Application of Energy-Saving Anode Yokes in 500 kA Aluminium Reduction Cells

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Abstract

Anode voltage drop is an important component of the overall electrolytic cell voltage drop, and reducing the voltage drop of the steel yoke is significant for lowering the anode voltage drop. Currently, conventional yokes in aluminium electrolysis suffer from problems such as high resistance, high energy consumption, vulnerability to oxidation and corrosion at high temperatures, and continuous reduction in the diameter of the steel stubs. This paper describes the disadvantages of traditional steel yokes, compares the industrial test results of several new energy-saving anode yokes, and statistically analyses their voltage drop and mechanical stress. The results show that the voltage drop of new energy-saving yokes is generally lower than that of traditional ones, and the corresponding reduction in DC energy consumption per tonne of aluminium is significant for energy-saving and carbon emission mitigation in aluminium reduction cells.

Keywords: 500 kA aluminium reduction cell, Energy-saving steel yoke, Steel yoke voltage drop, Energy saving and consumption reduction.

1. Introduction

Electricity cost accounts for 30–40 % of the total production cost in aluminium electrolysis, a major industrial power consumer. Under the national dual-carbon policy and tiered electricity pricing system, reducing the energy consumption of the potlines, optimizing resource use, and achieving cost reduction and efficiency improvement are urgent tasks for aluminium smelters. Reducing the average electrolytic cell voltage and improving current efficiency can both help decrease power consumption in electrolytic cells [1].

Currently, major aluminium smelters are using larger cells, with their current efficiency approaching optimal levels, making further breakthroughs difficult; thus, reducing the average cell voltage has become the main research direction for smelters and academic institutions. To reduce the average cell voltage, the focus should be placed on both cathode and anode voltage drops. Cathode blocks have evolved from partially graphitic, 100 % graphitic, semi-graphitized and fully graphitized, to fully graphitized with copper inserts, lowering cathode voltage drop to about 160 mV, roughly 150 mV lower than the traditional graphitic cathode, but further reduction faces a bottleneck. The anode yoke with stubs for aluminium reduction cells, in contrast, exhibit high voltage drop, offering greater potential for energy savings.

2. Current Status of Traditional Anode Yokes

The anode yoke for the cells is a key structural component connecting the anode rod to the anode carbon block [2]. In terms of conductivity, the anode yokes with stubs must carry the high current of the cells. In a 500 kA cell, each yoke carries around 10 000 A on average, requiring good conductivity. In terms of mechanical performance, the anode yoke connects the aluminium rod and the anode carbon block [3, 4], which weighs about 1300 kg and operates at high temperature, requiring the anode yoke to have sufficient strength and stiffness.

Currently, ZG200–400 cast carbon yokes are used in most domestic cells; these yokes have relatively low strength, and their deformation and failure rate during operation can reach as high as 20–35 % [4, 5]. Moreover, the traditional connection between aluminium anode rod and yoke is typically in the form of an explosion-welded transition clad, which forms three weld seams (Al–Al, steel–steel, Al–steel) between the rod and yoke, increasing resistance and voltage drop of the joint and thus raising energy consumption. Meanwhile, due to significant differences in thermal expansion coefficients between the explosion-welded steel-aluminium clads in the high-temperature electrolysis environment, large thermal stresses are generated. These stresses cause the interface to shear and crack easily, leading to high labour and cost for annual maintenance of the anode rod assemblies, which in turn increases electrolysis production costs. To address these issues, this project upgrades the structure and materials of anode yokes with stubs of the cells to reduce anode yoke and stub voltage drop, and contribute to lower overall cell energy consumption, and achieve comprehensive energy saving throughout the potline, resulting in energy conservation and emission reduction.

3. New Energy-Saving Yoke Technologies

3.1 Aluminium-Steel Direct Welding Technology

Aluminium-steel direct welding enables direct joining of aluminium and steel, as shown in Figure 1. It revolutionizes traditional welding methods, effectively overcoming limitations related to explosion clad quality and welder skill, achieving improved welding quality and contributing to energy saving in aluminium smelters. Key features of the new welding method are:

- Elimination of explosion-welded clads: enables direct Al-steel welding without the need for intermediate explosion clad;
- High welding efficiency: primary welding is performed by a robotic arm, offering high efficiency, consistency, and reliable quality;
- Energy conservation: results in two fewer weld seams, lowers the overall voltage drop, and supports energy conservation.

