Application of Intelligent Crust Breaking Cylinders in Aluminium Electrolysis

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Abstract

As a core actuator in aluminium reduction cells, the breaking cylinder system plays a critical role in breaking the crust formed by the electrolyte. Current pneumatic system designs face issues such as delayed valve response, significant pressure loss in compressed air, and high-temperature creep failure of sealing components. To effectively improve the performance of the crust breaking cylinders, technicians have optimized the pneumatic system design by installing a custom rope sensor on the cylinder, which is reliably connected to the crust breaking cylinder using a specially designed connector. This enables precise closed-loop control of the cylinder's operation. A large-bore shut-off control valve is also used, characterized by rapid switching, high flow capacity, excellent stability, and strong dust resistance. These optimizations enhance both the efficiency and quality of aluminium electrolysis production.

Keywords: Electrolytic cell, Intelligent crust breaking, Crust breaker cylinder.

1. Current Status of Crust Breaking Technology

As a key link in the aluminium reduction cell production process, crust breaking technology is limited by design flaws in the current pneumatic systems. At present, although the crust breaking cylinder system – being the core actuator of the aluminium reduction cell – plays an essential role in breaking the crust of the electrolyte, its performance is constrained by multiple factors.

1.1 Research Background and Significance

In the aluminium electrolysis production process, electrolytic cells serve as core equipment, and their operational efficiency and stability are directly related to the production capacity of the entire line. As a key actuator in the electrolytic cell, the breaking cylinder system undertakes the critical task of breaking the crust formed by the electrolyte. Its performance directly impacts the efficiency and energy consumption of the cell. However, the current pneumatic system design suffers from several shortcomings, such as delayed response of reversing valves, large pressure losses in compressed air, and creep failure of sealing components under high temperatures. These issues not only limit the performance of the crust breaking cylinder but also increase energy consumption and production costs in aluminium electrolysis.

With the continuous development of the aluminium electrolysis industry, demands for higher production efficiency and product quality are increasing. Therefore, optimizing the pneumatic design of the crust breaking cylinder system to enhance its performance has become an urgent issue for the aluminium electrolysis industry. This study aims to reduce the energy consumption of the crust breaking cylinder system and to improve production efficiency by optimizing the pneumatic system, adding custom rope sensors for precise closed-loop control, and adopting a large-bore shut-off control valve to improve response speed and stability [1].

The implementation of this research not only helps address the existing problems in crust breaking cylinder systems in aluminium electrolysis, improving the operational performance and stability of the cells, but also supports energy conservation, emission reduction, and sustainable development in the aluminium electrolysis industry. Furthermore, the widespread application of the research outcomes will help drive technological progress and industrial upgrading in the aluminium electrolysis sector, enhancing the overall competitiveness of China's aluminium electrolysis industry. Thus, this study holds significant theoretical and practical value.

1.2 Existing Technologies of Crust Breaking Cylinders

The following are some existing cylinder technologies used in electrolytic cells:

1) A purely pneumatic-loop breaking cylinder uses compressed air to drive the piston in a linear reciprocating motion. Its core components include the cylinder body, piston, piston rod, sealing rings, and cylinder head. The cylinder body is typically made of aluminium alloy or stainless steel. The piston moves the rod by compressing and releasing air, while the sealing rings ensure airtightness. Compressed air is controlled by a two-position five-way solenoid valve to enter the cylinder and drive the piston for the crust breaking action. Exhaust is handled through solenoid valve switching to complete the return stroke [2].
2) An electromagnetic reversing crust breaking cylinder uses a solenoid reversing valve to control the flow direction of compressed air, thereby driving the piston for reciprocating motion. The solenoid reversing valve shifts the spool position within the valve body using electromagnetic force to redirect airflow. When the solenoid is energized, the spool shifts to allow air to enter the cylinder from the lower end, driving the piston in the opposite direction and enabling bidirectional cylinder movement.

Although these cylinders have wide applications, conventional types are prone to issues such as seal wear in high-temperature and corrosive environments, leading to air leakage, breaker jamming, and delayed valve response.

This paper presents a new type of intelligent breaking cylinder that effectively addresses problems like poor sealing and breaker jamming. Together with a series of associated control systems, it significantly enhances production efficiency.

1.3 Current Research on Crust Breaking Cylinders

Through the implementation of this project, we are able to effectively solve the issue of crust adhesion during the breaking process and significantly reduce the consumption of compressed air. Additionally, by leveraging the collected detection signal data and the developed application software, the crust breaking and feeding system can be precisely guided and optimized to improve stable production operations.

