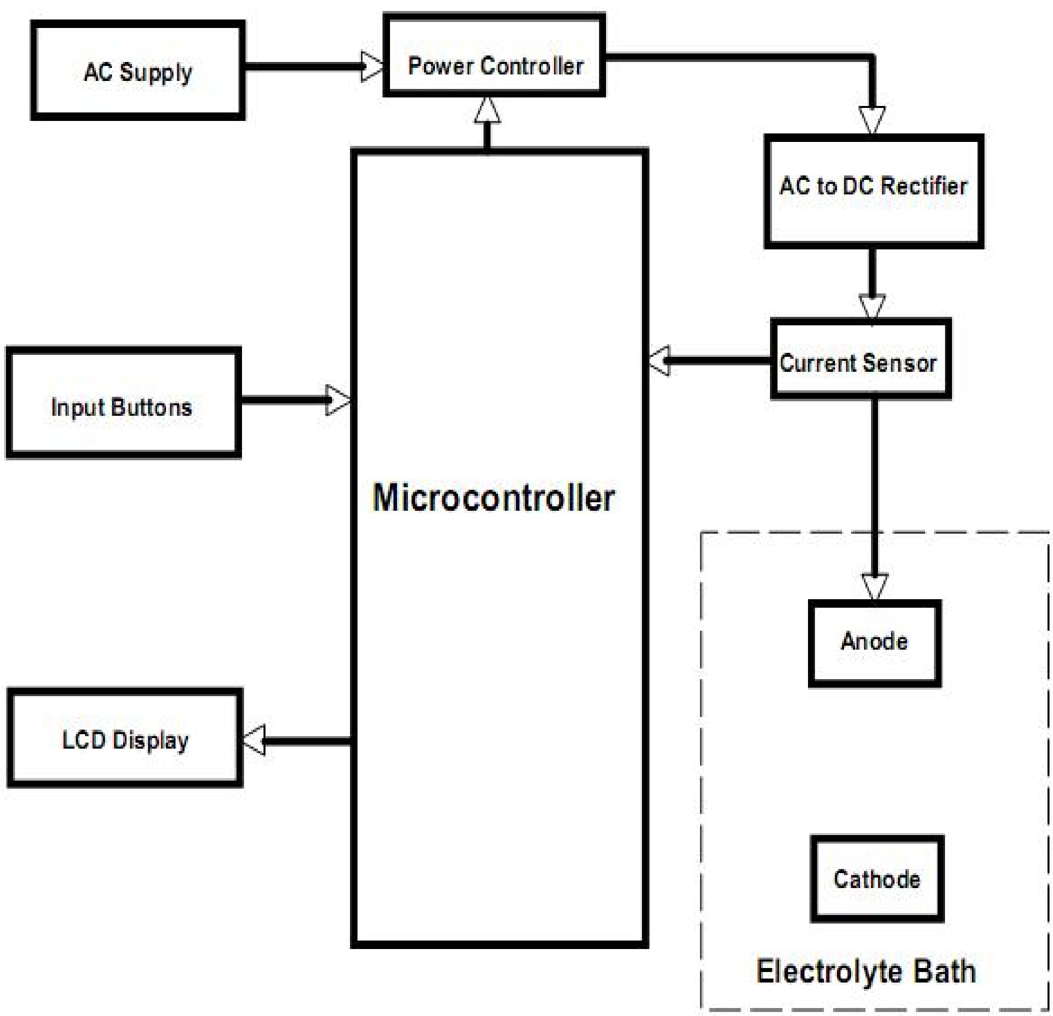

Fig. 1. Block diagram of the system

3.5 Analog to Digital Converter (ADC)

Internal ADC of the microcontroller was used for digitizing the input voltage from the current sensor.

Resolution = Measurement Range / ADC States.............. 6

10 bits ADC states = 1024
The minimum voltage the ADC can respond to is (5-0)/1024 = 4.88 mV

3.6 Current Measurement and Sensitivity

Measured Current = ADC reading * (Scaling constant / 1024) 7

Where scaling constant = Maximum Current
C code for capturing current value in Amperes is;
Current = current(20.0/1024.0);*

Applying equation (7), current sensitivity of the system = $4.88\times10^{-3} \times (20\div1024)$
95.3 µA

4. RESULTS AND DISCUSSION

4.1 Simulations

ISIS Proteus Schematic Capture Design and Simulation Suite were used for system simulation. The screen print of the simulation of the current sensor with voltage controlled current source input to the ACS712 current sensor is as shown in Fig. 3. The voltage output of the current sensor is monitored using voltmeter. The transconductance of the voltage control current source was set to 1. Screen print of the whole system simulation is shown in Fig. 3.

