A Deep Learning-Based Robot for Anode Cover Thickness (R-FACT) Measurement in Aluminium Electrolysis Cells

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Abstract

This paper presents a comprehensive study on the design, development, and validation of Robot for Anode Cover Thickness (R-FACT), an innovative automated robot for measuring the anode cover thickness in aluminium electrolysis cells. Addressing the challenges posed by harsh temperatures and elevated magnetic fields in potline environments, R-FACT integrates an Artificial Intelligence (AI)-based deep learning model, Depth Assessment and Recognition of Anode Cover (DARAC), which processes images captured by a dedicated camera to accurately determine the anode cover thickness. The mechanical system design comprises two primary compartments: the base housing power and actuation units and the cooled control compartment housing delicate electronics. A thermoelectric cooling assembly safeguards the electronics, while thermal insulation and magnetic shielding that are strategically placed ensure R-FACT's resilience in demanding environments. The electrical system is meticulously designed to supply adequate power to all components, incorporating safety considerations for charging procedures. The control logic involves a robust combination of three controllers and wireless communication for seamless robot navigation. A fully functional R-FACT prototype was rigorously tested at Emirates Global Aluminium (EGA) facilities, demonstrating notable navigation, effective cooling, and adequate shielding. Crucially, on-site testing of the AI-based measurement model achieved an outstanding accuracy of 97.6 % compared to manual measurements, highlighting R-FACT's potential to automate the anode cover thickness measurement process while significantly enhancing safety for plant operators. The findings of this paper contribute to the ongoing advancements in robotics and AI applications in the industrial sector, paving the way for future research and development.

Keywords: Aluminium electrolysis cells, Anode cover thickness measurement, Artificial intelligence, Deep learning, Robotics.

1. Introduction

The aluminium electrolysis industry heavily relies on the accurate measurement of anode cover thickness for optimising energy consumption, improving process efficiency, and reducing emissions [1]. Traditional measurement methods, such as manual inspections, are labour-intensive, time-consuming, and pose safety risks to workers. This paper presents the design, development, and testing of Robot for Anode Cover Thickness (R-FACT), an automated and Artificial Intelligence-powered system for anode cover thickness measurement. R-FACT

integrates an image processing model called Depth Assessment and Recognition of Anode Cover (DARAC) to provide accurate and real-time measurements of anode cover thickness. The successful implementation of R-FACT has the potential to contribute to the enhancement of anode top covering measurement in the aluminium electrolysis industry by improving productivity, reducing costs, and promoting safer working conditions through minimising the need of human intervention in harsh potline environment conditions.

2. Background of Anode Top Covering and its Measurement in Smelters

The process of aluminium electrolysis involves the electrolytic reduction of alumina (Al_2O_3) into aluminium metal in electrolysis cells or pots containing a molten electrolyte mixture mainly composed of cryolite (Na_3AlF_6), aluminium fluoride (AlF_3), calcium fluoride (CaF_2) and alumina. Figure 1 illustrates an electrolysis cell configuration. Carbon anodes are submerged in the electrolyte, and a high electric current is passed through the anode, causing dissolved alumina to be reduced to aluminium at the cathode, which is then collected at the bottom of the cell [2].

