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Experimental Simulation Analysis of Current Density Distribution by Kirchhoff's laws in a resistor network cell model

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Abstract*: In this process, variations in individual current distribution are due to a combined effect of spatially and temporally varied condition in the cell and usual preparations carried out during the cell operation. This process presents a resistor network model of an industrial copper reduction cell with equivalent circuits representing path resistance at individual anodes at the same time the practical cell structure. The model acquires time-varying resistance as the inputs and determines the corresponding time-varying anode current distribution. Unlike usual move towards that treat the system as a network of only anodes connected in parallel, the proposed model also considers the structure of an industrial reduction cell. The simulation results include current distribution during anode change and noise level change due to slot disappearance. This model and the simulation studies are the original measure in the direction of cell monitoring based on anode current measurements.*

Keywords*: current density, copper reduction cell, resistor network, electrodeposition, anode current distribution, direction of cell monitoring.*

I. Introduction

In this process Copper is produced via electrochemical reactions in electrolytic reduction of Copper in a molten bath of copper sulphate. The most favourable process efficiency of the progression can be achieved when the cell is in a balanced state. By its nature, this process is a semi-batch practice with a distributed nature. Electrical energy is required to break the Copper-oxygen bond in the thermodynamically stable Copper dissolved minimally in the electrolyte. A stream of constant direct current is applied[1-4] to the cell connected in series at varying Adm^2 's Each cell contains anodes, where each anode is supported by an anode rod which is attached to an anode beam. Thus anode is consumable during the process. The normal life of anodes varies depending on the anode size and operating conditions. This means that the anodes need to be replaced at the end of the trials. Anode resistance path in this work is classified as the individual path of the parallel network starting from the anode beam to the cathode. Each path consists of components as follows:

- Anode resistance.
- Sulphate bath resistance, as oxide is produced during the reduction process and forms a layer underneath the anodes, contributing to the path resistance. Since the implementation of slotted anodes, the resistance caused by oxide layer has been greatly reduced. However, the resistance will become significant once the slots are consumed during the operation [5-7].
- Electrolyte resistance and
- Impedance arisen due to reaction at both anode and cathode.

A. Anode as a resistor network

By measuring line current, deposition weight and cell voltage performance monitoring of measurements reflect the overall cell performance, but they are not able to address spatial variations occurring inside the cell. Recently, the measurement of individual anode current has attracted a lot of attention[8-13]. This measurement scheme has been used in anode current signal analysis, thermal model and process fault diagnosis. Seeing as the anode current signal is affected by both local cell condition and the signals on the other cathode, the distributed nature of the process can be represented by the measurement. There is a limited number of works which consider the anodes as a resistor network, for example, considers the cell with anode connecting in parallel for detecting anode spikes. However, the anode in copper reduction cell connected through anode and crossover with ammeter and voltmeter. Thus, the anode paths should be considered as a resistor network with anode, crossovers that connect them.

B. Equivalent Kirchhoff's Circuit Network

(Fig.1.1). illustrated an example of equivalent circuit network. "Anode" represents the anode resistance path from anode to cathode "Anode beam" is attached to anode rod, which supports anode, "Crossover" is the bridge that joins between the anode beams and "Riser" is where the direct current is introduced from a current source[14-19]. All the anode resistance paths are connected through the liquid molten copper (metal panel) at the bottom of the cell. The direct current is providing for stable current source which is then divided into four streams through the risers. The current coming from the risers is delivered to all the anodes through the anode beams and the crossovers. The current on the anode paths is then accumulated in the metal panel at the bottom of the cell.

To solve the circuit network, Kirchhoff's circuit laws are used. The **Kirchhoff's current law** states that the algebraic sum of currents in a network of resistors meeting at a point is zero, while the **Kirchhoff's voltage law** states that the sum of all voltage drops around a closed loop in an electrical circuit is zero.

- Therefore, joints (Fig.1.2) in the equivalent circuit can be treated with Kirchhoff's current law
- Whereas the loops (Fig.1.3.) are dealt with Kirchhoff's voltage law. The equation can be written as

$$P(R)I = Q$$

Where P and Q are Kirchhoff-related matrices is a function of anode path resistance and I −is a vector of current distribution in the cell.

