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Development and Demonstration of a Flexible Ingot Mould Filling System

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Abstract

Ingot casting machines are commonly used in the aluminium industry for producing various shapes of ingots, including special shapes such as deoxidizing cones.
Typical molten metal mould filling systems include casting wheels or oscillating feeding bowls that are prone to dross build-up and somewhat difficult to adjust. An automated flexible ingot mould filling system has been designed and installed to improve filling consistency and minimize metal spills outside the moulds. This filling system allows for flexibility of production equipment, enabling the use of different moulds or casting different alloys having different flow characteristics without changing the filling system.

Introduction

Open mould ingot casting machines are widely used to cast many different aluminium alloys in various shapes. Aluminium smelters typically use large casting machines at rates up to 20 tons per hour in the 22 kg remelt ingot shape (approx 15 ingots/minute). These machines are used at fixed parameters, casting pure metal on long production runs[1].

Smaller producers will produce more specialized products on small machines. These products can include variable ingot sizes of different alloys and more specialized products are also cast in open mould casting machines such as deoxidizing cones that are used in the steel industry.

These producers are facing the need for increased flexibility to meet specific customer demands. Such flexibility is somewhat difficult to meet using standard casting equipment since the metal feeding systems have a configuration that offers little place for process variation.

Problem to be solved

The casting machine for which the new mould filling system have been developed was an existing equipment having basic instrumentation and no automation.
The customer Sotrem-Maltech, a producer of specialty aluminium alloys, asked Dynamic Concept to solve problems related to three aspects: Consistency, Weight Control and Alloy Change. While dross generation and production rate are also important factors to consider, emphasis was not put on the latter since flexibility was more important in this particular case.

<u>Degassing cones</u>
Degassing cones having a weight ranging from 60 g to 225 g (2 to 8 ounces) are commonly used in the steel industry to remove oxygen from steel. These cones are handled and fed to molten steel using bulk feeding systems. These cones are typically cast in an array of cavities using an oscillating bowl.

<u>Need for increased consistency</u>
The degassing of steel dynamics requires a consistent cone size in order to yield predictable results. Thus, it is important that the weight variability of a cone batch be as narrow as possible. Customers also require the cones to be free from flashing to minimize the probability of feeding system blockages.

<u>Variable cone weight control</u>
Various steel producers have various feeding system configuration, hence requiring different cone sizes. Thus, it is important to control the individual weight of cones accurately.

<u>Recipe optimization according to variable alloy properties</u>
Alloys used to produce degassing cones can be high iron content aluminium (up to 4%). This iron content dramatically increases the viscosity and flow characteristics of the molten aluminium, thus causing production problems such as weight variability and undesirable flashing on the top of the cones.

<u>Remelt ingots</u>
Remelt ingots of various alloys are cast to meet specific customer alloy requirements. metal from recycling operations also have to be cast. Little control is possible on the alloy composition in this case, leading to challenges for the ingot casting machine operators.

<u>Need for increased consistency</u>
Consistent ingot weight and shape is critical to allow for stable bundling. Moreover, customers are expecting ingots to have consistent shape and weight.

<u>Recipe optimization according to variable alloy properties</u>
As for degassing cones, variable flow characteristics of the different alloys to be cast require the metal distribution system to be flexible in order to attain the target weight of the ingots.

Existing technologies

Typical open mould ingot casting machines used in the aluminium industry are equipped with the casting wheel mould filling system. Oscillating feeding bowls are also used for small shape ingot such as degassing cones.

In the magnesium industry, mould filling systems are typically of the feeding pipe type, whereas a steel feeding pipe is equipped with an integrated valve that opens when the pipe touches the bottom of the mould, allowing for underpouring of the metal and minimizing dross generation. Unfortunately, this solution is impractical for the aluminium industry due to the corrosiveness of the aluminium over other metals and the difficulty of realizing this kind of feeding system with refractory or ceramic materials.

<u>Metal level control</u>
The metal level control accuracy is of prime importance for any mould filling system. Such control is relatively easy when filling a

casting wheel from a holding furnace with level. However, casting directly from a crucible poses some challenges to the casting machine since there is a difference of level between the crucible metal surface and the launder surface.

Feeding bowl

The feeding bowl used for small shapes is made of a refractory lined steel container mounted on an axis allowing its oscillation. One side of the container has a series of U shaped openings allowing the metal to flow temporarily at each oscillation. The oscillations are timed with the movement of the conveyor so that a controlled amount of metal is poured in the mould at each oscillation. The oscillation can be controlled either with a cam or using an air cylinder.

While this system appears to be simple and adjustable (especially the air cylinder type which can flow during an amount of time that can be set differently according to the alloys and ingot size desired), there are many downsides:

- It is difficult to control the level in the bowl due to the constant oscillations
- The amount of dross generated is high due to the constant movement of the surface
- The openings are prone to dross / frozen metal buildup and mould to mould weight consistency is not reliable
- The difference of height between the pouring point and the bottom of the mould cannot be minimized, thus causing projections and flashing.

