Application and Prospects of Optical Fibre Measurement Technology for Current Distribution in Aluminium Electrolysis Cells

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Abstract

The anode/cathode current distribution in aluminium electrolysis cells represents the most comprehensive and sensitive information, which can be used for precise control of alumina feeding and cell condition diagnosis. However, due to high temperatures, strong electromagnetic interference, and complex structures, accurately measuring current distribution has become a significant technical challenge in the aluminium electrolysis industry. This paper compares several existing current measurement technologies and explains, from a theoretical perspective, why optical fibre current sensors can achieve accurate measurement of current distribution in aluminium electrolysis cells. To address the needs of single-point inspection and multi-point online measurement of anode/cathode current distribution in electrolysis cells, several measurement technical solutions are proposed and tested. These tests demonstrate a very good accuracy of the measurement performed with optical fibre current sensors, providing a feasible solution for achieving digital, intelligent, and precise control and management of electrolysis cells.

Keywords: Aluminium electrolysis cell, Current distribution, Anode current, Cathode current, Online monitoring.

1. Introduction

Current distribution in aluminium reduction cells is a critical design parameter. Liang and Liang [1] investigated the relationship between cathode current distribution and cell lifespan, noting that the melting of steel bars in the cathode by high-temperature molten aluminium serves as a key indicator of cell failure. Dynamic monitoring of cathode current distribution can provide real-time insights into the operational status of these steel bars. Modern aluminium electrolysis cells are trending toward higher current intensities, with line currents reaching 600 kA. However, control strategies for these cells remain rooted in line current and cell voltage regulation—a methodology first adopted in the 1960s [2]. The combination of larger cell sizes and traditional control methods exacerbates issues such as uneven alumina concentration, persistent low-voltage anode effects, reduced current efficiency, and PFC emissions. Research demonstrates that measuring anode current distribution to infer localized alumina concentration, coupled with zone-specific feeding control, can enhance alumina uniformity and improve current efficiency [3]. Thus, monitoring current distributions at both cathodes and anodes is vital for prolonging cell lifespan, stabilizing process conditions, and optimizing electrolysis efficiency.

Potocnik and Reverdy [2] outlined two established current measurement techniques: the voltage drop method and Hall sensor-based approaches. Wong et al. [4] recently reported advancements in the voltage drop method, while Liang and Liang [1] developed a cathode measurement device using Hall sensors. Wang et al. [5] pioneered the application of fibre-optic current sensors (FOCS) for measuring anode currents in 400 kA cells. By winding optical fibres around conductors and integrating reflectors with quarter-wave plates to form closed magneto-optic loops, they achieved current measurements with ±0.2 % accuracy. Using a portable FOCS to sequentially measure multiple anode currents under asynchronous conditions, the sum of all measured anode currents deviated by less than 2 % from the total line current. Li et al. [6] further developed a handheld fibre-optic instrument for measuring currents in riser busbars and cathode flexibles. Yi Meng et al. [7] proposed an FOCS-based solution for online monitoring of anode and zonal currents.

Since the initial publication of this work [5], we have focused on advancing FOCS technology for current distribution measurements in aluminium electrolysis cells, continuously refining methodologies and significantly reducing sensor costs. This paper presents technical solutions for single-point detection and multi-point online monitoring of anode/cathode current distributions, supported by application case and measurement results. Our findings demonstrate the superior accuracy of fibre-optic current sensing, offering a viable pathway toward digitized, intelligent, precision control and management of electrolysis cells.

2. Status of Current Distribution Measurement Technology

Current Distribution measurement in electrolytic cells faces several key challenges: First, the complex magnetic fields around the measured current cause significant interference with sensors. Second, the high ambient temperature severely impacts sensor reliability and accuracy. Third, sensor installation must avoid interference from periodic anode replacement. The following analyses the working principles and advantages of three potential solutions: equidistant voltage drop measurement, Hall-effect sensors, and fibre-optic current sensors.

