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CAM-Controlled Ingot Feeding Mechanism for Melting Furnaces

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Abstract: Aluminum ingot feeding systems are vital for ensuring efficient and controlled melting processes in aluminum production. This work presents a novel CAM-controlled ingot feeding unit specifically designed for furnaces employing non-oxidation melting technology. The system is composed of two primary units: a conveyor system for feeding to the input unit, and an input unit that consists of chucking (vice) units, conveyor chain, and a CAM unit with a special profile. When using 5 kg ingots, the system is capable of feeding up to 900 kg per hour. Spring-tensioned two-jaw vices are used to securely clamp the ingots during feeding. Up to three vices can be employed simultaneously, and they can be easily mounted onto the conveyor chain as required by the application. The conveyor chain speed of the input unit is adjustable via a motor inverter, allowing precise control of the ingot feeding rate to the furnace. The clamping and unclamping mechanisms are actuated by a cam unit with a specially designed profile, ensuring synchronized and reliable operation. The entire unit is engineered for easy installation onto the furnace structure. After fabrication, the system was tested continuously over a six-day period, and the results demonstrated that it is highly suitable for use in a production environment.

Keywords: Aluminum, Cam control, Dross, Feeder, Ingot, Melting furnace, Vapor explosion

1. Introduction

Aluminum is one of the most versatile and widely used metals in the modern world. Renowned for its lightweight nature, high strength, corrosion resistance, and recyclability, aluminum has become an essential material in the production of everything from aircraft to beverage cans. As global demand for aluminum continues to rise, the efficiency and sustainability of its processing methods have become increasingly important in meeting both economic and environmental objectives [1].

Melting is one of the fundamental processes in aluminum production, playing a crucial role in preparing the material for a wide range of applications. The efficiency and effectiveness of aluminum melting methods have a direct impact on both the quality of the final product and the energy consumption associated with the production process [2, 3]. Various melting techniques, such as crucible furnaces, immersion furnaces, induction furnaces, and reverberatory furnaces, each come with their own advantages and limitations. Similarly, energy sources including gas-fired or fuel-fired burners, radiant roof electric heaters, and immersion heaters powered by gas or electricity offer distinct benefits and drawbacks. Considering these factors, modern innovations in energy-efficient and environmentally friendly melting technologies are becoming increasingly important. Among these, non-oxidation melting furnaces are gaining popularity due to their high energy efficiency and significant reduction in aluminum loss [4].

Aluminum ingot feeding systems are essential components in the aluminum industry, playing a critical role in the melting process that prepares ingots for further manufacturing. These systems are designed to minimize risk and reduce the need for human intervention in hazardous areas, thereby enhancing both safety and operational efficiency. There are several types of aluminum ingot feeding systems, including gravity feeding systems [5], conveyor feeding systems [5], and robotic feeding systems [6–8]. Both gravity and conveyor feeding systems typically require a relatively large furnace opening to accommodate the ingot feeding. These large furnace openings result in greater heat loss and increase the exposure of

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liquid aluminum to air, which can negatively affect the melting process.

Additionally, in gravity and conveyor feeding systems, dropping ingots directly into the molten aluminum often causes splashing, which further exposes the melt to air and leads to excessive dross formation [9]. Although these systems are simple in design and therefore cost-effective, they require a high level of human intervention, which ultimately leads to an increased overall operational cost. While robotic feeding systems effectively mitigate these issues, they often require ingots with specialized geometries and specialized feeding units to the robot, which can increase production costs. Another major concern associated with feeding ingots directly into molten aluminum is the risk of a vapor explosion [10, 11]. This occurs when ingots containing high moisture content or surface water droplets are introduced into the molten metal, causing a rapid and potentially hazardous reaction. To prevent such incidents, a preheating process is typically employed to remove moisture from the ingots before insertion. In addition, introducing a large quantity of ingots into the molten aluminum all at once can cause significant temperature fluctuations in the melt. These fluctuations can negatively impact both the melting time and the quality of the molten aluminum.

To address the aforementioned challenges, this study introduces a novel ingot feeding unit designed for furnaces utilizing non-oxidative melting technology. The system comprises two main components: a conveyor for feeding to the input unit, and an input unit consisting of a conveyor chain, spring-tensioned clamping vices, and a cam unit with a specially designed profile. When using 5 kg ingots, the unit is capable of feeding up to 900 kg per hour, using ingots that are not preheated but properly stored. For secure handling, spring-tensioned two-jaw vices are employed. Up to three vices can be mounted on the conveyor chain, allowing for flexibility based on operational requirements. The chain speed of the input unit is adjustable via a motor inverter, enabling precise control of the feeding rate to the furnace. The clamping and unclamping actions are fully synchronized and controlled by the cam profile. Designed for straightforward integration with existing furnace systems, the unit was fabricated and subjected to six consecutive days of continuous testing. During this period, it demonstrated stable, efficient, and reliable performance, confirming its suitability for industrial-scale production environments.