C. Estimation of Modeling of electrolyte resistance

Assume that the anode path resistance should be provided as the initial condition. In this model, the components of path resistance are considered as follows:

- Anode resistance is decreasing, according to the consumption rate of copper anode. It is believed that the anodes are consumed evenly from the bottom so that the cross-sectional area (5.0 cm × 2.5 cm) of the anode is always the same. The rate of resistance change can be calculated by Faraday's equation.

$$R_{anode} = -\rho \frac{\frac{IM}{Fz}}{\rho_{copper}{}^{A^2}}$$

Where ρ − is the resistivity of copper, I −is the anode current, M −is the molar mass of the copper, F −is the Faraday's constant, z −is the valency of the copper, ρ_{copper} −is the anode density and A −is the cross-sectional area of the anode.

- Sulphate bath resistance, as oxide is produced during the reduction process and forms a layer underneath the anodes, contributing to the path resistance. Since the implementation of slotted anodes, the resistance caused by oxide layer has been greatly reduced. However, the resistance will become significant once the slots are consumed during the operation;
- Other resistance components on the anode path, including electrolyte resistance and impedance arise due to reaction at both anode and cathode are assumed to be constant during normal operation.
- During anode setting with respect to the various point position of cathode, the cell environment is disturbed, affecting all path resistance. In addition, as the temperature of a newly set anode is much lower than that of the electrolyte bath, the bath will "stagnant" around the newly set anode. The resistance change during these periods.

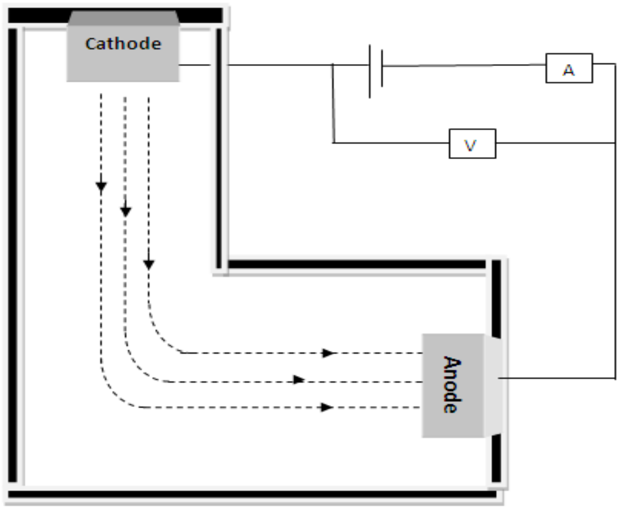
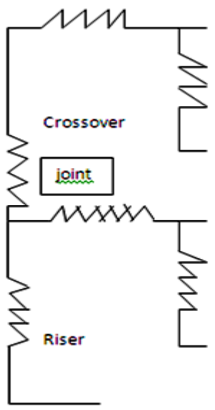


Fig.1.1. An Equivalent Copper reduction cell model



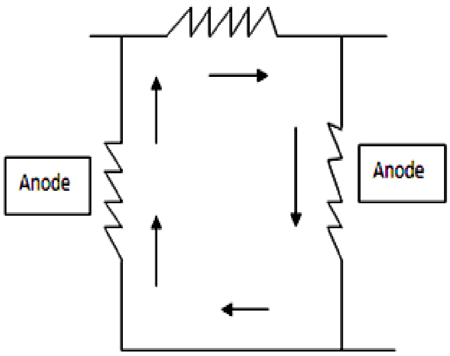


Fig. 1.2. A joint in network **Fig. 1.3. A loop in network**

D. Common Features of resistor network

The path resistance is varying due to anode consumption and bubble generation, thus the resulting current distribution will be time-dependent. This model calculates the individual anode current distribution of the resistor network based on the anode path resistance[20].The model structure is shown in (Fig.1.4). In "Anode Resistance" block, the resistance of copper anode is maintained for every set of individual anode current distribution results. In "Sulphate bath resistance" block, the model determines the resistance of the Sulphate bath based on the slot height, which is dependent on previous current distribution. The "Resistor Network" takes the varying path resistance as the input and determines the current distribution in different parts of the cell. Thus, the model is able to predict the path lines of individual anode current[21]. It also provides information on anode beams, crossovers and risers, which contain potential information for cell performance characterization.

E. Simulation of Anode locations

The resistance values and parameters used in the simulation are obtained and derived from various literatures. The relative ratio of the resistance components in an anode resistance path is from[22], the resistance due to bubble layer formation before and after the slot disappears can be found in[23]. And the percentage changes of path resistance during anode settings as well as the exponential current rise after the setting are derived from[24]. The anode design of the model is shown in (Fig.1.5).