Casting wheel

The casting wheel is the most commonly used mould filling technology. While optimized for long production runs of constant alloy composition, it lacks flexibility and requires a lot of heat to minimize the possibility of stalactite formation.

Moreover, from a specialty alloy producer point of view, the casting wheel has many inconveniencies:

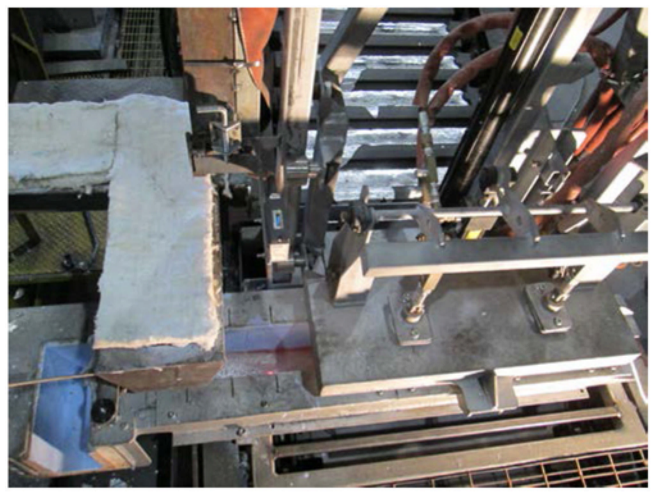
- Heating of the wheel while casting consumes a lot of energy
- The casting wheel shape is directly related to the mould shape and very small ingots such as degassing cones cannot be produced
- The flow of metal in the wheel and in the mould exposes a lot of fresh metal to the atmosphere, causing dross generation.
- If an ingot is stuck in the mould, it must be immediately removed manually or the chain must be stopped since the wheel interferes with the interior of the moulds
- There is no possibility to skip a defective mould

Description of the solution

Starting from a manually operated equipment, equipped with an oscillating bowl for cone production and a casting wheel for ingot production (moulds can be changed when different product shapes are required), Dynamic Concept proposed an automated mould filling system aiming to provide the following advantages for both applications:

- Increased consistency
- Variable weight control
- Recipe optimization according to alloy characteristics

This filling system had to include all the hardware modifications from the crucible tilting system down to the mould filling system, as well as automation and logical sequences required to operate the equipment safely in automatic mode.



Crucible tilting system

The existing equipment was using a crucible tilting table to feed the metal to the mould filling system.

A linear encoder was installed on one of the cylinders. The manual directional valve of the hydraulic power unit was replaced with a servo-controlled proportional valve.

The tilting of the crucible was looped with the metal level in the distribution launder.

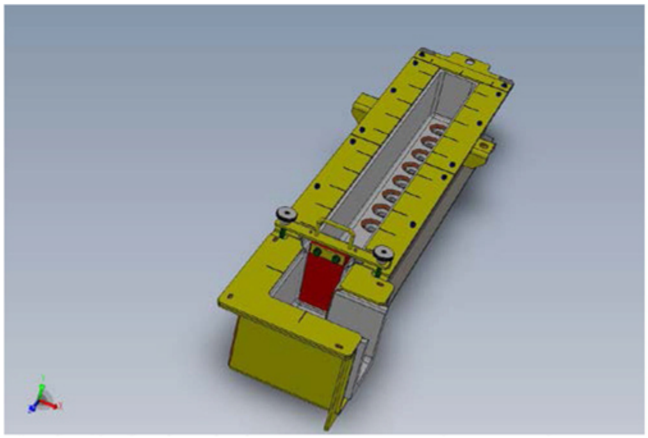
Distribution launder

A distribution launder, similar to those used in the Direct Chill process, was designed, with the difference that the pins and spouts were designed to be on/off instead of finely controlling the metal flow.

The distribution launder design prevents the oxide layer on the surface of the melt to be fed through the spouts since the metal is fed through the bottom of the launder.

Furthermore, keeping the metal level constant provides consistent flow characteristics (constant head) to the spouts.

The metal level drops significantly during the feeding of metal to the mould but the constant addition of new metal enables the level to reach the set point prior to the next opening of the pins.



The distribution launder has a gate at one end to empty its content into a pan in case of an emergency stop.

Pin and spout design

The pins and spouts are designed to allow full flow of metal as soon as they are open. The sealing faces are critical to prevent dripping while the pins are closed. Pin alignment must be accurately controlled to keep the sealing efficient.

The most efficient design was found to be using a conical spout opening (60 degrees opening angle) and an conical or hemispherical pin end. This provide a continuous sealing line even if there is a slight misalignment of the pin.

The spout diameter is set according to the desired metal flow. The spouts are made of individual cast parts inserted in the bottom of the launder refractory. Metal flow is calculated based on the time available to fill the moulds.

For this application, remelt ingot weight is 7 kg and there is a window of 4 seconds available. A flow of approx 0.88 kg/s is required using two 19 mm diameter spouts.

Since all pins must open and close simultaneously, a spring loading system is required to compensate for fabrication tolerances and thermal distortions. A slight compression is exerted in the closed position. The pins are actuated using a single compressed air cylinder that moves levers mounted on a common axis, themselves lifting and lowering the pins.

