Multi-Stage Particle Size Crushing and Storage-Transportation System for Spent Anodes

Hang Zhang[1], Jian Lu[2], Shaoyuan Lu[3] and Xin Zhao[4]
1, 4. Engineers, Smelter Design
2. Principal Engineer, Smelter Design
3. Senior Engineer
Guiyang Aluminium and Magnesium Design & Research Institute (GAMI), Guiyang, China
Corresponding author: 1310544564@qq.com
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Abstract

In the aluminium industry, butts recycling is a crucial yet challenging process. The traditional treatment is suffering from technical issues like uneven particle sizes, severe dust pollution and inadequate automation, which hinder resource recovery and endanger environment and workers' health. To address these challenges, this paper presents an integrated butts treatment system featuring multi-stage crushing, efficient dust collection, and intelligent conveying. The system enables precise control over the whole butts treatment process from crushing to storage-transport by employing 3-stage crushers for various sizes (coarse, medium, fine) with bag filters and automated conveying units. The results show significant improvements in the process efficiency and quality, reduced costs, supporting the industry green and intelligent transformation.

Keywords: Aluminium smelting, Prebaked anodes, Butts, Crushing, Transport.

1. Introduction

1.1 Industry Background and Issues

From a fundamental industry with high energy consumption and heavy resource dependence, aluminium smelters have long struggled with the treatment of butts (spent anode carbon blocks after electrolysis). Traditional butts treatment typically employs single stage crushing where after pressing, butts are fork-lifted from the dumping site to jaw crushers. The open-type process lacks effective dust control, causing dust levels of workshops to exceed standards by 10–15 times, severely endangering workers' health. High manual involvement and poor equipment integration limit efficiency, failing to meet modern large-scale production demands. Some smelters even directly sell butts for new anode carbon blocks, leading to low recovery efficiency of spent anodes and inevitably increasing operational costs. In China, butts were usually discarded in the past, but recently there is a tendency to fully recycle them for use as anode raw materials [1].

1.2 Research Objectives and Significance

Based on the experience from an aluminium smelter abroad, this paper describes an intelligent butts treatment system integrating crushing, storage-transport and dust collection. It achieves uniform particle size via multi-stage crushing, boosts efficiency with automation, and improves the working environment through efficient dust collection. Its application enables a shift from extensive to refined butts treatment in the aluminium industry, achieving closed-loop anode utilization and reducing workshop dust to below 10 mg/m^3, with significant economic, environmental and social benefits.

2. System Architecture and Technical Principles

The multi-stage butts crushing and storage-transport system adopts a modular design, comprising three core modules: pressing and crushing, storage-transport, and dust collection, integrated with an intelligent control system. These modules operate in coordination via sensors and PLC control. The overall process begins with a primary crusher, followed by a conveyor belt transferring butts to a medium crusher for further size reduction. The crushed material is then conveyed to a fine crusher for final processing. Dust generated at each crushing stage is collected in real time by bag filters. The materials that meet the particle size requirements are then transported to the butts silo through the automated storage and transportation system. Below the silo, a belt weighing feeder and an automatic telescopic chute enable automatic weighing and controlled unloading of butts, which are then loaded into tank trucks for delivery to downstream production areas. Figure 1 shows the system's process flow diagram.

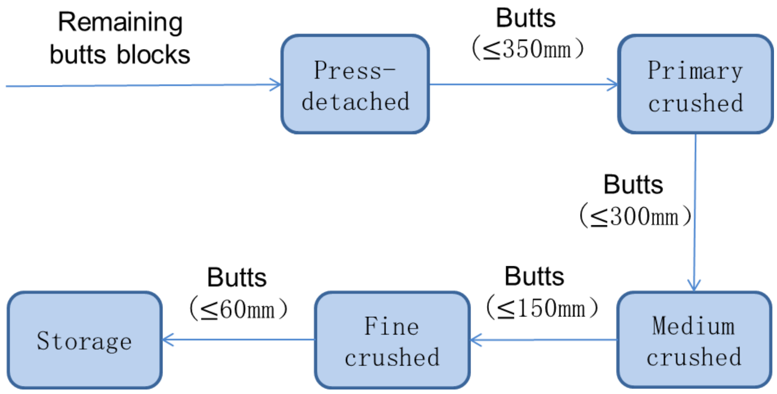

Figure 1. Process flow diagram of butts crushing.