Table 1 compares the proposed system with existing gravity and conveyor feeding systems, providing context for its performance relative to conventional feeding approaches while illustrating how key limitations are addressed with a balanced cost profile.

2. Design Considerations

Several key factors were carefully considered in the design of this unit. These include unit capacity, variations in ingot geometry, minimizing heat loss from the furnace, ensuring continuous and uniform feeding into the molten metal, preventing splashing at the point of entry, enabling easy adjustment of feeding capacity to the furnace, achieving precise control of the clamping vices, and ensuring seamless integration with existing furnace systems. Each of these criteria is discussed in detail in the following sections.

2.1 Capacity of the Unit

Furnaces utilizing non-oxidation melting technology are typically employed for medium-range melting capacities, generally up to 1500 kg per hour. This limitation is primarily due to their design, which often incorporates immersion heaters. As the required melting capacity increases, the number of heaters must also increase, leading to a larger furnace size. This, in turn, introduces several challenges, including maintenance complexity, cleaning difficulties, and reduced equipment lifespan.

To meet industrial demands while addressing these constraints, the capacity of the proposed ingot feeding system was set in the range of 900 kg to 1800 kg per hour, based on a one-minute feeding cycle. This performance can be achieved by adjusting the ingot weight between 5 kg and 10 kg. Additionally, the system's capacity can be

Table 1 – Comparison of the proposed unit with existing designs for its cost and performance

Designation	Cost	Human intervention	Heat emission	Splashing
Gravity systems	Less	High	High (large openings)	High
Robot systems	High	Less	Low (small openings-vertical inserting)	Low (In vertical inserting)
Proposed system	Moderate	Less	Low (small openings)	Low

further tailored to customer requirements by modifying the input cycle time and adjusting the number of clamping vices.

2.2 Variation of the Ingot Geometry

A variety of ingot geometries are available in the market, with the most common type illustrated in Figure 1. The bottom shape and dimensions of ingots can vary depending on the manufacturer. The illustrated ingot weighs 5 kg, which is a standard size. In this study, ingots ranging from 5 kg to 10 kg were considered. The ingot dimensions typically vary within the following ranges: 680 mm to 700 mm in length, 90 mm to 125 mm in width, and 35 mm to 50 mm in height. The geometry of the bottom surface is specifically designed to enable easy ejection from the mold during the casting process and may differ accordingly.

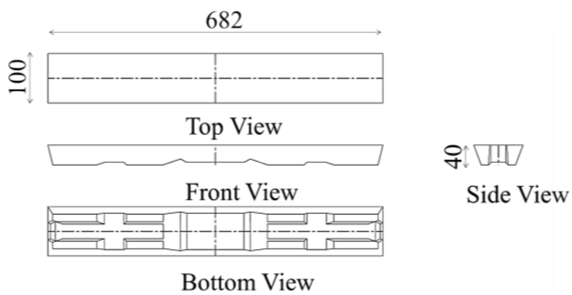


Figure 1 – Geometry of a common ingot

2.3 Reducing Heat Emissions

Heat emissions from an open area above molten metal depend on several factors, including the emissivity of the molten metal, the height of the opening above the molten surface, the area of the opening, and the rate of heat transfer. Among these, for a given furnace design, the area of the opening is typically the only parameter that can be adjusted.

Minimizing the opening area not only reduces heat loss but also limits the contact between air and the molten aluminum, thereby reducing dross formation. Based on this principle, the design sets a clearance of 50 mm on each side relative to the cross-section of the largest aluminum ingot used with the device. This clearance allows for the installation of a swinging door over the opening, further minimizing heat loss. As noted in Section 2.2, the cross-sectional dimensions of the largest ingot are 50 mm × 125 mm, resulting in a furnace opening size of 100 mm × 175 mm.

2.4 Continuous Feeding

The furnace in a production facility requires continuous feed to maintain its threshold level. To meet this requirement, the feeding unit is designed to operate at a set rate until the upper-level limit signal is received by the controller. Feeding resumes once the lower-level limit signal is detected. Additionally, the unit can adjust the feeding speed to match the amount of liquid consumed during each cycle. This approach helps ensure a steady supply and minimizes temperature fluctuations in the liquid metal.

