Development and Application of Automatic Flow Control and Emergency Devices in Aluminium Ingot Casting

Wen Wei
Support Engineer
Guangxi Hualei New Materials, Pingguo, China
Corresponding author: weiwen.man@foxmail.com
https://doi.org/10.71659/icsoba2025-ch014

Abstract

With the widespread application of aluminium materials in high-end fields such as aerospace and automotive manufacturing, the quality and production efficiency of aluminium ingot casting have become increasingly critical. Traditional casting processes face issues such as unstable flow control, fluctuations in molten aluminium temperature, and high risks associated with manual operations, resulting in low yield, production efficiency, and safety standards for workers of aluminium ingots. The adoption of an automatic flow control system and emergency device design enables rapid response in unexpected situations, effectively enhancing the automation level and safety assurance capabilities of the production process. The fully automated flow-controlled aluminium production line established by Guangxi Hualei effectively reduces manpower by 2–3 workers in the casting production line while increasing aluminium ingot production efficiency by over 44 %. Moreover, it achieves precise flow control to prevent molten aluminium leakage, resulting in zero incidents of leakage during casting or in the launder, which ensures both enhanced productivity and operational safety, offering valuable insights for aluminium ingot casting processes.

Keywords: Aluminium ingots for remelting, Automatic flow control, Emergency system, Laser ranging.

1. Background

In domestic production, the casting for classical aluminium ingots for remelting typically employs holding furnaces (non-tilting holding furnaces) equipped with molten aluminium tapping outlets. The flow rate regulation or sealing of the tap hole is manually adjusted using a stopper rod with a plug. Due to the poor precision and reliability of manual adjustment, the stability of molten aluminium flow is compromised, leading to potential aluminium ingot quality issues and production safety risks. Moreover, in cases of power outage or air supply interruption to the caster, delayed human response makes it difficult to promptly seal the tap hole, posing adverse effects on safe production. With the promotion of intelligent manufacturing in the aluminium industry, Computer Numerical Control (CNC) technology has been proposed to address issues such as flow control stability and automation in the casting process. The flexibility and intelligence of CNC technology enable rapid production plan adjustments based on market demand, driving aluminium casting and processing toward a more efficient and safer level.

2. Overview of Casting Process for Aluminium Ingots for Remelting

The production process of remelted aluminium ingots for ordinary aluminium includes key steps such as electrolytic molten aluminium, furnace charging, refining, skimming, sampling and inspection, tapping, residue removal, and cooling solidification, as shown in Figure 1. This series of procedures ensures both high quality and production efficiency of the aluminium ingots [1]. During this process, the alloying furnace technology achieves precise mixing and control of molten aluminium with different compositions to ensure the final product meets standard requirements and satisfies the demands of casting and mould forming [2]. When the molten aluminium from the electrolytic cells has high consistency in purity, it can be directly poured into moulds using ladles without the need for furnace preparation. However, if the molten aluminium contains excessive impurities such as electrolyte bath, it is unsuitable for direct casting via ladles [3]. Refining is the process of effectively removing non-metallic impurities from molten aluminium after it is poured into the holding furnace by using refining agents, which helps improve the purity and quality of the molten aluminium. Residue skimming refers to the process of eliminating residue from the molten aluminium. Sampling and testing involve collecting samples in a specified order and method for chemical composition analysis, enabling accurate determination of the product's chemical composition to ensure compliance with quality standards. Tapping is the controlled discharge of molten aluminium from the holding furnace, whereas direct casting into lifting ladles does not require tapping [4]. Residue removal is the process of eliminating surface dross from molten aluminium in the mould, primarily to improve the surface quality of the ingot. Cooling and solidification involve first indirectly cooling the molten aluminium in the mould through contact with cooling water (primary cooling), allowing it to solidify and take shape. This is followed by direct water spray cooling (secondary cooling) to reduce the aluminium ingot temperature to ambient levels. This cooling method effectively controls the solidification rate while ensuring production safety, guaranteeing efficient and secure aluminium ingot formation.