2.1 Butts Pressing and Crushing Process

2.1.1 Butts Pressing Process

See Figure 2 for the butt pressing process. Laser or ultrasonic probes automatically determine the height of the butts. Based on the results, the PLC controls the conveying system (such as chain conveyors, pusher mechanisms, or robotic arms) to direct the butts to the corresponding press:

- Large butts: fed into a dedicated large butt press (higher pressure, slower speed);
- Standard butts: fed into an automatic butt press (standard pressure, high speed).

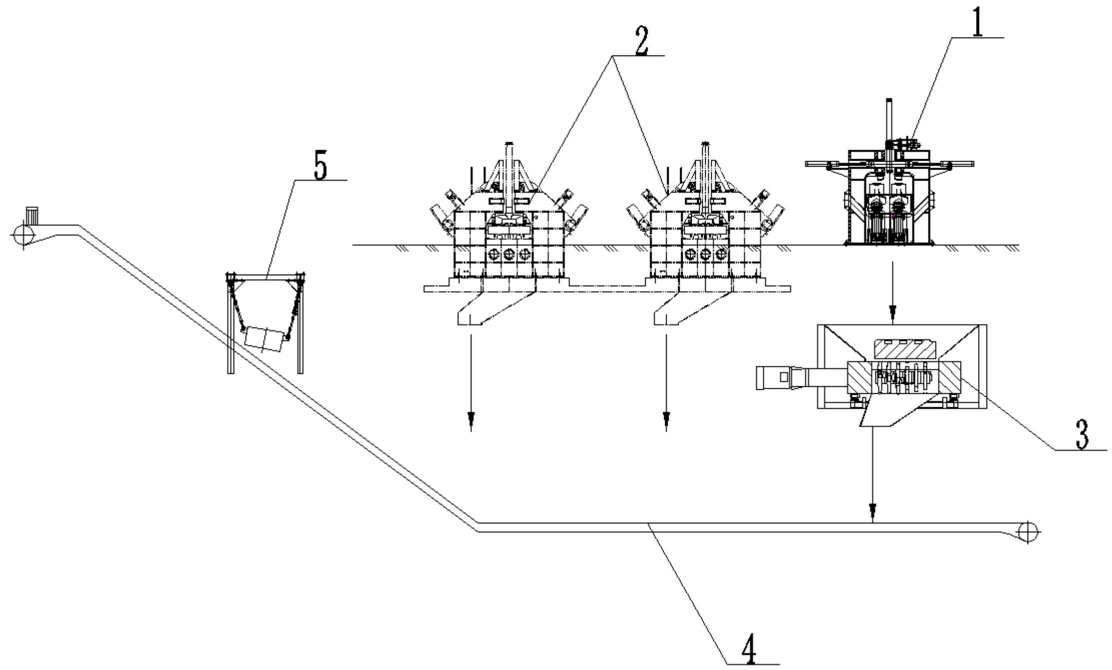

Figure 2. Equipment flow diagram of butts pressing process. 1-Large butts press, 2-Automatic butts press, 3-Hydraulic crusher, 4-First-stage high-angle belt conveyor, 5-First-stage de-ironing separator.

2.1.2 Butts Crushing Process

The butts crushing process adopts a three-stage progressive crushing system, as shown in Figure 3. Process parameters for each crushing stage are given in Table 1.

Table 1. Process parameters for each crushing stage.

