Stability of 500 kA Cells with Graphitized Cathodes and Copper-Insert Collector Bars During Early Operation

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https://doi.org/10.71659/icsoba2025-al017

Abstract

This paper analyses the issues of high noise, significant voltage deviations, and unstable performance observed during early operation of a 500 kA fully graphitized cathode aluminium reduction cell with copper-insert collector bars in a smelter. It further elaborates on the innovative control measures implemented and their corresponding effectiveness. These measures have significantly improved cell stability, reduced energy consumption, and ensured efficient and stable operation of the cells. Furthermore, the innovation and feasibility of using these control methods have been explored.

Keywords: Fully graphitized cathode, Copper-insert cathode collector bar, Aluminium reduction cell, Early operation of cells, Cell stability.

1. Introduction

In the production of electrolytic aluminium, the stable operation of the cells directly impacts production efficiency, energy consumption, and product quality. The early operation period (the post-start-up adjustment phase of about three months) is a critical transition stage for forming a regular ledge. The extent to which technical and economic indicators are met at this stage will have a significant impact on the service life of the cell and the subsequent stability of normal production operations.

Operational data from a smelter revealed significant anomalies during the first month of 500 kA fully graphitized cathode cells with copper-insert collector bars: (1) voltage oscillation noise reaching 50–60 mV, (2) voltage deviations exceeding 150 mV, and (3) degradation of cell stability. These issues led to higher power consumption, intensified thermal shocks to the potshell bottom/sidewalls, and compromised ledge integrity, adversely impacting subsequent performance. Although fully graphitized cathode cells with ordinary steel collector bars also face similar issues, the copper-insert collector bar structure exacerbates the problem due to its higher electrical conductivity and heat dissipation properties. This inherent incompatibility with conventional abnormal phase management strategies urgently demands the establishment of refined and differentiated control solutions. This study is of significant practical value for achieving safe, stable, and efficient operation of the cells.

This work was supported by references [1-6].

2. Fully Graphitized Cathode with Copper-Insert Collector Bars

The fully graphitized cathode with copper insert collector bars for aluminium reduction cells is an innovative technology that significantly enhances cell performance by combining the high electrical and thermal conductivity of fully graphitized cathodes with the composite structural advantages of copper-insert collector bars. The fully graphitized cathode has superior electrical and thermal conductivity, effectively reducing cathode resistance and decreasing energy loss, thereby improving current efficiency. Meanwhile, its uniform thermal conductivity helps stabilize the cell thermal equilibrium, mitigating risks of localized overheating and enhancing operational stability. The copper-insert collector bars employ a copper-steel composite structure, where the high conductivity of copper further reduces cathode resistance to improve current transmission efficiency, and the steel matrix provides sufficient mechanical strength to ensure structural stability of the cell cathode. This design reduces energy consumption while enhancing the durability of cells. The fully graphitized cathode incorporating copper-insert collector bars in the cells integrates the benefits of enhanced energy efficiency, prolonged cell lifespan, and improved production efficiency, thereby providing a novel technological approach for optimizing the aluminium electrolysis process.

3. Factors Affecting Stability During Early Operation

3.1 Management During the Cell Preheat

During the cell preheat, uneven preheat temperatures can lead to temperature variations within the cell ledge after startup, which is a critical factor affecting cell stability. Non-uniform temperature distribution may cause inconsistent expansion of the lining materials, which may induce internal stress and compromise the structural integrity and operational stability of the cell. It is noteworthy that the fully graphitized cathode with copper-insert collector bars, due to its superior electrical conductivity, is more sensitive to the uniformity of coke particle paving and the building of conductive networks during preheat. If not handled properly, its inherently higher current density may exacerbate risks of localized overheating or insufficient heating, requiring stricter preheat uniformity control compared to conventional steel collector bar cathodes.

3.2 Poor Management During the Initial Startup Phase

Improper initial voltage, bath height, and material replenishment procedures result in insufficient preheat of the cathode lining. Inadequate cathode lining preheat adversely affects its electrical conductivity and structural strength, leading to operational anomalies such as voltage fluctuations and uneven current distribution, thereby compromising the cell stability.