2. Application of Intelligent Crust Breaking Cylinder

2.1 Components of Intelligent Crust Breaking Control

A new type of intelligent cylinder is used in combination with a pneumatic control cabinet and cell control unit to form the cell actuation control system (see Figure 1).

2.2 Intelligent Crust Breaking Cylinder

The new intelligent breaking cylinder consists of an intelligent sensor, control valve, intelligent control box, and related devices. The intelligent sensor is one of the most critical components of the new intelligent breaking cylinder, operating on the principle of high-precision measurement and perception to monitor the cylinder's operating status in real time. Specifically, intelligent sensors (such as custom rope sensors) detect key parameters like cylinder position, speed, and force, convert them into electrical signals, and transmit them to the intelligent control box. Based on the received signals, the intelligent control box uses built-in algorithms and logic to accurately analyse the cylinder’s operating state and issue corresponding control commands.

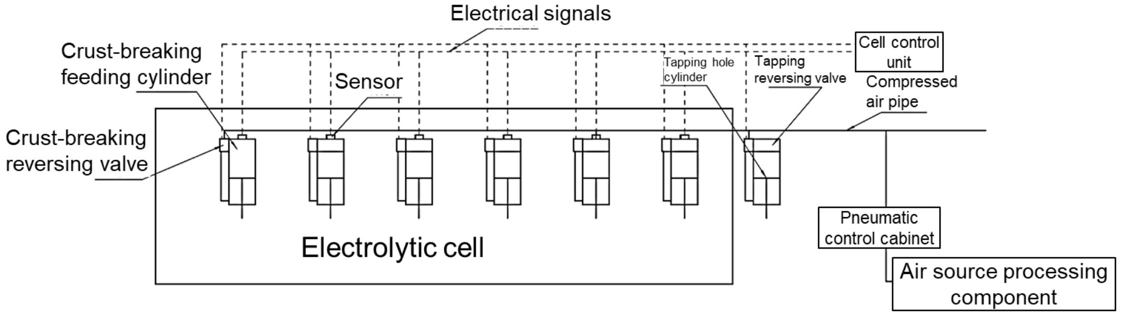

Figure 1. Schematic diagram of intelligent crust breaking in electrolytic cell.

The importance of the intelligent sensor lies in its ability to provide real-time, accurate data feedback, enabling the intelligent control box to execute precise closed-loop control. This optimizes cylinder efficiency, enhances crust breaking performance, and reduces energy consumption. Without data support from the intelligent sensor, the control box cannot make accurate decisions, and the intelligent functionality of the entire breaking cylinder system would be compromised.

2.3 Operating Principle of the Intelligent Crust Breaking Cylinder

As shown in Figure 2, compressed air passes through a water separator filter, is adjusted to the required pressure via a regulator, and then receives oil mist injection through a lubricator before entering the main air pipe above the cell. Compressed air enters the A chamber of the breaking cylinder through the P (Pressure) port to A port of the reversing valve, positioning the cylinder in the upper state. The depth value is set on the dedicated rope sensor as per process requirements, completing the preparation for crust breaking.

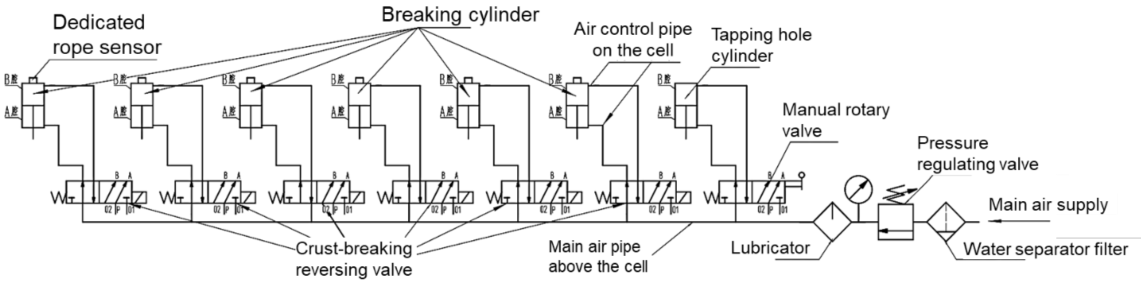

Figure 2. Pneumatic principle diagram of intelligent crust breaking in electrolytic cell.