Crushing Stage	Feed particle size (mm)	Discharge particle size (mm)	Capacity (t/h)	Motor Power (kW)
Primary crushing	≤ 350	≤ 300	≥ 50	45
Medium crushing	≤ 300	≤ 150	≥ 50	30
Fine crushing	≤ 150	≤ 60	≥ 50	30

Technical features:

(1) The toothed rolls in the primary crushing stage adopt a wear-resistant surfacing process, which significantly extends their service life (by over 30 %) and is suitable for processing high-hardness butts.
(2) Double-toothed roll crushers are used in all three stages. The combined action of shearing and extrusion reduces the risk of over-crushing and ensures particle uniformity.
(3) Shaft rotation sensors are adopted to monitor stalling/speed loss in real time and then prevent equipment from jamming via linked PLC control.
(4) Bearing temperature sensors are used with graded alarms (warning at 90 ℃ → shutdown at 95 ℃) to prevent bearing damage due to overheating.

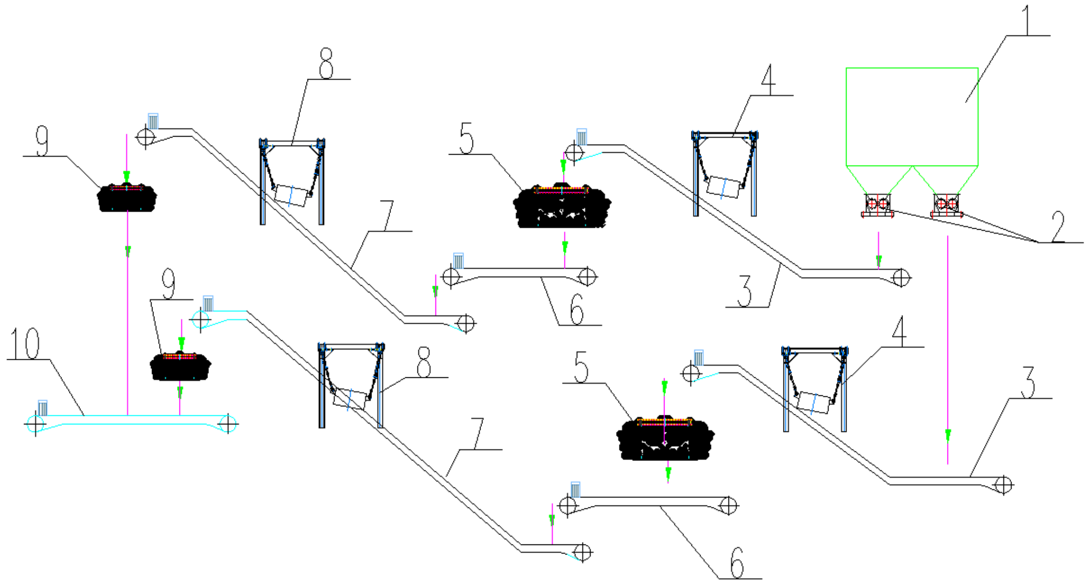

Figure 3. Equipment flow diagram of three-stage crushing process. 1-Buffer silo, 2-Primary double toothed roll crusher,3-Secondary high-angle belt conveyor, 4-Secondary de-ironing separator, 5-Secondary double-toothed roll crusher, 6-Primary horizontal belt conveyor, 7-Secondary high-angle belt conveyor, 8-Tertiary de-ironing separator, 9-Tertiary double-toothed roll crusher, 10-Secondary horizontal belt conveyor.

2.2 Butts Storage-transport Process

The butts storage-transport process is illustrated in Figure 4, with the following technical features:

(1) Efficient conveying: a combination of horizontal and vertical conveying solutions based on site conditions, adaptable to various spatial layouts.

(2) Eco-friendly and reliable: enclosed design + dust removal + wear-resistant materials, taking into account environmental protection and durability.

(3) Intelligent control: Multi-sensor coordination involving material level, weight, temperature, and more, enabling full automation.