3.3 Deficiencies in Operational Quality Control

A large amount of carbon dust not being promptly removed after startup leads to carbon-contaminated bath, increased bath voltage drop, and compressed anode-to-cathode distance (ACD). The presence of carbon dust increases bath resistance, reduces current efficiency, adversely affects uniform current distribution, and exacerbates cell instability.

3.4 Ledge Formation Failure and Related Issues

The newly installed cells lack well-formed ledge, resulting in high horizontal current density, elevated noise, and poor stability. After anode replacement, irregular current distribution and anode current deviation further exacerbate the instability of the cell. The ledge plays a critical role in stable cell operation by protecting the lining, reducing heat loss, and stabilizing current distribution. Inadequate ledge formation disrupts the thermal equilibrium and current distribution, adversely affecting the stability of the cell. The high conductivity of copper-insert collector bars of fully graphitized cathodes may lead to more uneven horizontal current density distribution before complete ledge formation, potentially causing more pronounced magnetic field fluctuations and cell stability issues (such as voltage oscillation) during the startup phase compared to conventional steel collector bar cathodes.

4. Management and Control During Cell Early Operation

4.1 Key Operational Controls for Cell Preheat

For the optimization of coke particle ratio, due to differences in cathode conductivity and heat dissipation compared to other cell types, continuous trials have been made to determine the optimal coke ratio. A 2 to 8 graphite-to-coke particle ratio is applied specifically at the four corner anode blocks, while pure coke particles are used in all other areas. This targeted adjustment for corner zones is implemented to accommodate the unique thermal and electrical conduction properties of fully graphitized cathodes with copper-insert collector bars. Compared to conventional steel collector bar cathode cells, the new design features enhanced overall thermal conductivity and stronger corner heat dissipation, thereby requiring less coke particle coverage at the corners to ensure a more balanced preheat temperature across the entire ledge, particularly in the corners. The temperature rise during cell ledge preheating is uniform and normal, as shown in the figure below. The curve represents a typical optimized preheat profile for a fully graphitized cathode cell with copper-insert collector bars. As a comparison, cells of conventional fully graphitized cathodes paired with ordinary steel collector bars under the same initial coke ratio (2:8 for corners) often exhibit delayed corner heating (temperature curves below the average).

Simultaneously, dedicated personnel monitor and adjust key operations such as anode rod installation, flexible busbar connection, and shunt installation to ensure uniform current distribution across all anode groups after energization and achieve homogeneous cell preheat, thereby minimizing temperature differentials of the areas. By strictly controlling these critical processes, preheat quality can be effectively improved, laying a solid foundation for stable cell operation.

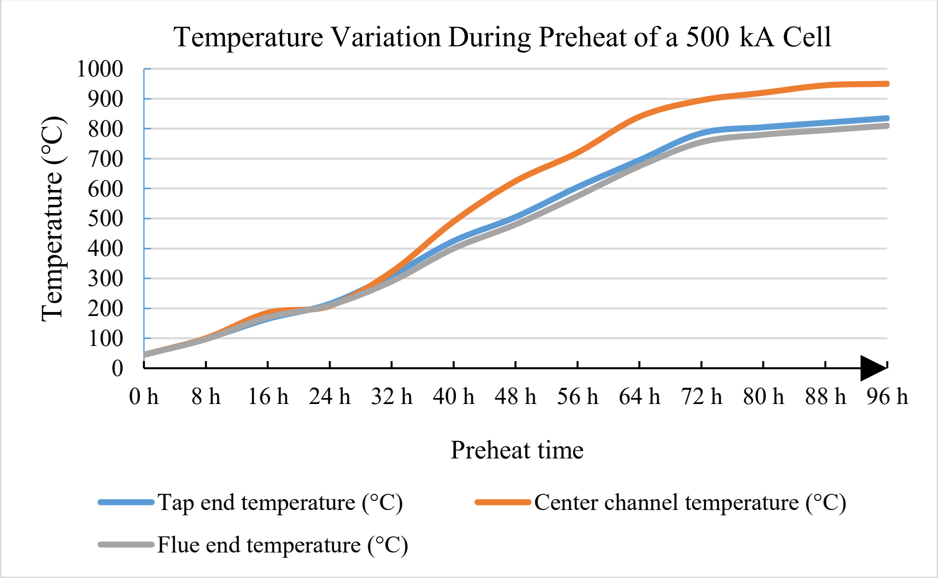

Figure 1. Ledge heating curve (non-standard curve).