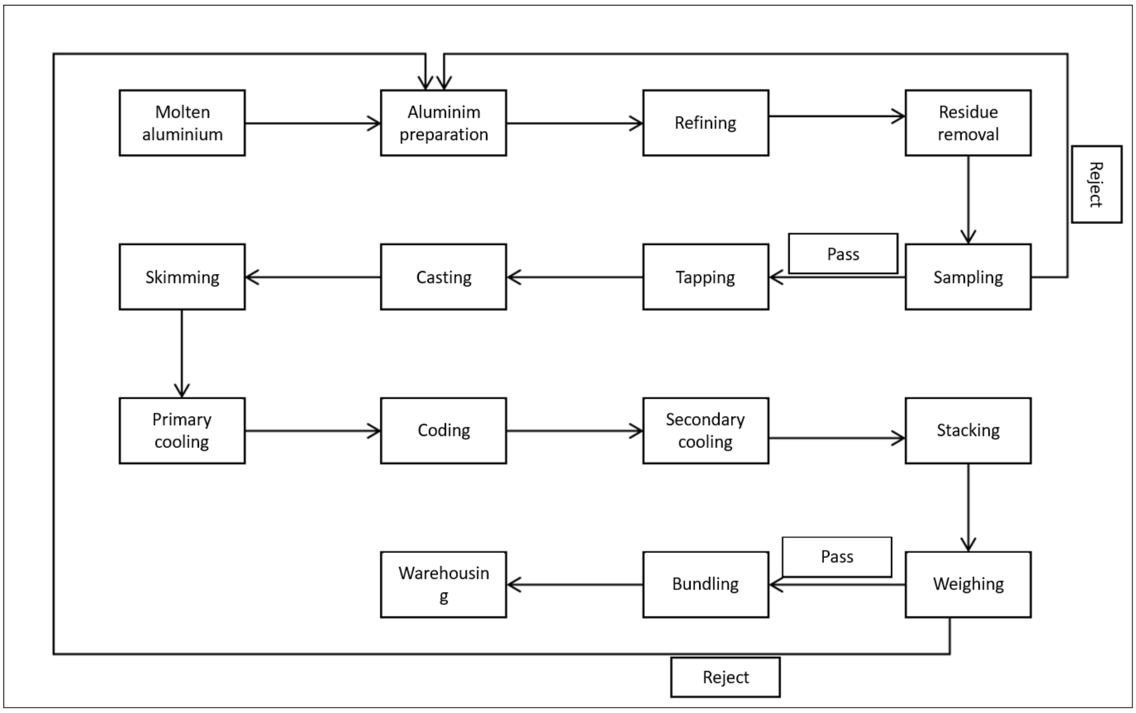

Figure 1. Schematic diagram of casting control and emergency equipment flow for aluminium ingots for remelting.

3. Automatic Flow Control Equipment and Process Flow

3.1 Composition of Control System and Control Process

The device is a new-generation automatic flow control system for aluminium ingot casting developed and applied by Guangxi Hualei. The system mainly includes a laser sensor, an auxiliary liquid level flow control mechanism, an automatic casting speed regulation device, a control system centre, and a ship-shaped casting ladle emergency tilt interlock device, as shown in

Figure 2. The laser sensor is used for real-time monitoring of the launder liquid level. Combined with the tap hole flow control actuator, it enables precise adjustment of the molten aluminium level height in the launder during the casting process. Meanwhile, the auxiliary liquid level flow control mechanism assists in automatic regulation, ensuring the liquid level remains in the optimal state throughout casting and preventing casting defects. The automatic casting speed regulation device adjusts the caster speed based on the launder liquid level through an adaptive speed control system, ensuring stable and efficient casting. In case of abnormalities, the emergency tilt interlock device responds rapidly to safeguard both equipment and personnel. Additionally, as a critical component of the liquid level control system, the control system centre effectively collects control data from each device and enables real-time monitoring through a data upload interface, as shown in Figure 3. The combined use of the equipment optimizes flow control during the casting process, enhancing production efficiency and safety.