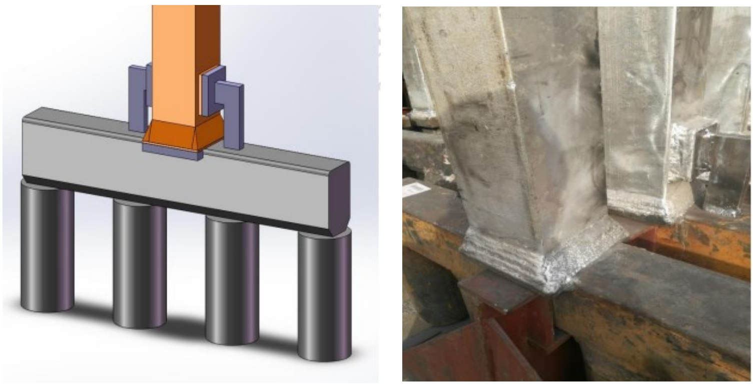

Figure 1. Aluminium-steel direct-welded yoke. Left: digital simulation, right: actual image.

3.2 Friction Welding Technology

Friction welding is a solid-state welding process commonly used for metal joining; as shown in Figure 2. Heat is generated by relative motion and friction between parts, combined with

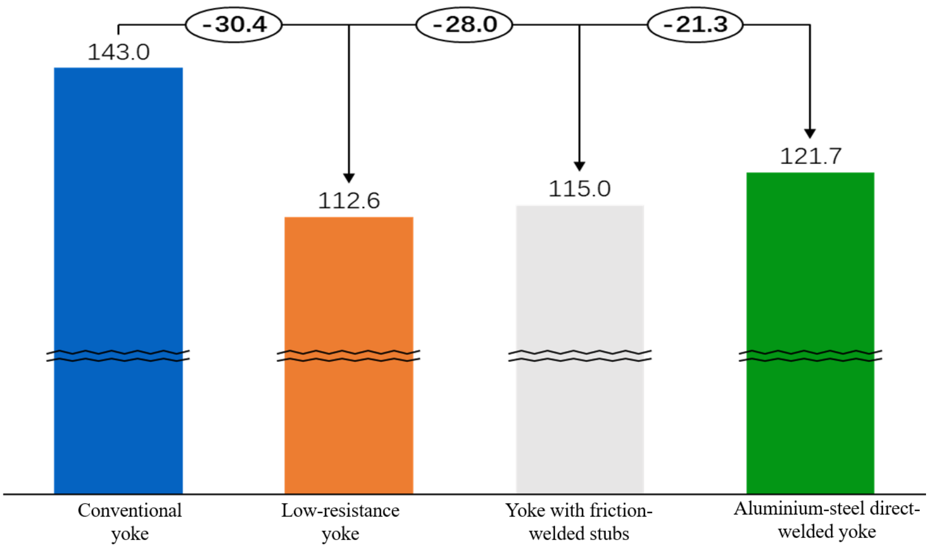

Figure 9. Comparison of voltage drop differences among various yokes in two measurements.

5. Conclusion

Since all three types of energy-saving anode yokes were introduced, the test cells have maintained stable operation and meet basic production requirements.

Throughout the test, the low-resistance yokes, yokes with friction-welded stubs, and aluminium-steel direct-welded yokes showed no signs of reddening or detachment, with good performance and no welding failures or rod breakages.

In terms of effectiveness, all three types of energy-saving yokes successfully reduced the anode assembly voltage drop. Among them, the low-resistance yoke delivered the best performance with a 30.4 mV reduction compared with the conventional yoke; the yoke with friction-welded stubs followed with a 28 mV reduction; and the aluminium-steel direct-welded yoke achieved a 21.3 mV reduction.

6. References

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