4.2 Standardized Operating Parameter Management

Statistical analysis is conducted on well-performing startup cell data to identify appropriate management protocols. Strict process control is then implemented for newly started cells regarding voltage, bath height, and material replenishment according to established standards. For instance, voltage is precisely regulated at different time points (as shown in Table 1), while parameters including metal height, bath height, electrolysis temperature, molecular ratio, and bottom voltage drop are managed through weekly refined control (as shown in Table 2). The cells with copper-insert collector bar cathode have lower cathode voltage drop and superior overall conductivity, theoretically enabling a marginally lower operating voltage compared to conventional steel collector bars at the same ACD. This specification incorporates operational optimizations, proposing a more aggressive reduction in the set voltage of cells with copper-insert collector bars after metal pouring, to facilitate ledge formation and reduce energy consumption. The parameters in Table 2 serve as universal baseline standards. For fully graphitized cathode cells with copper-insert collector bars, special attention must be paid to the following: Due to their significantly reduced cathode voltage drop (refer to the difference in cell bottom voltage drop requirements), the actual ACD becomes relatively larger under the same set voltage. This necessitates more precise regulation of energy balance by closely monitoring bath height, temperature, and other parameters in conjunction with real-time cell bottom voltage drop data, to avoid improper superheat conditions that may affect the formation rate and quality of the ledge. Compared to cells with conventional steel collector bars, the new design demands higher stability in molecular ratio and temperature to match its enhanced heat transfer and current efficiency potential.

Table 1. Voltage adjustment in the first month of cell operation.

Time Point	Set voltage (V)	
	Conventional steel collector bar	Copper-insert collector bar
After startup (after bath filling)	6–8	6–8
8 h after startup	5.5–6.5	5.5–6.5
8 h after startup - Before metal pouring	4.8–5.5	4.8–5.5
After metal pouring completion	4.8–4.5	4.8–4.5
Day 2 after metal pouring	4.4	4.40
Day 3	4.35	4.30
Day 4	4.30	4.20
Day 5	4.25	4.15
Day 6	4.20	4.10
Day 7	4.15	4.08
Day 8	4.10	4.06
Days 9–15	4.10–4.04	4.04–3.95
Days 16–30	4.04–3.95	3.95–3.90

Table 2. Standard levels for two interfaces during initial metal pouring.

Item	Week 1	Week 2	Week 3	Week 4
Metal height (cm)	18–20	18–21	18–22	19–22
Bath height (cm)	25–32	24–32	23–32	23–32
Electrolysis temperature (°C)	970–990	970–985	965–980	965–980
Molecular ratio	≥ 3.0	≥ 2.9	≥ 2.8	≥ 2.8
Conventional steel collector bars - Cell cathode voltage drop (mV)	≤ 235	≤ 235	≤ 235	≤ 235
Copper-insert collector bars - Cell cathode voltage drop (mV)	≤ 180	≤ 180	≤ 180	≤ 180

4.3 Carbon Dust Removal and Bath Purification

A specialized labour competition is established to comprehensively remove newly generated carbon dust from startup cells, purifying the bath and reducing bath voltage drop. For cells with contaminated bath, measures such as adding cryolite or crushed bath are implemented to lower temperatures and replace the bath. By reducing the bath voltage drop, cell voltage is decreased, thereby releasing ACD. This enhances electrolysis efficiency, minimizes voltage fluctuations, and improves cell stability.