In the aluminium ingot casting process, the stability of the molten aluminium flow velocity in the launder is crucial for ingot quality. When the flow rate decreases with the reduction of molten aluminium in the furnace and falls below the standard casting speed, manual adjustment of the tap hole flow has low control accuracy. By adopting an adaptive speed regulation device, which automatically or manually saves the operating height value to set operational standards, precise control of casting flow velocity can be achieved.

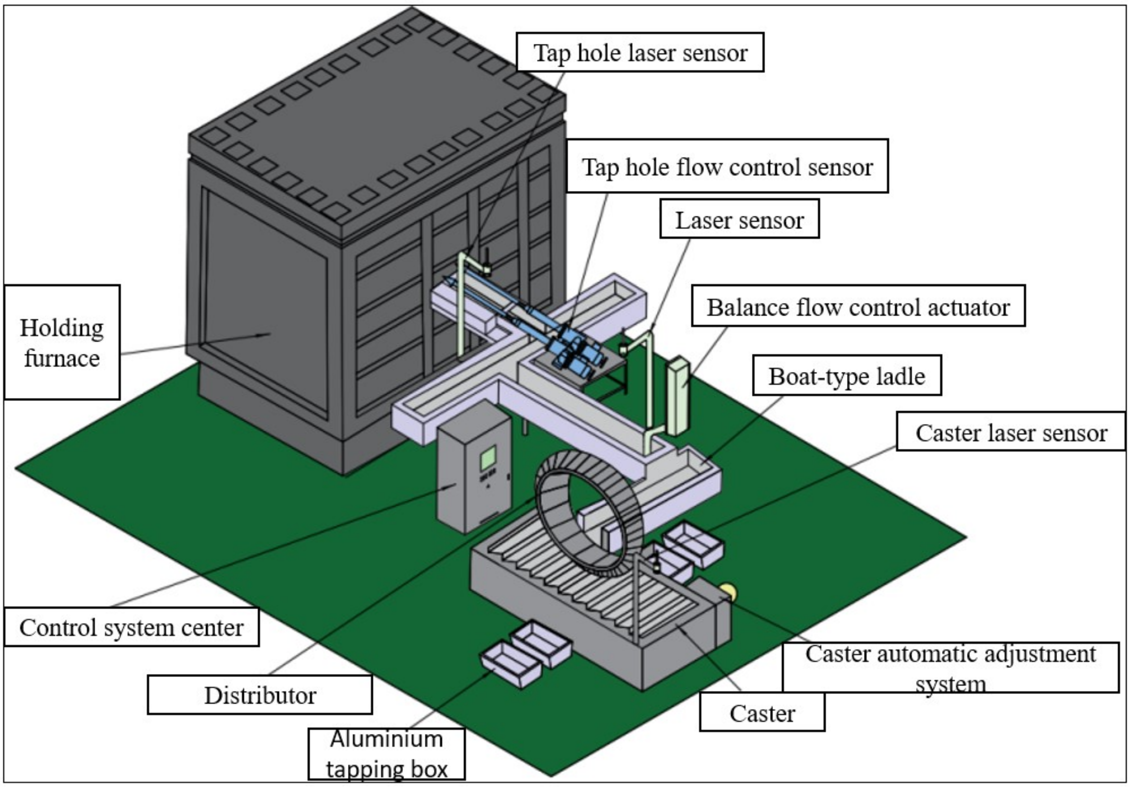

Figure 2. Schematic diagram of flow control and emergency equipment for casting of aluminium ingots for remelting.