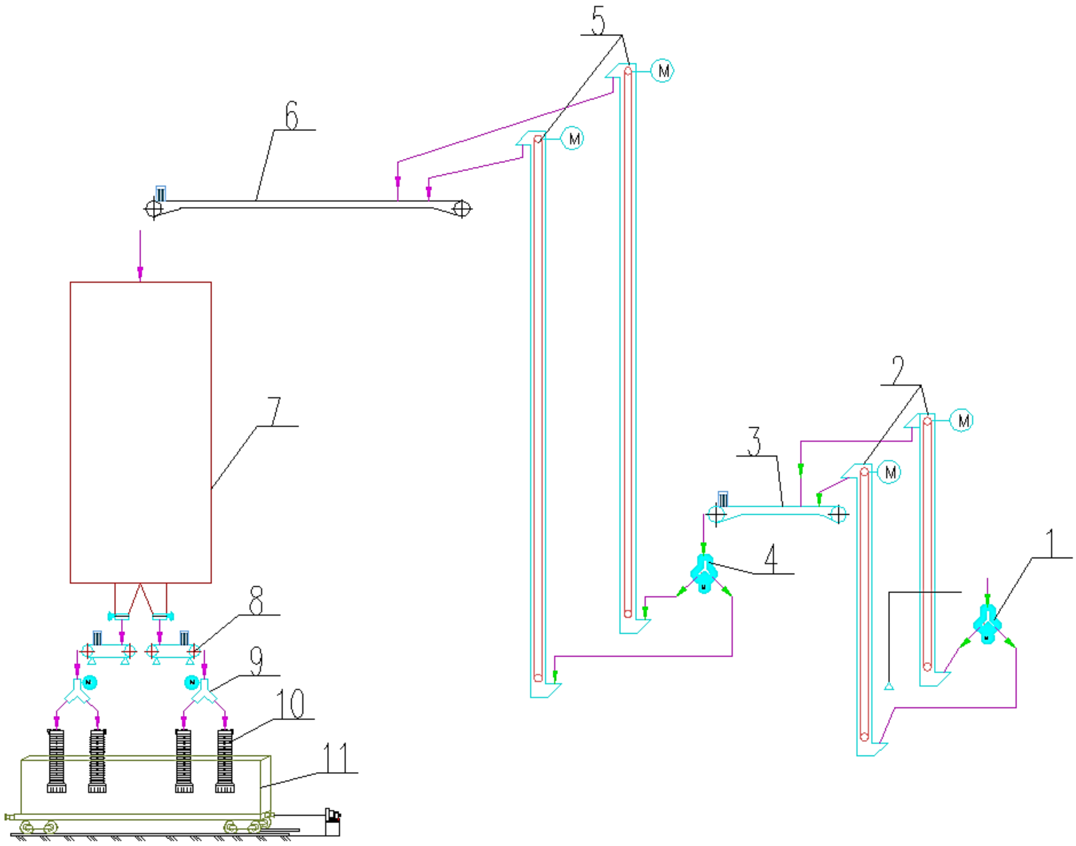

Figure 4. Equipment flow diagram of butts storage-transport process. 1-Primary electro-hydraulic three-way diverter, 2-Primary bucket elevator, 3-Primary horizontal belt conveyor, 4-Secondary electro-hydraulic three-way diverter, 5-Secondary bucket elevator, 6-Secondary horizontal belt conveyor, 7-Butts silo, 8-Constant weight feeder, 9-Tertiary electro-hydraulic three-way diverter, 10-Telescopic Hose, 11-Tank Truck.

2.3 Control Process of Dust Collection System

Based on the equipment layout, a segmented dust collection system is adopted, consisting of three units: P-1, P-2, and P-3. The process parameters of each dust collection system are shown in Table 2.

Table 2. Process parameters of dust collection systems.

Dust Collector	Air Volume (m^3/h)	Fan Power (kW)	Fan Flow Rate (m^3/h)	Fan Outlet Pressure (Pa)	Associated Process Section
P-1	42 000	75	47 427	3 986	Primary crushing
P-2	71 000	132	77 900	3 984	Medium and fine crushing
P-3	26 000	55	30 533	3 921	storage-transport

Technical highlights of the dust collection system:

(1) Filter bags are made of PTFE-coated needle-punched felt, with a filtration efficiency ≥ 99.5 %, effectively capturing dust particles with a diameter ≥ 0.3 µm.

