Demand-Based Feeding Control for Different Zones in Aluminium Reduction Cell to Improve Uniformity of Alumina Concentration

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Abstract

The spatial uniformity of alumina concentration distribution is one of the major challenges faced in the production control of high-amperage reduction cells. Due to the lack of accurate distributed current information, feeding control in reduction cells nowadays still relies on cell resistance changes derived from cell voltage and line current, making it difficult to validate and practically apply any soft measurement strategies for alumina concentration. Based on the current distribution information provided by the precise zone current measurement method developed by our team, this paper introduces several alumina feeding control strategies based on zone resistance changes, including: an improved trigger criterion for stage switching between overfeeding and underfeeding, taking into account zone resistances, thus keeping alumina within a narrower concentration band; and a demand-based feeding strategy featuring dynamic nested control, where underfeeding/overfeeding stages are independently adjusted for each zone, to achieve uniform control of alumina concentration between zones.

Keywords: Aluminum reduction cell, Demand-based feeding control, Zone resistance, Alumina concentration distribution.

1. Introduction

Driven by the need to pursue investment returns, newly constructed or retrofitted aluminum reduction cells are increasingly becoming larger in scale. The 500–600 kA cell type has become the mainstream now, with the number of anodes reaching 48–56 and the number of feeding zones increasing to 6–8. The length of the cells has extended to over 25 m, while the width remains about 4 m. To reduce energy consumption caused by the molten bath resistance, the anode-cathode distance (ACD) has been decreased from 5 cm to less than 4 cm. As a result, the height and volume of the bath have decreased, which in turn has a negative impact on its flow capacity, thus increasing the difficulty of alumina-feeding control.

As it is well-known, the uniform distribution of alumina concentration can improve the process stability of the cell and achieve higher current efficiency. Therefore, the number of feeding ports in large high-amperage cells has been increased to 6–8. Each feeder supplies alumina to 4–8 anodes. However, due to various factors, alumina concentration distribution still varies greatly in large cells, indicating poorer control than in smaller cells [1].

In particular, the prevalent feeding control strategies used in today's large high-amperage cells still rely on cell resistance changes derived from cell voltage and line current. In these strategies, it is assumed that the alumina consumption rate is the same in different feeding zones, and thus the alumina feed rate in each zone is set to be equal. This is the biggest reason for the poor control of alumina concentration in these cells. An important way to solve this problem is to know the alumina consumption rate in each zone in real time. That means detecting the current of anodes in each zone and feeding alumina on demand based on the zone currents.

The measurement of zone currents can be obtained by summing up the currents of each anode within that zone. However, conventional methods such as the voltage drop method [2, 3] and the Hall sensors method with a matrix structure [4, 5] are difficult to provide accurate zone currents for the control system due to significant measurement errors. Wang et al. [6] were the first to report the precise measurement of anode current using a Fiber-Optic Current Sensor (FOCS). But this method was limited to single point measurement research [7–9] because of the high cost [10]. In 2023, by bending the optical fibre loop to form a saddle-shaped structure, it became possible to accurately measure the currents of any number of anodes using one single optical fibre loop [11, 12]. This significantly reduced the cost and laid an economically feasible technical foundation for demand-based feeding control for different zones in aluminium reduction cells.

This paper first theoretically justifies the use of one saddle-shaped sensing optical fibre loop to measure the individual anode current or zone current, based on the principle of Ampère's circuital law that the circulation (line integral of magnetic field) is independent of both the shape of the integration path and the shape of the current-carrying conductors enclosed within the loop. Then several alumina feeding control strategies based on zone current changes are introduced, especially a demand-based control strategy of independent feeding for each zone.

1.1 Theoretical Explanation of Measuring Anode and Zone Current Using FOCS

Ziegler et al. [13] introduced the basic principles of FOCS, pointing out that by forming a closed optical path, the interference of background magnetic fields can be effectively eliminated. This makes the FOCS particularly suitable for current measurement of conductive bodies such as anodes in the aluminium reduction cell environment. Bohnert et al. [14] from ABB company were the first to report the precise measurement of the line current of a 500-kA reduction cell using a FOCS. Reports on the application of FOCS in anode current measurement came later [6, 10]. In particular, by bending the sensing optical fiber loop into a saddle-shaped structure, it can be easily installed onto the anode beam for online measurement of both individual anode current and zone current without affecting production operations such as anode changing [11, 12]. Both numerical simulations [15] and paired tests on industrial cells [12] have verified the accuracy of measurements using this saddle – shaped FOCS. In fact, this saddle – shaped structure was designed based on two important yet often overlooked characteristics of Ampère's circuital law: the line integral of the magnetic field around the closed loop is independent of the integration path's shape and the measured conductor's shape. Below, a further theoretical explanation of these two characteristics is provided.

According to the principle of Faraday magneto-optic effect, the magnetic deflection angle of the polarization plane, i.e., the magnetic rotation angle θ transmitted in a closed optical fibre loop is given by the following Formula (1):

$$\theta = NV \oint_L \boldsymbol{H} \cdot d\boldsymbol{l} \tag{1}$$

where:

θ Magnetic rotation angle, rad

N Number of turns

V Verdet constant of the optical medium, rad/A

$\boldsymbol{H}$ Magnetic field strength A/m corresponding relationship between the limits of cell resistance-related parameters and zone resistance-related parameters, and what this relationship is, remains to be further studied.

(3) Optimization of the underfeeding and overfeeding coefficients (α and β)

Clearly, the values of the coefficients α and β in feeding strategies with zonal dynamic nested control shown in Figures 4 and 5 will still be empirical, dynamic parameters to adapt to different cell types and raw alumina sources. Optimizing these coefficients is also one of the key points to achieve good results when applying these control strategies.

(4) Online estimation of the alumina concentration for different zones

The research on the online estimation of spatial alumina concentration using the multi-level REKF method presented by Bao et al. [19, 21–23] from The University of New South Wales is of great value, especially when the zone currents can be accurately measured. Not only can the estimated results be used to dynamically track the feeding control effect but also, based on the change trends of zone resistance and alumina concentration, diagnose the possible long-term feeder deviation problems.

Finally, in recent years, an increasing number of aluminum smelters in China have been upgrading their alumina feeding systems to enable independent single-point feeding. Consequently, during anode changing, the amount of alumina fed can be reduced based on practical experience, thereby minimizing the potential for sludge formation, and good results have been achieved [24]. These efforts have provided a good basis for the promotion of the alumina feeding control strategies proposed in this paper.

3. Conclusions and Suggestions

1) Both theoretical studies and industrial experiments have shown that the fibre-optic current sensing measurement technology is applicable for the online measurement of zone anode currents, and at present, it stands as the sole available approach.
2) Incorporating zone resistance information into the feeding control system can prevent the emergence of extreme scenarios and optimize the prevalent control strategy.
3) The uniformity of alumina concentration will be achieved by using demand-based feeding strategy with zonal dynamic nested control

With the funding support from a science and technology major project in Guangxi province, the strategies proposed in this paper will undergo industrial test research at Guangxi Tianlin Baikuang Aluminum Industry Co., Ltd. The feasibility will be verified, and the experimental results will be gradually presented in future papers.

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