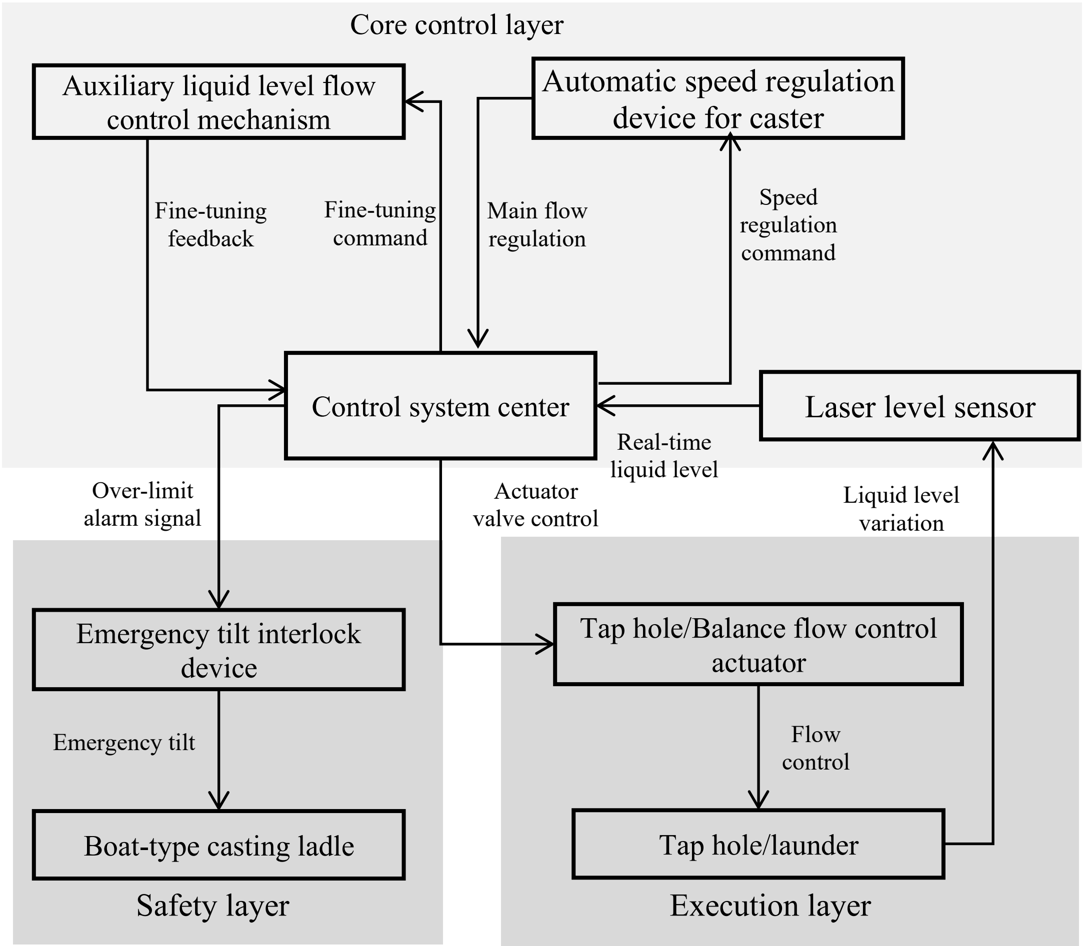

Figure 3. Schematic diagram of control and emergency equipment for casting of aluminium ingots for remelting.

3.2 Precision Control Assurance Measures

The system employs a dedicated microcontroller circuit board and a hardware ADS module for precise control, replacing software-simulated ADS to enhance signal conversion accuracy and stability. The mainstream STM32 chip is selected to meet current input/output interface requirements, while reserved expansion interfaces ensure future system upgrade flexibility. In the field of distance measurement for high-temperature molten aluminium, domestic laser sensors face accuracy limitations due to the extreme thermal environment. Therefore, high-precision laser sensors imported from Switzerland or Japan are selected to ensure precise measurement under high-temperature conditions. For flow control, a PID algorithm is adopted, which guarantees high-precision system performance for both large and minor flow adjustments.

3.3 System Safety Interlocking

In the aluminium casting process, stable operation is critical. By setting high/low level alarms and ultra-high-level monitoring for the molten aluminium in the launder, real-time status tracking can be achieved to prevent abnormal situations. In cases of irregular flow rate, unexpected caster shutdown, or aluminium runoff, the holding furnace tap hole actuator is activated for emergency sealing, while the boat-shaped launder directs the molten aluminium to the aluminium tapping box, which enhances production stability while ensuring personnel and equipment safety.