2.5 Eliminating the Splashing

Splashing of liquid aluminum increases the surface area exposed to air, promoting the formation of dross. This reduces aluminum yield and increases both material loss and dross buildup along the boundary walls. Dross deposits on the walls cause several issues, including wall damage, cavity filling due to capillary action (leading to cracks), and the need for frequent cleaning and maintenance.

To eliminate splashing, this device lowers the ingot vertically into the molten aluminum at a very low speed. Once the ingot is submerged halfway, the clamping grip is released, allowing the remaining portion to sink under gravity. As feeding continues, the ingot begins to melt, with the upper part heated by the surrounding liquid aluminum. This process helps remove moisture from the ingot, reduces temperature differences, and minimizes fluctuations in the temperature of the molten aluminum.

2.6 Changing the Feeding Capacity

This design allows for the integration of up to three chucks on the chain, effectively tripling the feeding capacity. Additionally, the feeding speed can be adjusted using an inverter, providing further control over the overall feed rate.

For example, with a one-minute cycle time and a single chuck handling 5 kg ingots, the unit can feed approximately 300 kg per hour. When three chucks are used at the same speed with the same ingot weight, the feeding capacity increases to 900 kg per hour. If 10 kg ingots are used under the same conditions, the capacity can reach up to 1,800 kg per hour.

The one-minute cycle time is based on experimental data showing that a 5 kg ingot melts in approximately 40 seconds in molten aluminum at 680°C without stirring, and in about 20 seconds with stirring. However, these values can vary depending on several factors.

2.7 Control of the Clamping Vices

Precise control of the clamping vices at both the ingot loading point and the furnace input point is essential to ensure proper ingot capture and release. Any malfunction at these stages can lead to a system-wide jam. This control is achieved using two mechanical cams mounted on the unit's steel frame, which engage with cam followers attached to the moving jaws of the vices. When the cam followers come into contact with the cams, the cams push the moving jaws to open the vices, allowing the ingot to be released into the furnace.

Once an ingot is released at the designated cam release point, a photoelectric sensor detects the position of the vice and sends a signal to stop the input unit until the next ingot reaches the capture position.

An additional photoelectric sensor is installed at the end of the feed conveyor to detect the presence of an ingot. When an ingot is detected, the sensor triggers the system to activate the input unit. The vice, in its open state, moves toward the loading point and pushes the release lever of the mechanical stopper, allowing the ingot to load into the vice. Simultaneously, the cam followers disengage from the cam, causing the vice to close and securely clamp the ingot. A mechanical stopper is positioned at the ingot capture point to accurately halt the ingot, ensuring it is properly aligned for secure clamping.

2.8 Easy Integration with Furnace

The base of the unit is constructed from a 16 mm thick steel plate, providing a stable and durable foundation. Its vertical design results in a relatively small footprint, making it well-suited for installation on existing furnaces. The unit can be either bolted or clamped directly to the furnace face, offering flexibility and ease of integration into various setups.

3. Detail Design

The unit consists of two main components, a feed conveyor and input unit, which are mounted on a base plate, as illustrated in Figure 2. The conveyor, fixed in the horizontal direction, transports the ingot to the vice on the input unit. The input unit, oriented vertically as shown in Figure 2, inserts the ingot into the furnace along the vertical axis.

The conveyor includes two key elements: a photoelectric sensor mounted at its end to detect the presence of an ingot, and a mechanical stopper positioned at the vice loading point to precisely halt the ingot for clamping.

The input unit comprises three clamping vices equipped with cam followers, a conveyor chain, two sprockets, two mechanical cams that control the opening and closing of the vices during operation, a motor to drive the sprockets, and a photoelectric sensor to detect the position of the vice. Detailed design criteria for each of these components are discussed in the following sections.