(2) Pulse-jet automatic cleaning where compressed air pulse cycles are controlled via PLC, extending filter bags' service life.

(3) Dust-free ash conveying using a dynamic chute and pneumatic conveying, achieving fully enclosed, dust-free ash transfer to the silo.

3. Process Flow Characteristics and Control Strategies

3.1 Process Flow Characteristics

(1) A three-stage crushing and conveying process is adopted, with one unit in operation and one standby for each stage. In cases of low production capacity, a single line can operate while the other remains on standby. The standby line can be activated during equipment failure, preventing production stoppages during maintenance.

(2) Production capacity is adjustable. The system allows selection between single-line or dual-line operation based on required capacity, avoiding the issues of "undersized capacity overload" or "oversized capacity underload," and overcoming the shortcomings of insufficient or excessive capacity.

(3) Integration of multi-stage iron removal technology. Self-unloading de-ironing separators are installed on belt conveyors, significantly reducing the iron content in materials after multi-layer iron removal.

(4) Equipped with automatic heat tracing units. Considering the extremely cold climate of the plant's location, outdoor devices are equipped with automatic heat tracing units. Motors on devices such as bucket elevators and belt conveyors are equipped with these units, ensuring normal operation even under extreme temperatures of -50 °C.

3.2 Intelligent Control Strategies

The system adopts Siemens S7-300 PLC as the control core, featuring the following characteristics: 1) Short cycle time, high processing speed, and a relatively powerful instruction set capable of handling complex functional requirements effectively; 2) Compact design and modular structure, suitable for dense installation with minimal space requirements, providing great advantages in space-constrained environments; 3) Available with CPUs of various performance levels, powerful and comprehensive in functionality, and a wide range of modules for selection; 4) Minimal maintenance required, with no need for battery backup, and capable of operating in harsh environments [2].

Operating parameters of each device (such as motor current, bearing temperature, material level height, etc.) are collected through distributed I/O modules, and real-time monitoring and operation are realized via Human-Machine Interface (HMI). Key control strategies include:

- Load adaptive control: By monitoring the crusher load using current sensors, when excessive feeding causes motor overload, the feeding belt speed is automatically adjusted or feeding is paused to prevent equipment damage.
- Dust collection interlock control: When the crusher is started, the dust collector is activated simultaneously; after the equipment stops, the dust collector continues running for 10–15 minutes to ensure complete dust removal from the pipeline.
- Fault diagnosis and alarm: The system integrates fault diagnosis functions that can detect anomalies in real time (such as belt misalignment, excessive bearing temperature rise, over-limit dust collector differential pressure, etc.) and notify operators through audio-visual alarms.

4. Project Implementation Results

This design was implemented in a 0.5-MTPA aluminium smelting project located in a severely cold region abroad. After one year of system operation, significant results were achieved.

4.1 Significant Improvement in Dust Collection Performance

Dust concentration control**:** In response to the high-concentration dust generated during crushing and conveying, efficient multi-point dust hoods were installed at key dust emission points (such as crusher inlets and belt transfer points), and membrane bag filters were adopted. Material transfer between equipment was achieved via connecting devices (such as electro-hydraulic three-way diverter or material cut-off valves), ensuring that the entire conveying process was fully sealed and no dust was exposed.

Application results: Workshop dust concentration was reduced from 10–15 times above standard (under traditional process) to below 10 mg/m^3, meeting occupational health standards.

4.2 Enhanced System Operation Stability

Equipment backup design: Dual-line mode of "one operating, one standby" was adopted for crushing and conveying processes. For example, when the mainline crusher shut down due to foreign object blockage and protection triggering, the system automatically (or via one-click by the operator) switched to the standby line, effectively ensuring continuous supply of butts to the potrooms.