4.2 Nickel System

Screen print of the Nickel system simulation is shown in Fig. 5. Using Faraday's Law of electrolysis;

M= 1.095 * alt

Mass of Nickel deposited is:

1.095*0.97*16.62109*(20.98999/3600)

=0.1029331g

This value is as shown in the screen printed simulation on the computer system (Fig. 5). The Appendix is an extract of the C- program which processes CURRENT and TIME display of the LCD.

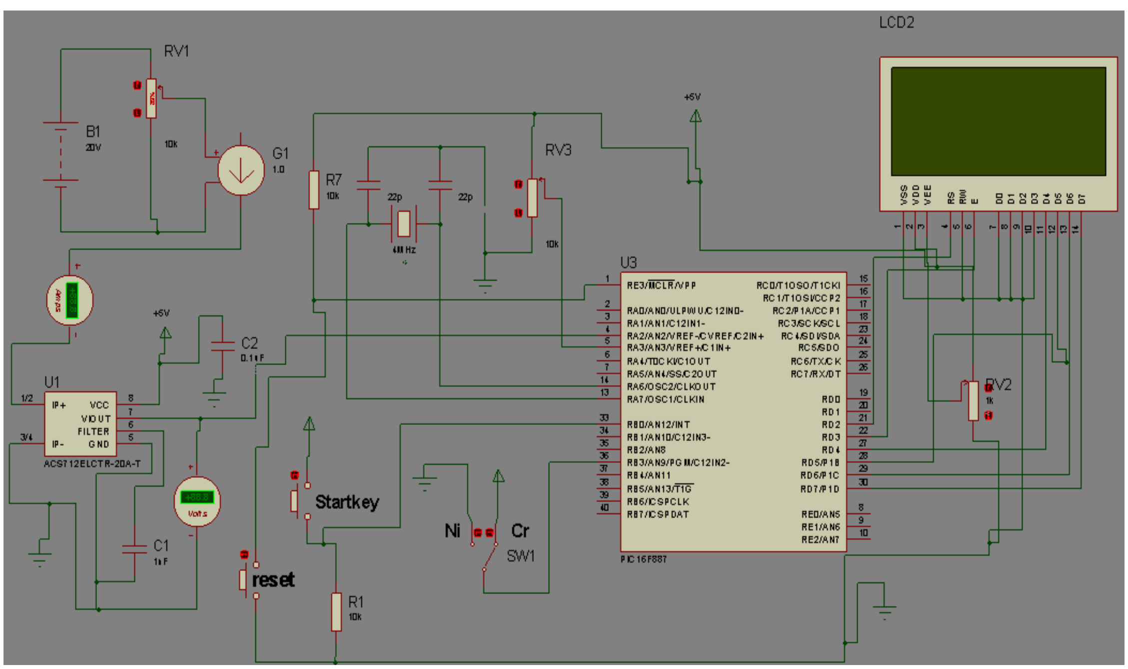

Fig. 2. Schematic of the system

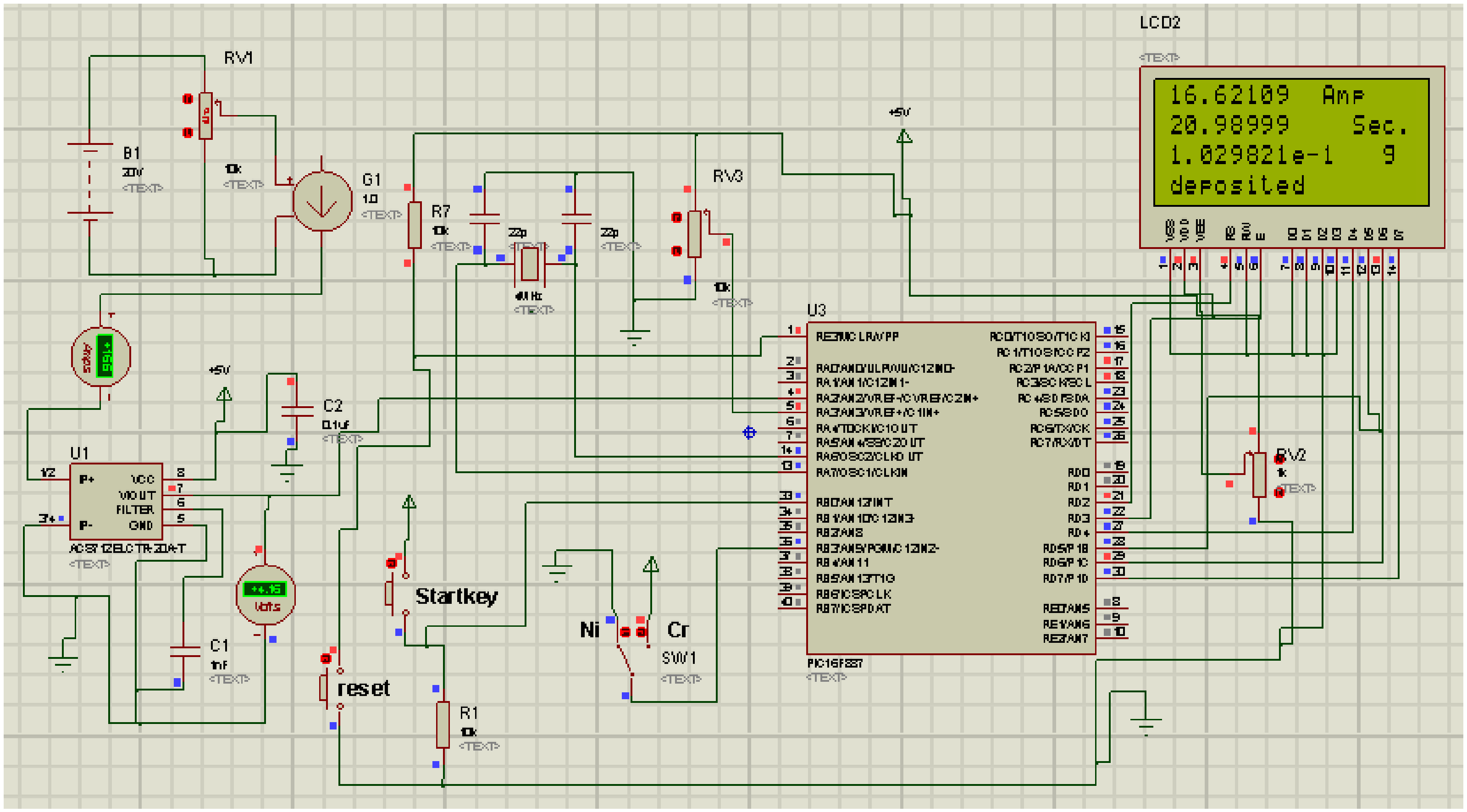

Fig. 3. Screen print of the system simulation

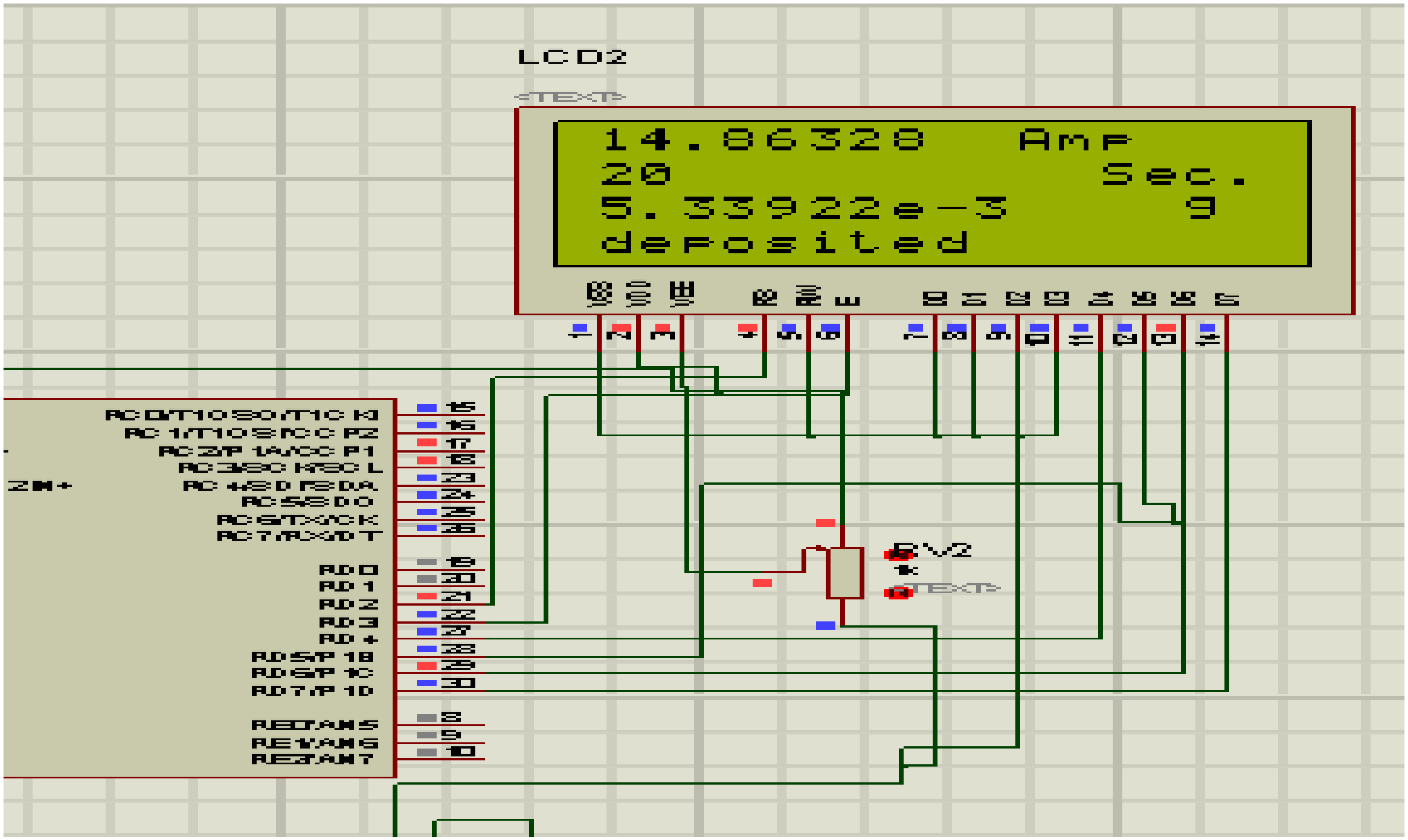

Fig. 4. Chrome system simulation

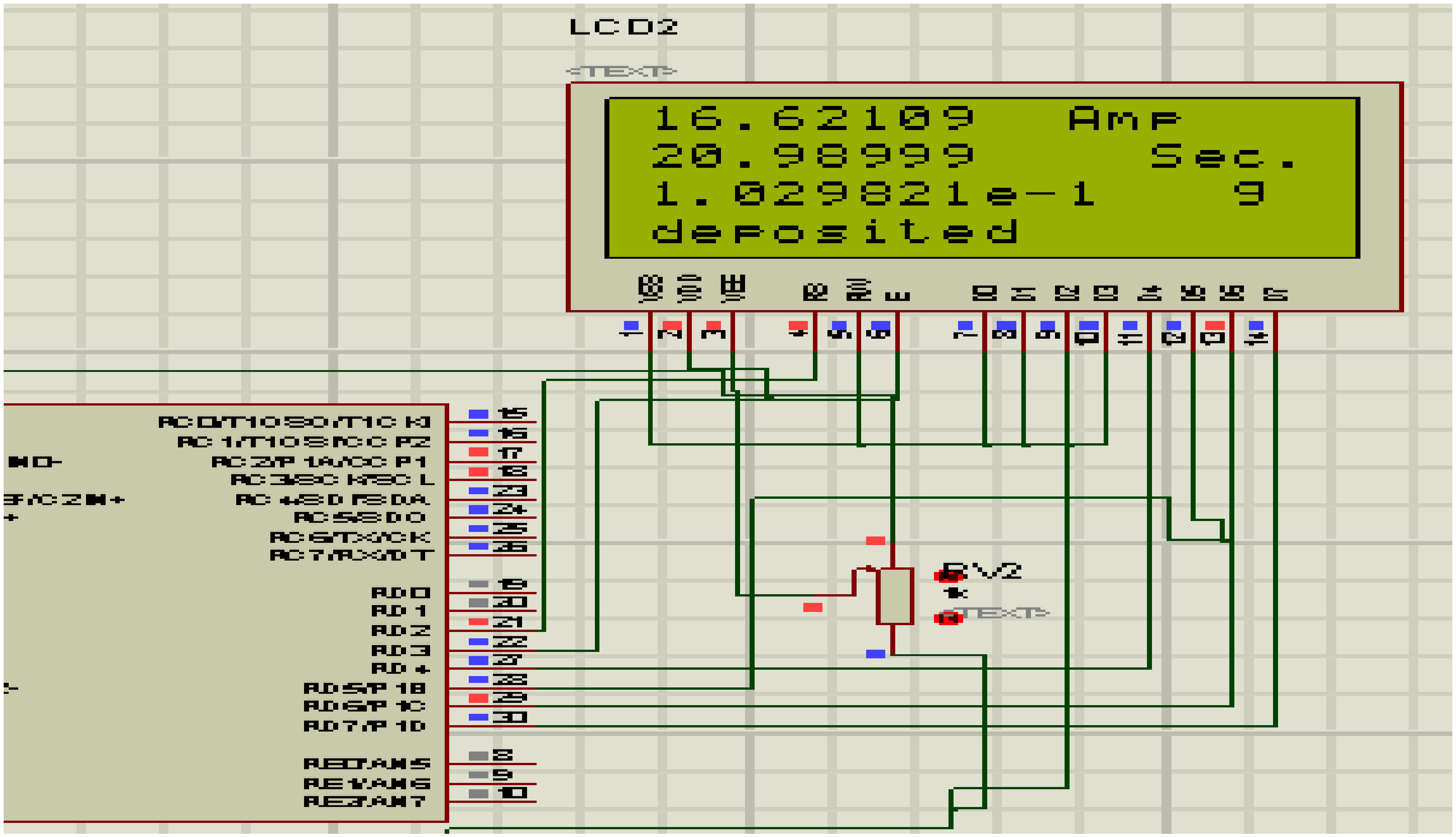

Fig. 5. Nickel system simulation

4.3 Chrome System

Screen print of the Chrome system simulation is shown in Fig. 4. Using Faraday's Law of electrolysis;

M = 0.3233 * aIt
