Intelligent Storage and Conveying System for the Preparation of Multiple Particle Size Fractions and Grades of Electrolyte

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Abstract

This paper addresses the issues of low efficiency, high energy consumption, uneven material distribution and clogging during the electrolyte storage and conveying process in the electrolytic aluminium industry, proposing an intelligent multi-grade particle size electrolyte storage and conveying system. The system integrates multi-grade storage silos, intelligent material distribution modules, dynamic transport structures, and automation control technologies, achieving precise storage, graded conveying, and blending of electrolytes. This system can reduce total energy consumption by approximately 18 %, decrease manual maintenance frequency by 30 %, and ensure equipment maintenance frequency aligns with the green transformation needs of the aluminium industry. This research provides an efficient, stable, and environmentally friendly storage and transport solution for the aluminium industry, offering significant economic returns and promotion value.

Keywords: Electrolyte storage and conveying, Intelligent control, Energy-saving, Reducing labor costs.

1. Introduction

1.1 Background and Issues

In the aluminum electrolysis production process, the thermal equilibrium management and insulation performance of the electrolytic cell are key factors that directly affect current efficiency, energy consumption and cell lifespan [1]. As an important component of the thermal insulation layer, the electrolyte (mainly composed of the cryolite-alumina system), which is processed by crushing and screening after butts cleaning, is used as the anode cover. Its physical and chemical properties (including particle size distribution, thermal conductivity, porosity, etc.) significantly affect the heat dissipation characteristics from the top of the anodes.

Existing studies show that there is a nonlinear relationship between the particle size composition of the covering and its thermal resistance properties [2]: Fine particles (< 1 mm) can increase bulk density, thereby enhancing insulation effects, but excessively fine materials reduce permeability, exacerbating anode oxidation. Coarse particles (> 5 mm) facilitate gas diffusion but increase heat loss due to reduced contact thermal resistance. Additionally, the thickness uniformity and dynamic sintering behavior of the cover can affect the chemical stability of the electrolyte by altering the covering effect of alumina. In current industrial production, the electrolyte crushing and conveying systems generally face the following technical bottlenecks:

(1) Particle size control limitations: Traditional jaw crusher – linear screening systems can only produce a single particle size range (typically 2–10 mm), unable to achieve multi-grade proportional feeding based on the cell thermal equilibrium needs (e.g. newly started cells require high insulation, while aging cells need more heat dissipation).

(2) Automation defects: Issues, such as screen clogging and crusher overload caused by fluctuating material moisture content, lack intelligent monitoring methods and still require manual intervention, resulting in labor intensity exceeding the Chinese standard GB 3869-1997 *Classification on Intensity of Physical Work* level III [3].
(3) Low energy efficiency: The unit energy consumption of the crushing process is 8–12 kWh/t, and it is not integrated with the cell thermal status monitoring system (e.g., online cell voltage and sidewall temperature data) for closed-loop control.

This inefficient management model for anode cover can no longer meet the modern aluminum smelter demand for precise thermal equilibrium control and intelligent production. Therefore, there is an urgent need to develop an intelligent conveying system with multi-grade particle size collaborative control functions. Optimization directions include: reconstruction of mechanical models for the crushing process, particle size online detection based on machine vision, and core technology breakthroughs in data interaction with the MES system.

1.2 Research Objective and Significance

This paper aims to design an intelligent multi-grade particle size electrolyte storage and conveying system, which classifies and stores different particle size electrolytes and alumina in multi-grade storage silos. Combined with intelligent material distribution and dynamic transport technologies, it realizes precise blending and automated conveying. This paper will analyze the system structure, process flow, application effects, and advantages, providing the aluminum electrolysis industry with an efficient, energy-saving, and environmentally friendly conveying solution.

2. Overall System Structure and Process Flow

2.1 Overall System Structure

The intelligent multi-grade particle size electrolyte storage and conveying system uses a modular design, consisting primarily of a storage module, blending module, discharging module, and intelligent control system. Each module is interconnected via sensors and a Programmable Logic Controller (PLC) control system. The system mainly comprises the following core equipment:

1. Bucket elevators: Used to lift electrolyte materials to a higher elevation. It uses a ring chain drive structure with a conveying capacity of up to 50 t/h and a lifting height of up to 30 m. Equipped with level sensors, it can automatically control feeding and unloading to prevent material blockage and equipment overload. A dual-unit configuration ("one standby, one active") ensures uninterrupted operation.

2. Vibrating screens: Used to classify electrolytes by particle size. Based on electrolyte characteristics, a stepped screen layout is adopted: preliminary screening at 15 mm in the front section and fine screening at 3 mm in the rear. Screening accuracy is controlled within ±5, and efficiency reaches 95 %. A fault alarm shuts down the equipment automatically when bearing temperature is higher than 70 °C. The unit supports PLC integration and interlocks with other devices.

3. Storage silos: Designed to store electrolytes and alumina of various particle sizes. Two silos are configured for each particle size, plus one dedicated silo for alumina. An additional silo stores material returned from the dust collection system, ensuring sufficient supply for blending requirements.

4. A disc feeder: Precisely controls the feeding rate. Feeding accuracy is within ±2 %, with a capacity of 50 t/h. It handles materials with particle sizes ≤ 30 mm.

5.2 Outlook

Future optimization of the entire system can be pursued in the following areas:
(1) Deep Integration of Digital Twin Technology
By leveraging 3D modeling and IoT sensor data, a high-fidelity digital twin model of the equipment can be built to mirror the real-time operating status of the physical system. Machine learning algorithms can be applied to predict the remaining service life of key components (such as bearings and gear reducers) [5], enabling predictive maintenance and reducing the risk of unplanned downtime.
(2) AI-Driven Intelligent Ratio Optimization
Deep learning can be used to analyze operational data such as electrolytic cell temperature and current efficiency, dynamically optimizing the electrolyte-to-alumina blending ratio and improving current efficiency by 0.5–1.2 %.
(3) Green Energy and Low-Carbon Upgrades
The motor system incorporates a “variable frequency drive + regenerative braking” design to recover braking energy and feed it back to the grid, reducing overall energy consumption by an additional 8–12 %. Exploration of hydrogen energy drives or photovoltaic energy storage systems can further reduce the carbon footprint and contribute to achieving dual carbon goals in the aluminum industry [6].
(4) 5G + Edge Computing for Remote Operation and Maintenance (O&M)
Deployment of a dedicated 5G network and edge computing nodes enables millisecond-level data interaction, supporting remote diagnostics and AR-assisted expert maintenance. A cloud-based big data platform can be established to accumulate production data, continuously optimizing the blending process and equipment energy efficiency [7].

6. References

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