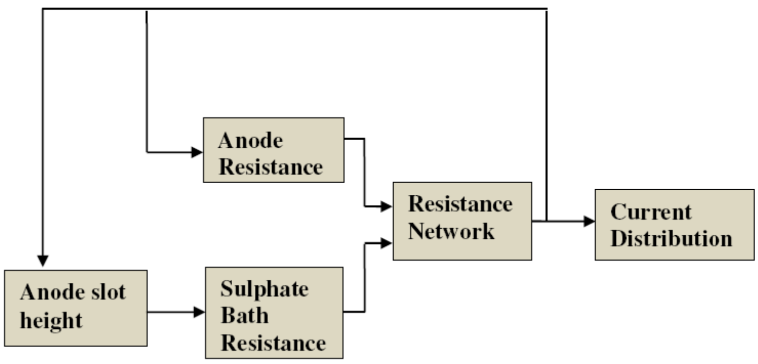


Fig. 1.4. Block diagram for the resistor network model

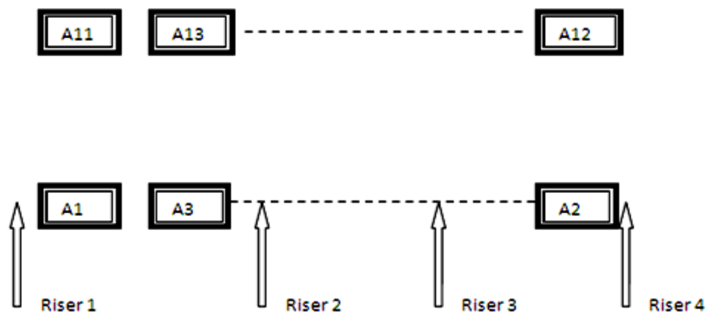


Fig. 1.5. Relative anode location in simulation [A1-Anode 1]

The idea of the following simulation is to show the model is capable of capturing the dynamics in anode resistance and sulphate bath layer resistance. The starting path resistance and slot height are selected accordingly. The results also demonstrate that it is important to include anode beams and risers in the resistor network as they generate relation between different anode paths and the potential of use riser current as a cell performance display. If not at all the simulations start with a set of anodes with a random combination of anode ages.

F. Anode Setting

Anodes in this process need to be relocated as they are consumed during the reduction. (Fig.1.6). shows the response of individual anode currents during an anode setting. As Anode 1 was replaced at about an hour after the simulation has started. The current on that anode drops to zero, followed by an exponential current rise during the stagnant layer melts. At the time when the current of Anode 1 is reduced to zero, current increases in the other anodes are observed. These currents decreased when the new anode starts to represent current exponentially. These variations are due to the relative position of the anode that was recently set. It must be distinguished that only the anodes opposite, adjacent to and away from the recently set anode are shown in (Fig.1.7). which represent current represent of anodes at different position. The correlations of anode related processes from G.C.Barber[24] are used in this model to simulate the impact of a recently set anode on anode current distribution, which might vary between different cell technologies. The correlations can be calculated each time an anode is replace and estimated so that the results can be close to reality.

G. Route of Anode Current

In (Fig.1.8). represented all the anodes in the cell are placed in the cell at the same time, which are focus to exponential current rise. If the anode paths are considered as resistors merely connected in parallel, all the anodes will expose the same behavior. Conversely, which is showing that even if the differences are small, there are deviations of current curves from each other due to the interactions between anode paths and anode beams, risers and crossovers. This is a case in point of illustrating the significance of including cell structure into the model.

H. Riser Current

At the same time as the response of the riser currents to anode setting at different locations varies significantly. Every abrupt alteration in riser currents corresponds to one anode setting event in the simulation occurring at different parts of the cell, the behavior of riser currents is characterized in (Fig.1.9). This shows the potential to use riser currents to detect changes in anode currents.