The cell control unit sends a signal to the pilot valve of each crust-breaking reversing valve, causing the pilot valve to activate the reversing valve. Compressed air flows from the P port to the B port into the B chamber of the cylinder, applying pressure to the top of the piston and pushing the cylinder downward. The residual air in the A chamber is discharged through the A port to O1 (Outlet) port. The piston pulls the rope sensor’s steel cable downward to the set depth, and the sensor sends a position-reached signal, indicating completion of the crust breaking action.

Once the control unit receives the signal, it sends a return command. The reversing valve reverses, and compressed air is directed from the P port to the B port (in simplified logic, this continues the path for explanation; in actual operation, the valve switches to direct air into the A chamber), applying pressure to the underside of the piston (effectively pressurizing the A chamber to move the piston upward). The sensor's steel cable is retracted, the piston returns to the upper position, and the sensor emits a position-reached signal, marking the end of the crust breaking process.

Since each breaking cylinder is individually equipped with a pilot control valve, crust-breaking reversing valve, and dedicated rope sensor, the crust breaking and feeding cylinders can be controlled independently. The cylinder can intelligently adjust the depth and frequency of breaking based on the electrolyte depth, molecular ratio concentration, and crust thickness. By collecting downward movement data from the sensor to determine whether the crust surface has been penetrated and sending feedback to the control unit, intelligent control functions such as secondary breaking and alarms can be achieved. Upward feedback signals from the cylinder are also collected to ensure it is in the upper position, preparing it for the next cycle.

2.4 Setting of Crust Breaking Depth

The breaker head crust breaking depth is dynamically set based on the electrolyte level at each point, with the goal to ensure the breaker head enters the electrolyte layer by approximately 70 mm, penetrating the hard crust layer without damaging the anode. The current system's depth setting range is adjusted to a maximum of 50 mm.

To avoid human errors in settings or prolonged shallow breaking that may lead to crust accumulation, a "5 shallow breaks + 1 deep break" cycle mode is used. For the first five breaks, the depth is set to 80 % of the process-required base value (e.g., 50–60 mm), i.e., 40–48 mm, to quickly clean the surface layer of the hard crust. For the sixth break, the depth is increased to 60 mm to fully penetrate the crust surface and prevent blockage of the electrolyte and alumina channel. The system automatically records the number of breaks, with the cycle counter resetting at midnight daily to avoid counting confusion across days.

Return depth definition: As shown in Equation (1), the displacement distance from the breaker head to the point where the cylinder is fully detached from the crust surface, which should be slightly larger than the breaking depth (normal difference: 5–15 mm, due to the elastic rebound of the crust).

$$D_{\mathrm{return}} = D_{\mathrm{breaking}} + \Delta D_{\mathrm{elastic}} \tag{1}$$

where:

D_{return}	Return depth (mm)
$D_{breaking}$	Breaking depth (mm)
$\Delta D_{elastic}$	Elastic compensation value for crust surface (mm).

Crust surface accumulation warning: If the difference between return depth and breaking depth exceeds 30 mm, the system judges the crust as abnormally thick, indicating a large buildup. Crust Surface blockage alarm: If return depth equals breaking depth (difference ≤ 1 mm), it indicates crust surface blockage.

2.5 Alumina Sludge Treatment

During production, there are issues such as excessive cavity bottom sludge, alumina leakage, non-feeding at single points, or alumina blockage can occur, leading to uneven alumina distribution, reduced current efficiency, and increased energy consumption from continued abnormal feeding [3]. In such cases, the sludge treatment function can be used to control material feeding in stages over a long period, regulating the feeding volume at the affected points. This phase-based, precise alumina control reduces accumulation, restores alumina dissolution balance, and avoids production interruption caused by complete suspension of feeding, thereby ensuring cell stability. The parameter settings are shown in Figure 3.