Application results: Single-line fault switching time ≤ 2 minutes; unplanned downtime per year reduced from 100 hours (traditional process) to 20 hours.

Intelligent monitoring and protection: PLC continuously monitored parameters such as motor current, bearing temperature, and material level, automatically adjusting the load to reduce overload risk.

Application results: When continuous high current or abnormal bearing temperature rise was detected, the system automatically slowed the upstream feeder or paused operation briefly to cool down, effectively preventing equipment damage due to overload. At the same time, upstream and downstream equipment was automatically started or stopped based on material level. This reduced overall system failure by 40 %.

4.3 Flexible Capacity Adjustment via Automation

Dual-line adjustable mode: Depending on capacity demand, single-line (low load) or dual-line (high load) operation could be selected, with butts handling capacity flexibly adjustable in a range of 30–60 units/hour.

Adaptive control: Feeding speed was dynamically adjusted via current sensors to keep the crusher load rate stable at 85 % ± 5 %. For example, a high-precision current sensor was installed on the main crusher motor to provide real-time load feedback.

Application results: When the load approached 90 %, the system automatically reduced the feeding speed slightly; when it dropped below 80 %, the speed was increased. This ensured the crusher consistently operated within the efficient and safe range of 85 % ± 5 %, maximizing equipment utilization and reducing blockage risk.

Particle size uniformity improvement: The three-stage crushing produced uniform discharge particle size, meeting anode production requirements. The measured particle size distribution is shown in Table 3.

Table 3. Discharge particle size distribution.

Particle Size Range (mm)	Proportion (%)
≤ 30	15.2
30–50	68.5
50–60	14.3
＞60	2.0

4.4 Significant Reduction in Labour Costs

Automation replaced manual labour: the entire process – from butt pressing and separation, to crushing and conveying – was fully automated. After butts were transported out of the potrooms, they passed through an automatic pressing and separation machine that separated the steel stubs from the carbon blocks. The crushing line then performed automatic crushing, screening, and conveying. Qualified crushed materials were automatically delivered to the butt silo. Throughout the process, personnel were only required at key monitoring points (e.g., central control room) and for minimal inspection roles.
Application results: Traditional semi-automated production lines required 20 workers (involving extensive manual handling, cleaning, and equipment operation). In contrast, the fully automated line operated with just 8 staff (mainly for monitoring, inspection, and emergency response), resulting in an annual labour cost reduction of approximately 960 000 RMB (133 kUSD approx.).

4.5 Savings on New Anode Procurement Costs

Butts recycling: In traditional processes, butts were sold for new anodes. The proposed system enables full reuse of crushed butts as raw materials for new anodes, thus forming a closed-loop production system. An aluminium smelter of 500 kt/a capacity can produce about 50 kt/a of butts. Recycling them saves approximately 3 000 RMB (415 USD approx.) per tonne on new anodes procurement costs, equating to an annual cost saving of around 150 million RMB (20.7 MUSD approx.).

5. Conclusion and Outlook

5.1 Research Conclusion

The proposed multi-stage butts crushing and storage-transport system achieves precise particle size control of butts through a three-stage crushing process. It effectively addresses dust pollution using bag filter dust collection technology and improves production efficiency through automated conveying equipment. Compared with traditional butt treatment process, this system offers higher crushing efficiency, uniform particle size, superior eco-friendly performance, and a high degree of automation, providing an advanced technical solution for butts treatment in the aluminium industry. Additionally, it enables closed-loop butt treatment, promoting butts reuse and significantly reducing operating costs.

5.2 Technical Outlook

Future system optimizations may include:

- Addition of a material screening system: to classify and store butts based on different particle sizes, thereby meeting various production requirements.
- Incorporation of a vision recognition system: to automatically detect and intercept oversized butts and return them to the crusher for reprocessing.
- Deployment of AGV intelligent robots: to swiftly clear blockages at the crushing station and restore normal operations in case of material jams.

6. References

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