Mass of Chrome deposited is:
0.3233*0.20*14.86328*(20/3600)
=0.00533922 g

This value is as shown in the screen printed simulation on the computer system (Fig. 4).

4.4 Limitations of Conventional Electroplating Processes to Microcontroller-based Design

In conventional, loss of current, and decrease in efficiency due to open circuit. Also, it is difficult to preset required mass for deposit and time of flow of current. In Microcontroller-Based Design, you can instantaneously monitor the amount of substance liberated or deposited, while conventional method lacks capacity for instantaneous measurement.

5. CONCLUSION

From the results of simulations above for both Nickel and Chrome systems, deposition could be monitored in real time with the display of current, time and instantaneous mass deposition displayed on the screen. Once the mass intended to be deposited is reached, the system can be stopped and the sample removed. This system gives the accurate mass deposition and avoids wastage of energy which cannot be achieved with the conventional system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Extract of the C- program which processes CURRENT and TIME display of the LCD.

```
while(1) {                    // Endless loop
current = ADC_Read(2);              // Get 10-bit results of AD conversion
current = current*(20.0/1024.0);  // Convert the ADC value to current value
Lcd_Cmd(_LCD_CLEAR);          //   Clear LCD Screen
FloatToStr(current, txtshow);    // Convert the current value to text format for LCD display
Lcd_Out(1,1,txtshow);              // Display on column 1, row 1
Lcd_Out(1,11,Amp);                 // Display on column 11, row 1
FloatToStr(time, time_show);      // Convert time to text format for LCD display
Lcd_Out(2,1,time_show);           // Display on column 1, row 2
Lcd_Out(2,13,"Sec.");              // Display on column 13, row 2
if(RB3_bit==1){
Mass Deposited = 0.3233*current*0.20*timeh; //Compute for Chromium system}
else {Mass Deposited = 1.095*current*0.97*timeh;  //Compute for Nickel system}
Float To Str (Mass Deposited, Mass Depo Show); // Convert the mass deposited to text format for
LCD                                                     // Display
Lcd_Out(3,3,MassDepoShow);                       // Display on column 3, row 3
Lcd_Out(3,11,"g");                        // Display on column 11, row 3
Lcd_Out(4,3,"deposited");                 // Display on column 3, row 4
delay_ms(200);                  // give a delay of 200 milliseconds
```


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