Development and Application of Aluminium-Steel Full-Section Direct Welding System for Cathode Voltage Drop Reduction

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Abstract

For long-running aluminium potlines, the connection methods between cathode collector bars and peripheral busbar in electrolytic cells face several pain points, including traditional welding of explosion-welded transition joints or compression connections, which suffer from multiple weld seams, unstable construction quality, and high on-site magnetic field intensity. These issues lead to increased voltage drop at the connection points, thereby raising the specific power consumption per tonne of aluminium. To address such issues, the Institute has jointly developed a cathode energy-saving and voltage drop aluminium-steel full-section direct welding system. This paper introduces the core functional modules of the system, including the fully automated aluminium-steel bimetallic welding and forming module, the multi-physical field test data cloud-based expert decision comparison system, and the high-magnetic full-current online quality optimization welding technology module. Through practical applications in 180–420 kA potlines, the system demonstrates a significant reduction in cathode connection voltage drop after precise optimization, with comparative analysis and conclusions drawn based on production data.

Keywords: Cathode collector bar, Aluminium-steel direct welding, Energy-saving and consumption reduction, In-situ welding.

1. Introduction

The aluminium reduction cell, as the core equipment in aluminium electrolysis production, has its conductive efficiency, thermal equilibrium, and operational lifespan directly influenced by the connection method of the cathode collector bar [1]. Although traditional welding technologies such as explosion welding and compression joints are widely used, they exhibit significant drawbacks [2].

Explosion welding achieves the bonding of dissimilar metals through instantaneous high-temperature, high-pressure, and high-energy impact, but the process control is complex and prone to the formation of interfacial brittle phases and residual stress [3, 4]. Brittle intermetallic compounds (e.g., $FeAl_3$, Fe_2Al_5, etc.) can significantly degrade the mechanical properties and conductive stability of the joint. During long-term operation, residual stress may induce crack propagation, severely compromising the safety and service life of the electrolytic cell. Mechanical compression joints, on the other hand, rely on physical contact fastening via bolts or hydraulic pressure, but they suffer from high contact resistance and susceptibility to oxidation. In high-temperature, highly corrosive environments within electrolytic cells, the crimped interface tends to loosen with increasing thermal cycles, leading to degraded conductivity, localized overheating, or even burn-through. This ultimately reduces electrolysis efficiency and increases energy consumption. Additionally, crimped structures incur high maintenance costs, requiring periodic tightening or replacement of connecting components, which complicates production management [5, 6].

To address the above issues, Guiyang Aluminium and Magnesium Design & Research Institute collaboratively developed aluminium-steel full-section direct welding system for cathode voltage drop reduction. This system ensures high conductivity while optimizing welding materials and process parameters, achieving high-quality aluminium-steel connections. It combines excellent mechanical strength with long-term operational stability, providing a novel solution for upgrading the cathode connection structure of aluminium reduction cells.

2. Description of System Module Composition

This cathode energy-saving and voltage-reduction aluminium-steel full-section direct welding system consists of three core modules: the aluminium-steel bimetallic fully automated welding and forming system, the multi-physical field test data cloud-based expert decision comparison system, and the high-magnetic full-current online quality-optimized welding technology.

2.1 Aluminium-Steel Bimetallic Fully Automated Welding and Forming System

This system has successfully developed an aluminium-steel bimetallic welding fully automated forming module. Through systematic research on the automated surfacing process at the cathode collector bar end and the circumferential welding process, it has achieved automated technological upgrades in cathode collector bar welding, as shown in Figure 1. Core technological breakthroughs in the production line include:

1) The innovative development of a stabilized cathode collector bar transfer device, which utilizes an intelligent robotic arm cooperative operation system. Through inhouse-developed control software for the double-arm tilt welding process, it effectively resolves the technical challenges of inclined surface welding, ensuring stable and reliable weld quality.

2) Based on the characteristics of the aluminium-steel direct welding process, a streamlined welding production line has been established, equipped with three dedicated planar welding systems. By adopting a layered progressive welding strategy, each system is responsible for welding different material layers, forming an efficient assembly-line operation mode that improves welding efficiency by over 40 %.

3) A unique workstation was designed with inclined cathode group placement, where the coordinated interaction between an intelligent clamping system and the welding robot control system established a first-level collector bar adaptive transfer line, achieving seamless connectivity between welding processes.

4) The production line integrates key technologies such as precise robotic arm control, multi-station collaborative operation, and intelligent transfer, forming a complete automated solution for fused welding of cathode collector bars, providing efficient and stable intelligent production equipment for aluminium reduction cell manufacturing, significantly improving welding quality and production efficiency.

2.2 Multi-physical Field Test Data Cloud-Based Expert Decision Comparison System

The multi-physical field test data cloud-based expert decision comparison system establishes an electrolytic cell optimization framework based on comprehensive lifecycle analysis of electric and magnetic field data, as shown in Figure 2. First, the system employs specialized instruments such as gauss meters, fiber-optic current sensors, and multi-point voltage drop testers to collect full-scale data from operating electrolysis potlines. Next, all test data is uploaded in real time to a cloud-based expert decision system, where intelligent comparisons are made against a vast database of operational data from peer electrolytic cells to accurately identify weaknesses in the current busbar system. Finally, the system utilizes machine learning algorithms to perform in-

6. References

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