4.4 Quality Control and Improvement in Operations

It is necessary to strictly enforce the quality control of anode replacement in newly started cells. Anodes should be replaced within 3 days after cell startup, ensuring an 8-hour minimum interval between anode replacement and aluminium producing in the same cell. During anode replacement, it is necessary to strengthen the setting of new anodes, monitor current distribution shift-by-shift, and adjust anodes with abnormally distributed current to ensure uniform current distribution, guaranteeing that new anode conductivity reaches the qualified range in 16 hours. In addition, it is necessary to perform quantitative carbon dust removal. Since the cells are started using coke particle preheat, excessive carbon dust accumulates; thus, intensified carbon dust removal is essential to mitigate its adverse effects on cell stability.

4.5 Voltage Control Innovation

To address the issues of big noises and easy voltage deviation from the setpoint during the early phase of fully graphitized cathode cells with copper-insert collector bars, conventional practices such as maintaining a slightly higher voltage for stability (suitable for ordinary cells) are abandoned. Instead, an innovative approach avoiding reliance on elevated voltages to stabilize the cell is adopted. It involves temporarily disconnecting the RC and gradually stepping down the voltage toward the target value. Once stable operation is achieved, the RC is reconnected for autonomous control. By regulating voltage to reduce energy input, this strategy promotes ledge formation and enhances the cell's disturbance resistance. This innovative voltage control method not only reduces energy consumption but also improves cell stability and robustness against disturbances. This refined voltage control strategy fully utilizes the voltage margin provided by the low electrical resistance of copper-insert collector bar cathodes, achieving a lower average operating voltage while ensuring stability, which is a performance benchmark difficult for conventional steel collector bar cathode cells to match due to their higher cathode voltage drop.

5. Effect of Management and Maintenance during Early Periods

5.1 Noise Control

Through the implementation of various measures, the noise value during the early period of new cells has been controlled within 40 mV, effectively reducing its impact on the production environment. This also indicates a significant improvement in the operational stability of the cells, demonstrating that the new measures have effectively addressed the prominent noise issue specific to the new cell design. As shown in Figures 2 and 3, a clear reduction in cell noise can be visually observed.

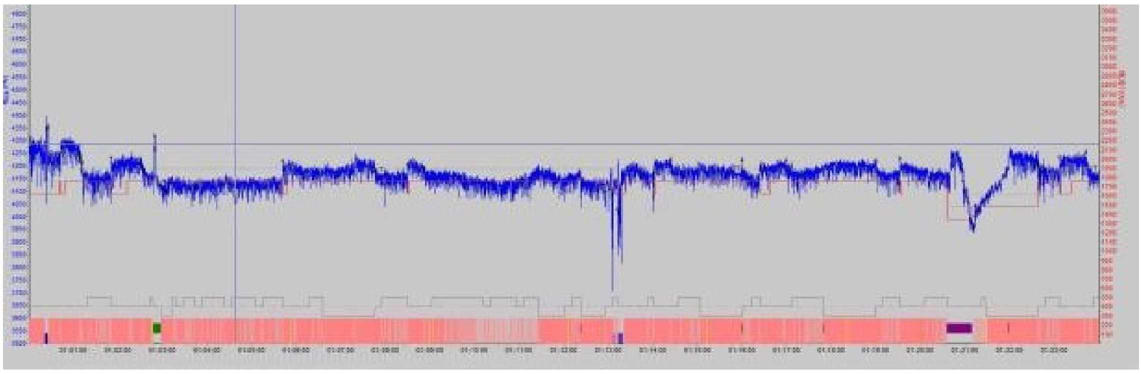

Figure 2. Noise of fully graphitized cathode cells with copper-insert collector bars before improvement.