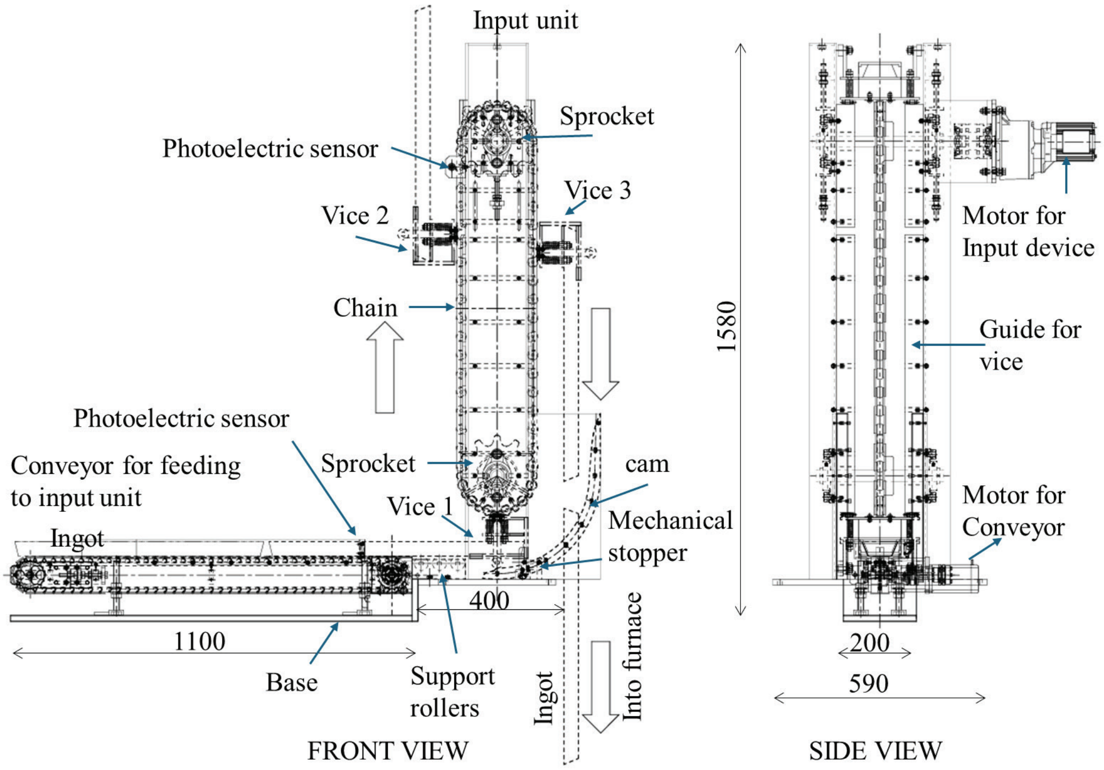


Figure 2 – Proposed ingot input system

3.1 Conveyor

The conveyor primarily consists of a conveyor chain, two sprockets, a chain supporter, a motor, a flexible coupling, a chain tension adjustment unit, height adjustment bolts, guides for the ingot, and one photoelectric sensor. A welded slat conveyor chain was selected to facilitate smooth and reliable transport of the ingot to the vice on the input unit.

The total conveyed mass, including a safety factor of 1.5, was considered to be 30 kg. The conveyor width was chosen as 130 mm to support the largest ingot size; however, within the available slat sizes, a slat width of 101.6 mm was selected.

The cycle time for the input unit was set at one minute, and with three chucks in use, the time per chuck is 20 seconds. Based on this, the time required for the ingot to reach the stopper was estimated at 10 seconds.

The total conveying length is 1690 mm, which includes the length of the ingot and the center distance between the sprockets. Accordingly, the conveyor speed was calculated to be 10 meters per minute.

The chain load (F) was then tentatively calculated using Equation (1) to select the appropriate chain type.

$$F = W \times f_1 \times K_v \times \frac{G}{1000} \quad \text{...(1)}$$

where W is the total mass of the conveyed objects, f_1 is the coefficient of friction, K_v is the speed coefficient, and G is the acceleration due to gravity.

By substituting the values W = 30 kg, f_1 = chain rollers rolling on rail + base chain plates sliding on rail = 0.12 + 0.30 = 0.42, K_v = 1, and G = 9.81 m/s^2 into Equation (1), the force F can be calculated as: F = 0.13 kN.

The chain selected was the one with allowable roller and attachment loads exceeding the calculated force F and compatible with the chosen slat width. To determine the maximum chain load (F_m), Equation (2) was used.

$$F_m = (W + 2.1 \times M \times C) \times f_1 \times \frac{G}{1000} \quad \text{...(2)}$$

where W is the total mass of conveyed objects, M is the mass of moving parts per meter, C is the center distance between sprockets, f_1 is the coefficient of friction between the chain and guide rail, and G is the gravitational acceleration. By substituting the values W = 30 kg, f_1 = 0.42, M = 7 kg/m, C = 0.99 m, and G = 9.81 m/s^2 into Equation (2), the maximum chain load F_m was calculated as: F_m = 0.19 kN.