The pin actuating mechanism is mounted on a moving frame which is placed on the top of the launder in casting position. The moving frame is lifted using a pneumatic cylinder for maintenance and preparation.

Materials

All metal transfer troughs and distribution launders are made of regular refractory materials, with high performance insulation to minimize heat losses at low flows.

Various materials can be used for the pins and spouts. Satisfactory results have been attained using N-14, N17 and graphite.

Control strategy

With on/off control pins, the amount of metal that is sent to the moulds is controlled by the opening time of the pins. Since the flow is very constant from one pin to the other (being dependent upon the spout diameter and metal head only), a predictable amount of metal is sent to the moulds and the variation is minimal.

The timing of the opening of the pins is made using a proximity sensor that detects the mould position.

The metal level in the distribution launder is kept constant using a laser sensor linked to the tilting control of the crucible. The large level difference between the pouring point of the crucible and the launder prevents controlling using a direct PID loop (level pour is not possible). Instead, the tilting velocity is limited to a safe value that allows some margin on the available metal flow at any angle. Then, the proportional valve is opened using a table comparing the actual level in the launder to the set point. This way, the level is kept within a close range sufficient for process accuracy.

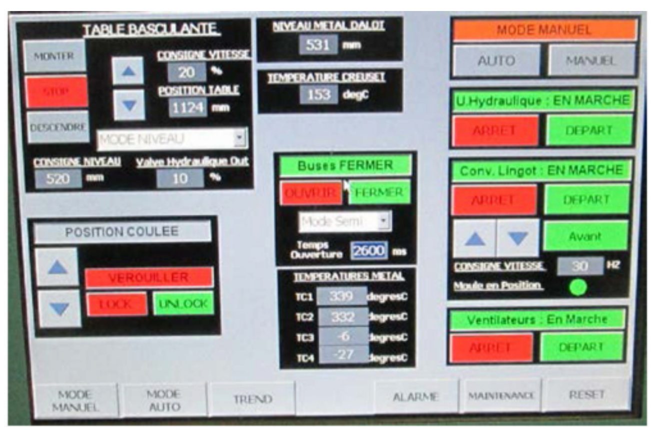
The startup is made manually since the available metal level in the crucible is variable and to avoid the level sensor problems that can occur at initial filling of the launder (reflections).

The ending sequence is initiated when there is an insufficient metal flow coming from the crucible to keep the metal level constant in the launder. To compensate from the reduced flow, the conveyor chain slows down to allow time to the metal to fill the launder between two moulds. The machine simply stops on low level alarm in the launder when the chain is at minimum speed and there is no more metal.

Control system

The casting is controlled using a PLC. The following instruments have been added for the control of the machine:

- Linear encoder on the crucible tilter cylinders
- Infrared sensor to detect ready to cast position of the tilter
- Laser level sensor on the launder
- Proximity sensor for mould detection
- Sensors for pins position (open/closed)



Typical operational parameters
For typical ingots weighing 7 kg, operational parameters are as follows:

Metal head	75 mm
Spout diameter	19 mm (2 spouts)
Opening time	3.30 seconds
Metal temperature	730˚C
Chain speed	6 moulds / minute

Opening time, metal head and metal temperature are closely related and must be kept constant during the process.

Advantages of the new system

This new system provides many advantages over the other technologies.

Recipe flexibility vs alloy properties
Using the PLC it is easy to preset recipes based on alloy properties to avoid variation of ingot size when changing alloys.

Spout to spout consistency
Since the spouts are not subject to dross buildup, individual ingot and cones sizes are in a much narrower range.

Ingot size consistency
Automation and accurate control of the process parameters allow for greater ingot size consistency.

Ingot size flexibility
The new system provides such control that it is easy to adjust the ingot size allowing the production of different products using the same moulds.

Splashing reduction
Since the spouts are close to the moulds, and the timing of the metal flow can be adjusted, then metal splashing can be minimized by accurately timing the beginning of the mould filling.

Possibility to skip moulds
In the case where an ingot is stuck in a mould, or if an individual mould is found to be defective, it is possible to continue casting by just skipping the defective mould, with the addition of an encoder on the conveyor to track individual mould positions.
Since the feeding system is not interfering with the mould cavity, then the chain does not have to be stopped if an ingot is stuck or a mould is missing or damaged.

Future work

While the actual system is satisfactory, there are a few areas where potential for future improvements have been identified:

- Automation of the starting sequence
- Improvement of pin actuator system for quick change and offline maintenance
- Optimization of pin and spout materials to maximize durability

Conclusion

While existing casting wheel mould feeding systems have proven performances for large capacity production equipment operating under constant conditions, this technology lacks flexibility when it comes to small productions of various alloys and sizes. On the other hand, oscillating bowls provide the possibility to cast small shapes but they are prone to dross build-up.
An automated mould filling system using pins and spouts provides the flexibility to cast various shapes using the same filling equipment while allowing for easy recipe adjustment when changing alloys and sizes. This system is adaptable on any existing equipment.

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