3.4 Selection of Heat-Resistant Materials for Equipment

In the metallurgical industry, laser sensors are used to measure the height of molten aluminium, where high-temperature environments pose challenges to their stability and measurement accuracy. To ensure long-term stable operation of the sensors, stainless steel is first selected as the housing material, significantly reducing the impact of thermal radiation on the sensor. Additionally, combining air cooling and thermoelectric cooling technologies enables efficient heat dissipation, preventing sensor inaccuracy due to overheating. The integrated application of these protective measures not only enhances the stability of metallurgical laser sensors in high-temperature environments but also ensures the accuracy of molten aluminium level measurement, providing reliable support for the automation and “intelligentization” (i.e. intelligent use of data) of ingot casting production.

4. Practical Application Effects of Automatic Flow Control and Emergency Devices

The aluminium ingot production line in the cast house of Guangxi Hualei mainly consists of a 40-tonne holding furnace, a continuous casting machine with single ingots weighing 25 kg, and other auxiliary facilities. In 2022, the installation and application of automatic flow control and emergency devices effectively resolved manual operation issues such as tapping/plugging furnace tap holes and flow regulation at the tap hole of the casting holding furnace. The device plays a central role in ensuring safe production, reducing the average frequency of laundering and casting aluminium leakage incidents from 2 times/year to zero. The automatic level monitor promptly triggers an alarm when the molten aluminium approaches the high or low level of the launder, while simultaneously linking with the furnace tap hole flow control mechanism to automatically execute sealing or opening operations, effectively preventing aluminium leakage incidents. Furthermore, the entire level monitoring process eliminates the need for frequent manual visual inspections, significantly reducing labour intensity and the risk of human operational errors. In terms of productivity improvement, the production line operators were reduced from over 13 to 10 personnel. The automatic flow control system precisely balanced the molten aluminium flow rate and casting speed, increasing the continuous fault-free casting duration per session from 4.6 hours to over 8 hours and raising the hourly aluminium ingot output from 27 to 39 tonnes, a 44 % efficiency gain. Meanwhile, production interruptions caused by human factors are reduced, enhancing equipment utilization and overall line efficiency. Effective process control has minimized waste from frequent startups, shutdowns, and adjustments, increasing the ingot yield from 99.1 % to 99.8 %, reducing residue aluminium ingots and waste aluminium generation, and further lowering production costs.

5. Conclusion

In summary, the application of intelligent flow control technology in aluminium ingot casting has significantly improved flow control precision and production safety. In the design of the device, the intelligent flow control technology was optimized for emergency response, flow control accuracy enhancement, and automatic speed regulation. By refining the flow control algorithm, more precise flow adjustment has been achieved, while the integrated control technology has improved the overall system stability and collaborative operation capability. In practical application, the production cost is reduced, and the required workforce is decreased by 2–3 personnel, enhancing the automation level of the production line and lowering manual operation intensity. The integrated control system enables precise regulation of the molten aluminium level in the flow channel, improving production line stability and increasing aluminium ingot production efficiency by 44 %, and ensuring both enhanced productivity and production safety.

6. References

1. Xianyou Du, et al., Innovative modifications for long-term use of aluminium ingot casters [J], *Yunnan Science and Technology Management*, 2022 (5): 60–62 (in Chinese).
2. Decai Liu, A Brief discussion on the application of electric control technology in molten aluminium chute emergency devices [J], *World Nonferrous Metals*, 2021 (8): 225–226 (in Chinese).
3. Kairong Xu, Research on Si element control technology in the casting process of remelting refined aluminium ingots [J], *Metallurgy and Materials*, 2024, 44 (12): 118–120 (in Chinese).
4. Jinqiao Li, Jingang Zhu, Measures to reduce casting loss rate of aluminium ingots for remelting [J], *Chemical Enterprise Management*, 2020 (15): 76–77 (in Chinese).