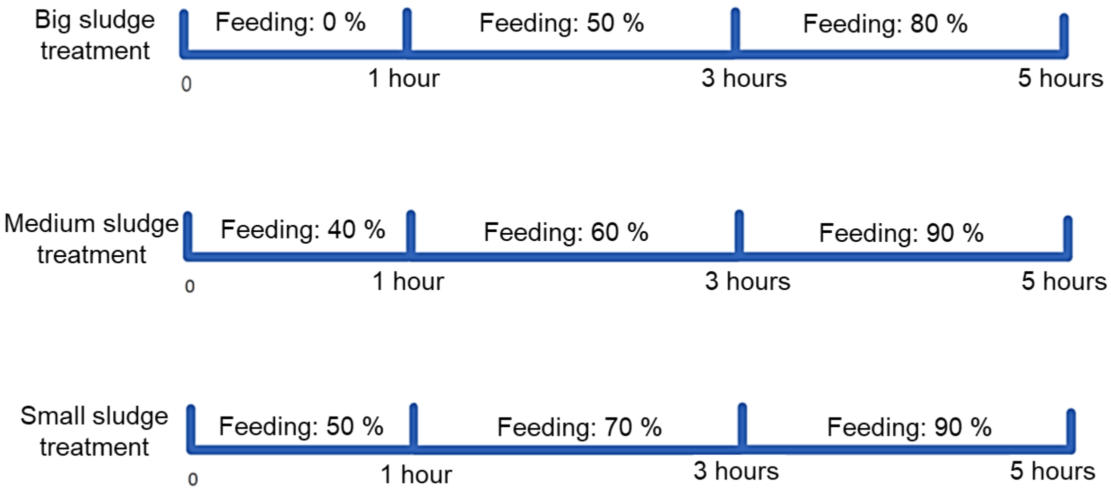

Figure 3. Alumina sludge treatment parameter control diagram.

3. Effectiveness of Intelligent Crust Breaking Cylinder Application

After the implementation of the intelligent breaking cylinder in an aluminium smelter, the optimized breaking process allowed for on-demand crust breaking and automatic adjustment of breaking force, significantly reducing compressed air consumption. Additionally, it automatically adjusted the feeding method and feeding volume based on the cell condition, maintaining a balanced alumina concentration in the electrolyte and thereby improving energy efficiency [4].

3.1 Comparison of Sealing Component Creep Failure

To verify the effectiveness of the intelligent breaking cylinder sealing component in preventing creep failure, three experimental cells and three comparison cells, with minimal differences in all aspects, were selected. Daily checks were arranged for the corresponding cell cylinders to inspect if the sealing components experienced air leakage due to high-temperature creep. This comparison was conducted continuously for one year. Under normal usage conditions, as shown in Table 1, the average number of days until creep failure and subsequent replacement creep failure in comparison cells without the intelligent breaking cylinder was 239 and 238 days, respectively. For experimental cells with the intelligent breaking cylinder, the average number of days until creep failure and subsequent replacement failure was 342 and 338 days, respectively, showing a significant improvement in the durability of the sealing components.

3.2 Comparison of Compressed Air Consumption

After using intelligent breaking cylinders, compressed air consumption was significantly reduced, as effective sealing and responsive reversing valves greatly minimized air loss. The intelligent breaking cylinders optimized the crust breaking process, not only reducing unnecessary compressed air waste but also enabling the pneumatic system to operate more smoothly and efficiently. This not only decreased the probability of equipment damage from overuse but also reduced production downtime caused by equipment failure, ensuring the continuity and stability of electrolytic production [4].

Table 1. Durability of sealing components in different cylinders.

Type	Creep Days of Sealing Components	Creep Days After Replacement
Test Cell 1	338	325
Test Cell 2	342	331
Test Cell 3	346	358
Average	342	338
Standard Cell 1	235	223
Standard Cell 2	228	241
Standard Cell 3	254	252
Average	239	238

3.3 Economic Returns

With intelligent breaking cylinders, the lifespan of sealing components was extended. Over a two-year period, the savings from avoiding one replacement cycle across 300 cells – each with six breaker cylinders and each sealing component costing 200 RMB (28 USD approx.) – amount to an estimated annual savings of 180 000 RMB (24.9 kUSD/y approx.).

The production of compressed air requires substantial electrical energy. In aluminium smelters, breaking cylinders typically operate continuously, so the significant reduction in compressed air consumption directly reduces energy usage. Moreover, the notable decrease in compressed air usage brings both direct and indirect economic returns to the smelter, serving as an effective measure in energy conservation, cost reduction, production efficiency improvement, and product quality enhancement, contributing significantly to sustainable development.

4. Conclusions

The application of intelligent breaking cylinders has shown remarkable results. It extended the service life of sealing components by over 40 %, significantly reduced compressed air consumption during the crust breaking, effectively reduced the maintenance workload for cylinders, and greatly enhanced the operational stability of electrolytic cells, making it highly worthy of broader implementation.

5. References

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