2.1 Equidistant Voltage Drop Method

The measurement principle of the Equidistant Voltage Drop Method is based on Ohm's Law. Taking the anode rod current measurement model shown in Figure 1 (Left) as an example, this method directly measures the voltage drop across a specific length of the anode rod. By combining this with the rod resistance, the anode current (I_a) flowing through the rod can be calculated with Equation (1) [8].

$$I_a = \frac{V_1 - V_2}{R_a} = \frac{V_1 - V_2}{\rho \, {}^{L}\!/_{S}} \tag{1}$$

where:

I_a	Anode current, A
$V_1 - V_2$	Measured voltage drop between the two pins of voltage measurement fork, V
R_a	Calculated resistance of the conductor segment, Ω
ρ	Resistivity of the aluminium conductor (which varies with temperature), Ω·m
L	Length between the measurement pins, m
S	Cross-sectional area of the aluminium conductor, m²

In practical applications, however, measurement accuracy is limited to approximately 10 % or even lower due to factors such as:

- Surface oxidation of the conductor rod,
- Poor electrical contacts,

In the future, at least the following research efforts will be conducted:

1) Portable current measurement devices will be more widely adopted for current distribution measurements in electrolytic cells. These devices can effectively monitor electrolysis parameters, optimize process conditions, identify damaged sections of electrolytic cells for repair, and extend cell service life.
2) Online monitoring systems for cathode and anode currents will enable the establishment of long-term operational databases for electrolytic cells. The collected data will support in-depth research on the electrolysis process, providing a foundation for advanced functions such as intelligent operation and health management of electrolytic cells.
3) Regional current online monitoring systems, with more cost-effective implementation, will integrate with cell control systems to deliver precise alumina feeding. This advancement will enhance electrolysis efficiency and reduce carbon emissions – a highly promising development.

6. References

1. H. Liang and S.J. Liang, Visualization of cathode current distribution in aluminum pots, *Light Metals* 2020, No.5,30–37 (Chinese).
2. Vinko Potocnik and Michel Reverdy, History of computer control of aluminum reduction cells, *Light Metals* 2021, 591-599, https://doi.org/10.1007/978-3-030-65396-5_81
3. Joan Boulanger et al., Imaging alumina distribution using low-voltage anode effect detections in anodic current, *Light Metals* 2022, 331-338, https://doi.org/10.1007/978-3-030-92529-1_46.
4. Choon-Jie Wong et al., A smart individual anode current measurement system and its applications, *Light Metals* 2023, 43-51, https://doi.org/10.1007/978-3-031-22532-1_6.
5. Yongliang Wang et al., Testing and characterization of anode current in aluminum reduction cells, *Metallurgical and Materials Transactions B*, 2016, 47, 1986-1998, https://doi.org/10.1007/s11663-016-0632-y.
6. J.G. Li et al., Research on the handheld fiber-optic current sensor for aluminum electrolysis current measurement, *Chinese Journal of Scientific Instrument*, 2022, 43(12), 39-48.
7. Yi Meng et al., Accurate measurement of anode current in aluminum electrolysis: from ideal to reality, *Light Metals* 2024, 586-595, https://doi.org/10.1007/978-3-031-50308-5_75.
8. S. Yang et al., Anode current measurement for aluminum reduction cell based on equidistant voltage drop at anode beam, *Nonferrous Metals Engineering*, 2019, 9(12), 62-68 (Chinese).
9. Z.F. Zhang et al., Measurement of magnetic fields of individual anode current based on magnetic shielding ring in aluminum reduction, *Nonferrous Metals (Extractive Metallurgy)*, 2015(10), 44-48 (Chinese).
10. Guido Frosio and René Dändliker, Reciprocal reflection interferometer for a fiber-optic Faraday current sensor, *Applied Optics*, 1994, 33(25), 6111-6122, https://doi.org/10.1364/ao.33.006111.
11. L.J. Wang and J. Hu, Development and application of high DC fiber optic current detection system, *Shandong Metallurgy* 2017, 39(01): 69-70 (Chinese).
12. J. Tie, R.T. Zhao and Z.F. Zhang, Accurate measurement and its application of anodic current in aluminium electrolysis, *Metallurgical Industry Automation*, 2018, 42(01), 49-53 (Chinese).
13. J.L. Yi et al., Application exploration of optical current measuring instrument on 400kA electrolytic cell, *Yunnan Metallurgy*, 2022, 51(02), 171-177 (Chinese).
14. J. Tie et al., Regional anode current measurement system and electrolytic cell measurement system based on single fiber optic ring, CN 2023109487869, 2023.07.31