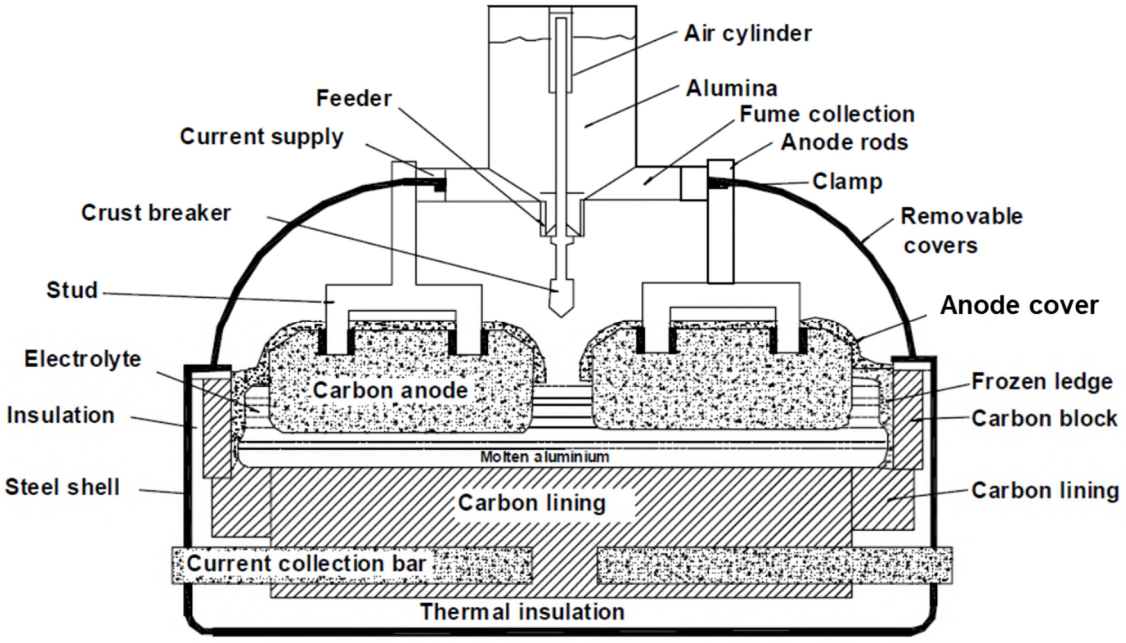

Figure 1. Aluminium electrolysis cell with anode cover, modified from [3].

The thickness of the anode cover, which is a layer of crushed bath and alumina, plays a vital role in the efficiency of the aluminium smelting process [1]. The anode cover layer serves several purposes, including reducing heat loss from the cell, protecting anodes from air oxidation, minimising the release of harmful emissions, and maintaining an optimal temperature within the cell [1]. Accurate measurement of the anode cover thickness is crucial for maintaining optimal cell conditions, which in turn enables timely adjustments to the cover layer, ensuring efficient energy allocation and reducing the environmental impact of the smelting process.

Traditional methods of anode cover thickness measurement involve manual inspections, where operators visually assess the cover layer and use physical tools such as increment-based scale or rods to determine its thickness. These methods present several limitations:

- Labour-intensive: Manual inspections require significant human effort and are time-consuming, leading to reduced operational efficiency.

11. References

1. Mark P Taylor, Anode cover material – science, practice and future needs, *Ninth Australasian Aluminium Smelting Technology Conference and Workshops*, Terrigal, Australia, 4-9 November 2007, Paper 11.
2. Halvor Kvande and Per Arne Drabløs, The aluminum smelting process and innovative alternative technologies, *Journal of Occupational and Environmental Medicine,* Vol. 56 May Suppl 2014, S23-S32. https://doi.org/10.1097/JOM.0000000000000062 .
3. Shiva Prasad, Studies on the Hall-Heroult aluminum electrowinning process, *Journal of the Brazilian Chemical Society,* Vol. 11 No. 3 2000, 245-251.
4. American University in Dubai team wins EGA's latest Al Robot competition, EGA News 29 March 2023, https://media.ega.ae/american-university-in-dubai-team-wins-egas-latest-al-robot-competition/ , retrieved on 4 May 2023.
5. Rikiwa Yamashita, et al., Convolutional neural networks: an overview and application in radiology, *Insights Into Imaging* 9 2018, 611-629.
6. Salerh Albelwi and Ausif Mahmood, A framework for designing the architectures of deep convolutional neural networks, *Entropy* 19.6 2017, 242.
7. Xu Han et al., Pre-trained models: Past, present and future, *AI Open* 2 2021, 225-250.