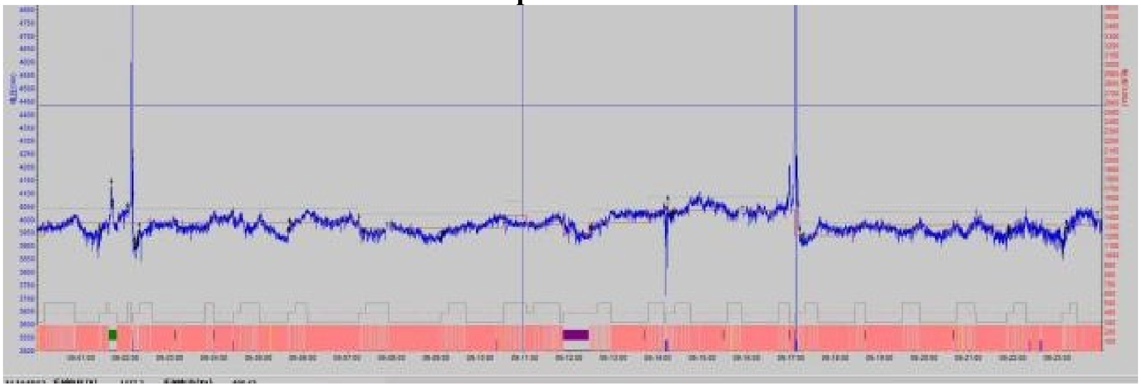

Figure 3. Noise of fully graphitized cathode cells with copper-insert collector bars after improvement.

5.2 Control on Voltage Deviation

The voltage deviation of new cells is controlled within 50 mV, achieving a reduction of approximately 100 mV in operating voltage compared to the pre-improvement status. This not only mitigates voltage fluctuation induced damage to the cells but also delivers significant energy-saving benefits.

Table 3. Voltage operation statistics of two cells before improvement.

Cell No.	Cell age/days	5	15	30
602	Set voltage/V	4.250	4.140	4.040
	Operating voltage/V	4.437	4.295	4.198
	Voltage deviation/mV	187	155	158
529	Set voltage/V	4.269	4.029	3.920
	Operating voltage/V	4.379	4.153	4.062
	Voltage deviation/mV	110	124	142

It can be seen from the statistical data before improvement that when no measures are taken, the cell operating voltage is high and the voltage deviation is large, resulting in difficult reduction of the voltage of new cells, such as Cell 602; Secondly, even if the voltage is dropped to the set value, the operating voltage is still high and the voltage deviation is large, resulting in the increase of power consumption, such as Cell 529.

Table 4. Voltage operation statistics of two cells after improvement.

Cell No.	Cell age/days	5	15	30
607	Set voltage/V	4.273	4.070	3.933
	Operating voltage/V	4.422	4.140	3.947
	Voltage deviation/mV	149	70	14
228	Set voltage/V	4.274	4.067	3.920
	Operating voltage/V	4.389	4.132	3.954
	Voltage deviation/mV	115	65	34

According to the enhanced statistical data, following the implementation of the improvement measures, the cell operating voltage decreased significantly compared to the pre-improvement values. Particularly after the cell age reached 10 days, both the working voltage and voltage deviation fell within the acceptable range, showing a reduction of over 100 mV from the initial values. These results indicate a favourable improvement effect.

5.3 Improvement of Ledge Regularity and Stability

The stability of the new cell has been significantly improved, ensuring the formation of a well-structured ledge and laying a solid foundation for efficient long-term operation. A stable ledge structure facilitates uniform current distribution and effective heat transfer, thereby enhancing production efficiency and product quality in the cell. Through refined management tailored to the characteristics of fully graphitized cathode cells with copper-insert collector bars, their stability during the early period is notably superior to that of conventionally managed cells of the same type, as well as that of fully graphitized cathode cells with ordinary steel collector bars during same periods. This creates favourable conditions for the rapid formation of a regular and robust ledge in the new-design cells and serves as the key foundation for their subsequent efficient and long-life operation.

6. Conclusion

A smelter implemented a series of innovative management and control measures to address issues during the early operation period of 500 kA fully graphitized cathode cells with copper-insert collector bars. The effectiveness of these measures, particularly innovative voltage regulation, enhanced carbon dust removal, and optimized graphite-coke particle ratio during preheat, has been thoroughly validated through comparative analysis of data from traditional cells in the same smelter as well as pre-improvement data from the new cells. This approach provides a proven solution for the early period management of large-scale fully graphitized cathode cells with copper-insert collector bars, while also offering valuable insights for optimizing other cell types. In future electrolytic aluminium production, these innovative practices can serve as a reference for other enterprises, contributing to technological advancement and sustainable development in the industry.

7. References

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