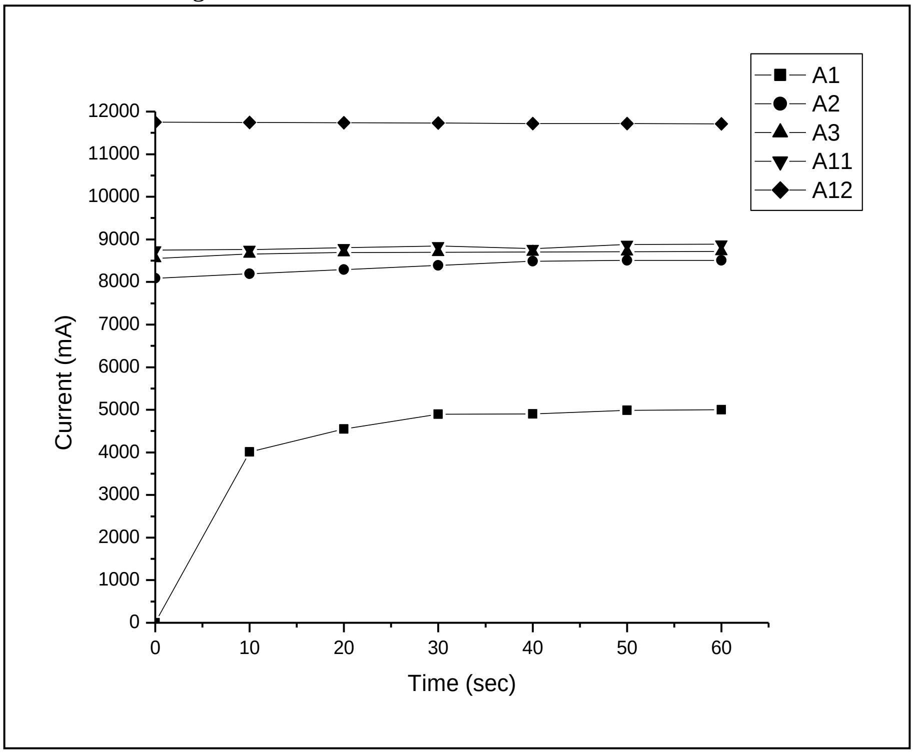


Fig.1.6. Anode current response during anode setting

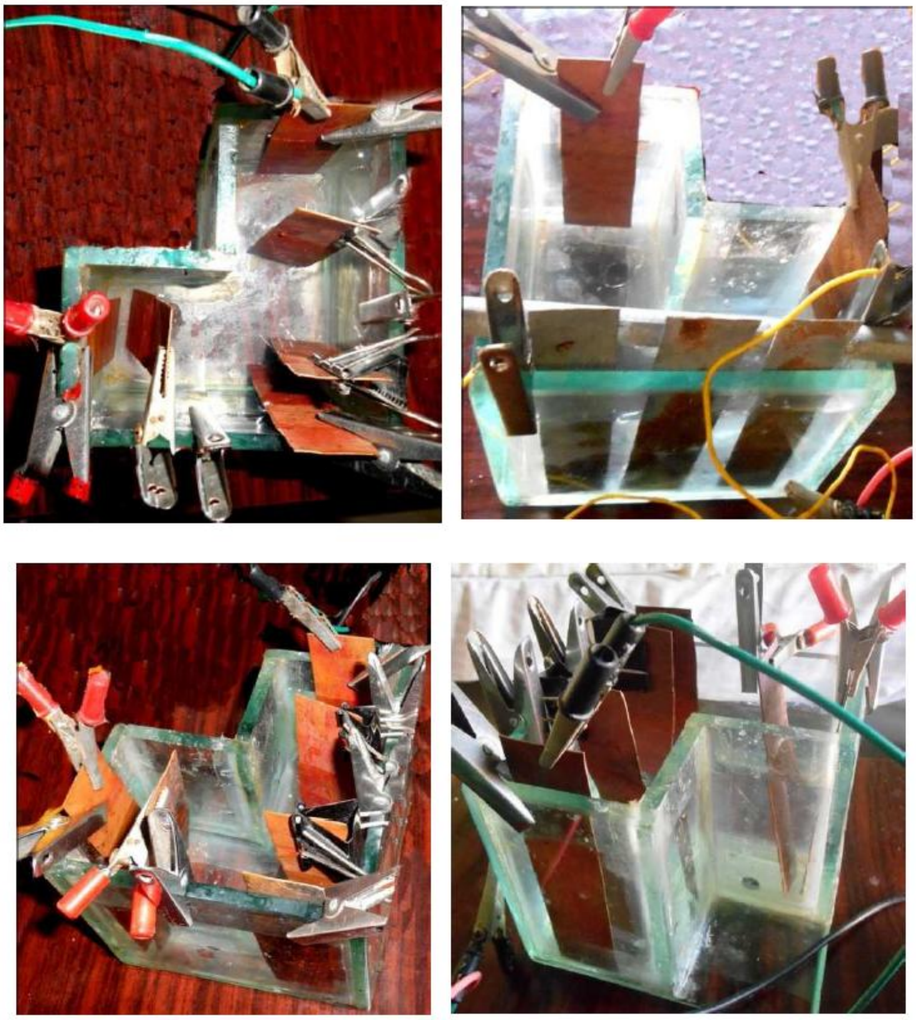


Fig. 1.7. Anode setting at different position during Anode current response

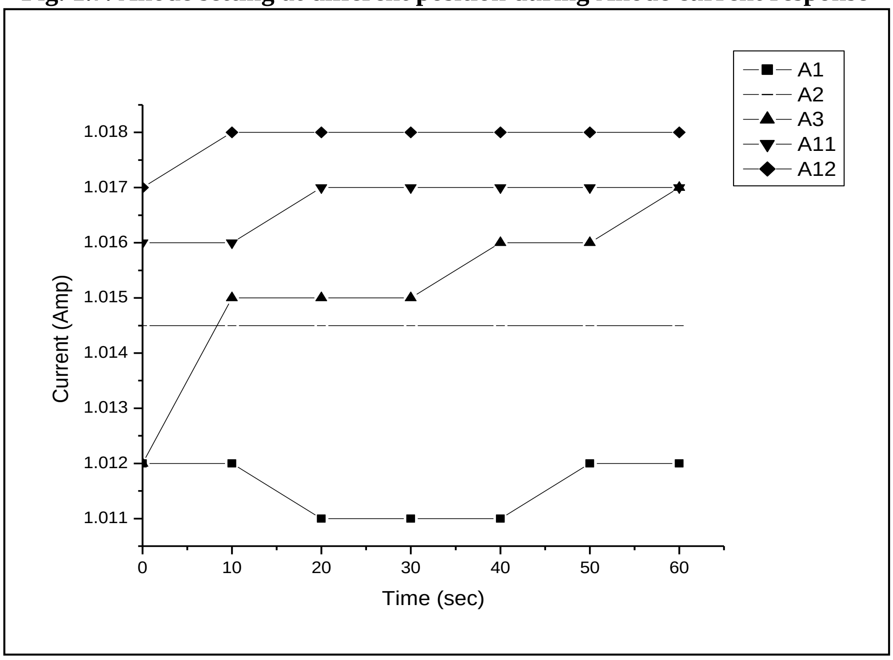


Fig. 1.8. Anode current distribution under same condition

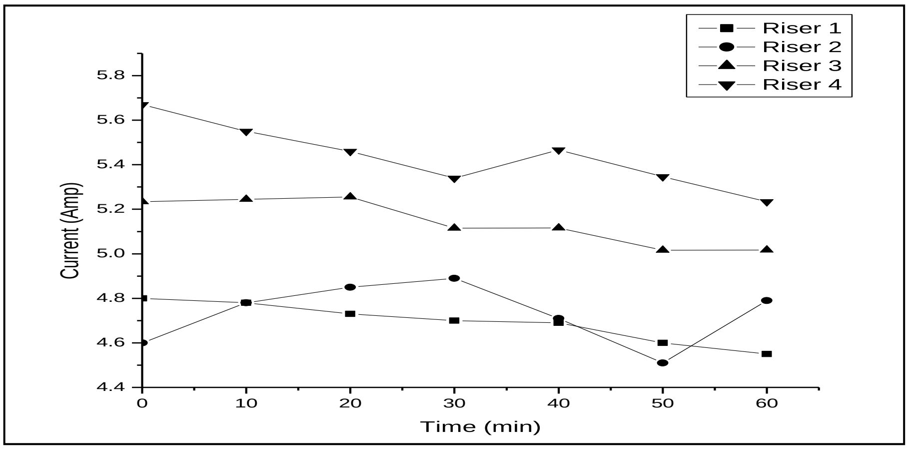


Fig.1.9. Riser current showing a number of Anode settings at different position

II. Conclusion

This work process represents an equivalent resistor network model for current distribution analysis. It takes the time-varying resistance of the anode paths as the input and determines the time-varying current distribution at different parts of the cell. The model not only considers resistance of the anode paths, but also includes resistance of the anode beams, the crossovers and the risers. The model is capable of capturing the dynamics change of anode and bath resistance as well as the interactions between anode paths and anode beams, risers and crossovers. As explained by the simulation results, it is important to include cell structure in the resistor network to account for the interactions. It also provides predictions to analyze currents on anode beams, risers and crossovers to obtain more information about the system. The progress of this model can be regarded as the first step towards cell performance monitoring using individual anode current measurement.

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