Development and Application of an Online Quality Inspection System for Prebaked Anodes

Qing Wei[1], Jinguo Wang[2], Hao Wang[3], Dong Zhou[4] and Yunchen Ma[5]
1. Senior Engineer
Zhengzhou Non-ferrous Metals Research Institute, Zhengzhou, China
2, 3, 4. Senior Engineer
5. Engineer
Baotou Aluminium, Baotou, China
Corresponding author: weiqing8935183@163.com
https://doi.org/10.71659/icsoba2025-el020

Abstract

Prebaked anodes are a critical material in aluminum electrolysis production, and their quality directly impacts the efficiency and stability of the electrolytic aluminum process. Traditional anode assembly workshops heavily rely on manual operations for quality inspection of guide rods and carbon blocks, as well as for detecting carbon block loss. This approach suffers from low efficiency, high error rates, intense labor requirements, and difficulties in data management. To address these issues, Baotou Aluminum Group and Chalco Zhengzhou Research Institute of Nonferrous Metals jointly developed an online quality inspection system for prebaked anodes.

This system is capable of monitoring both external and internal defects of the anodes. For external defect detection, high-definition cameras are installed on the production line to capture digital images of the carbon block surfaces. Machine vision technology is then employed to integrate quality defect features of the anode carbon blocks into a deep learning algorithm model. By extracting detailed features and continuously iterating the model through accumulated data samples, the system achieves precise monitoring of surface defects on the carbon blocks. For internal defect detection, the system leverages the principles of elastic wave reflection and diffraction when encountering voids, cracks, or other porous media. It utilizes a non-destructive testing method based on the impact-echo technique. By extracting echo signals from three characteristic surfaces of the carbon anode and performing frequency domain analysis to generate interference spectra, the system accurately identifies internal defects within the carbon blocks.

The intelligent online inspection system for prebaked anode quality enables automated and rapid detection of both external and internal defects in carbon blocks. This significantly improves the quality of carbon blocks used in electrolytic aluminum production, reduces the labor intensity of manual inspections, and provides a robust foundation for efficient, low-consumption, stable, and environmentally friendly electrolysis production.

Keywords: Prebaked anode, Non-destructive testing, Machine vision, Deep learning

1. Introduction

As a key material for electrolytic aluminum, the quality of anode carbon blocks directly affects the efficiency and safety of production equipment. With the technological requirements for efficient, low consumption, and high stability of electrolytic aluminum production, higher demands have been placed on the quality of anode carbon blocks. In the production process of carbon anodes, it is inevitable to have appearance defects (such as cracks and pits) and internal defects (such as pores and inclusions), which lead to a decrease in mechanical strength, uneven conductivity, and affect the efficiency of electrolytic production, even causing production accidents.

The traditional anode assembly workshop heavily relies on manual operation in the quality inspection of aluminium rods and carbon blocks, as well as the detection of carbon block loss, which has problems such as low efficiency, large errors, high labor intensity, and difficult data management. The development of efficient and high-precision carbon block defect detection methods is an inevitable trend in the industry to improve production efficiency, reduce labor costs, and enhance product quality.

2. Principle of Carbon Block Defect Detection

2.1 Principle of Carbon Block Appearance Defect Detection

The appearance defects of carbon blocks are mainly characterized by the following types of typical features:

- Surface cracks: distributed linearly or in a network pattern, irregular edges, usually with high aspect ratios and directionality, and appearing as local gray level mutation areas in the image.
- Pits and protrusions: Most of them are irregularly shaped. Under light, pits appear as dark areas with smooth transitions at the edges; while protrusions, due to shadow effects, form local alternating light and dark features.
- Edge defect: Local loss of carbon block contour, manifested as a sudden change in geometric shape, can be detected through edge continuity analysis.
- Surface pollution and color difference: Oil stains, dust and other pollutants cause abnormal local reflectivity, which shows significant differences from the substrate material in specific bands (such as near-infrared).

These defects can disrupt the uniformity and continuity of material surfaces in optical imaging, providing distinguishable visual features for image processing-based detection. Therefore, the appearance defects of carbon blocks are mainly identified and classified automatically through optical imaging and image processing technology. The specific process of carbon block visual inspection is as follows:

1. Image acquisition and preprocessing. Using high-resolution industrial cameras combined with multi angle light sources (such as circular LEDs or coaxial light) for image acquisition and suppressing high light absorption interference on the surface of carbon blocks through diffuse reflection illumination. Grayscale, histogram equalization, and Gaussian filtering are applied to the original image to enhance the contrast between defect areas and the background, while suppressing noise.

2. Defect feature enhancement and segmentation. Complete image acquisition and preprocessing, use image processing techniques to analyze surface anomalies of anode carbon blocks and segment the images.

    - Crack defect segmentation method: using direction sensitive Sobel operator or Gabor filter to extract crack edges, combined with morphological processing (such as skeletonization) to remove pseudo defects.
    - Pit/bump segmentation method: Laplacian operator or local binary pattern (LBP) is used to highlight surface roughness features, and irregular areas are segmented through region growing algorithm.
    - Edge defect segmentation method: based on Canny edge extraction and Hough Transform to analyze contour integrity and locate geometric anomalies.

3. Multi feature fusion and classification. Extract the morphological parameters (area, perimeter, circularity), texture features (gray level co-occurrence matrix), and depth information (assisted by structured light 3D reconstruction) of surface defects on carbon blocks and construct multidimensional feature vectors. Classify defect types using Support Vector Machines (SVM)

6. References

1. Mohsen Ahmed Shukralla et al., The roadmap of AP-ALBA to 400 kA, *Proceedings of 39th International ICSOBA Conference, Virtual Conference,* 22–24 November 2021, *TRAVAUX* 50, 625–635.
2. Dinesh R. Gunasegaram, Dirk Molenaar, Towards improved energy efficiency in the electrical connections of Hall-Héroult cells through finite element analysis (FEA) modeling, Journal of Cleaner Production, 89, 2015, 1–19. https://doi.org/10.1016/j.jclepro.2014.11.002
3. Dirk Molenaar et al., Experimental investigation of factors affecting the electrical performance of the stub to carbon connection, *Light Metals* 2013, 1359–1364. https://doi.org/10.1007/978-3-319-48144-9_211
4. Dolfy Antonio Sinaga et al., Stub to carbon design improvement, *Proceedings of 41st International ICSOBA Conference,* Dubai, UAE, 5–9 November 2023, *TRAVAUX* 52, 1007–1016.
5. ANSYS, ANSYS Mechanical APDL Element Reference, 2014.
6. Kai Ding et al., Prediction of voltage loss on electrical connections for aluminium smelter reduction cells, *Proceedings of the Institution of Mechanical Engineers*, *Part C: Journal of Mechanical Engineering Science*, 226(4), 2012, 981–994. https://doi.org/10.1177/0954406211417369
7. Daniel Richard et al., Carbon to cast iron electrical contact resistance constitutive model for finite element analysis, *Journal of Materials Processing Technology*, 132, 2003, 119–131. https://doi.org/10.1016/S0924-0136(02)00430-2