The final chain selection was made to satisfy the requirements of Equation (3).

$$F_m \times K_v \leq Max.allowable\ load \quad \text{...(3)}$$

Based on the selected chain, the sprockets were chosen accordingly. Then, the motor power (P) required to drive the chain was calculated using Equation (4).

$$P = \frac{F_m \times V}{60} \times \frac{1}{\eta} \quad \text{...(4)}$$

where η represents the transmission efficiency of the drive unit. By substituting the calculated values along with η = 60% into Equation (4), the required power is determined to be P = 0.05 kW. Based on this result and available catalog specifications, a 90 W three-phase motor with a gear ratio of 1:40 was chosen to match the required conveyor speed. The sprocket size was also determined from the catalog data, with a selected pitch circle diameter of 78.23 mm.

3.2 Input Device

The input device consists of a chain with attachments, two sprockets, clamping vices, a photoelectric sensor, two cams, a motor, a flexible coupling, vice guides, a chain adjustment mechanism, a mechanical stopper, and a base plate.

3.2.1 Vice

The vice is used to clamp the ingots at the input point and transport them to the designated position. In this design, three vices are utilized to achieve the full operational capacity of the unit. The vice is illustrated in Figure 3 and consists of two jaws: a fixed jaw and a moving jaw.

The moving jaw is supported by four coil springs, while the opposite side is guided by two cam followers. Six rollers are mounted on the fixed jaw to maintain contact with the guide, ensuring smooth and stable sliding motion.

The springs are selected to provide sufficient clamping force, allowing the vice to securely hold an ingot with a height variation of up to 5 mm, and to accommodate the maximum jaw opening defined by the cam's displacement. A rolling friction coefficient of μ_R = 0.4 is assumed between aluminum and steel, which is lower than sliding friction to ensure a safe and reliable clamping action.

The frictional force F_R is given by Equation (5), where R_R is the normal force.

$$F_R = \mu_R \times R_R \quad \text{...(5)}$$

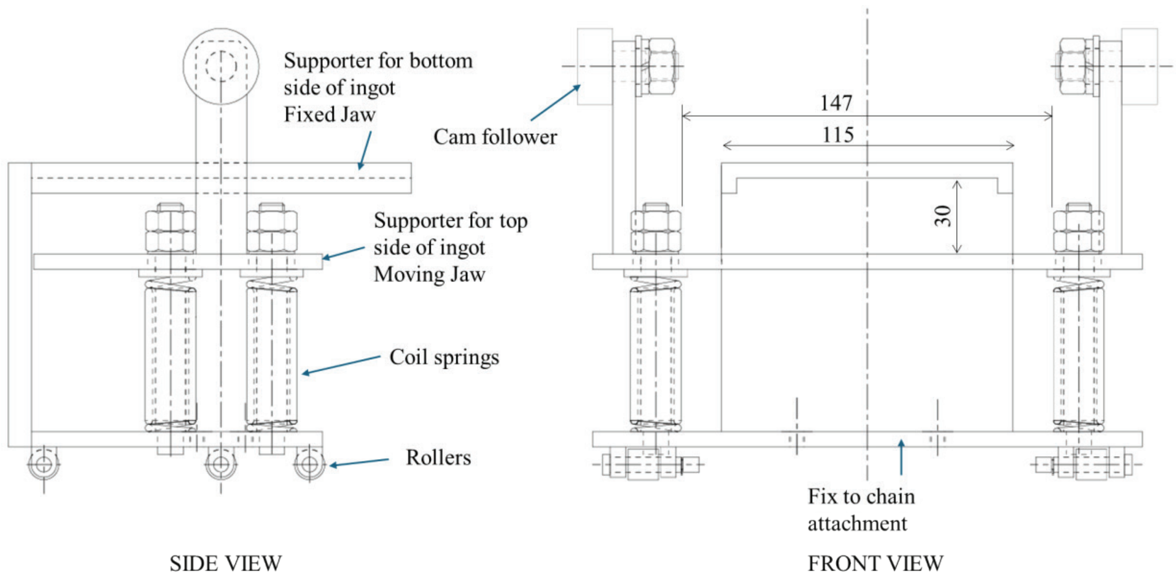


Figure 3 – Schematic diagram of vice

In this design, the minimum height variation for a 5 kg ingot is considered to be 5 mm (35 mm – 30 mm), and for a 10 kg ingot, 15 mm (45 mm – 30 mm). To ensure a secure grip of the aluminum ingot, the required friction force must exceed 49.05 N for the 5 kg ingot and 98.1 N for the 10 kg ingot.

By substituting these values into Equation (5), the required normal force (R_R) is calculated as 122.63 N for the 5 kg ingot and 245.25 N for the 10 kg ingot.

Taking the lower value of 122.63 N and dividing it by the number of coil springs used, the minimum required spring constant was calculated to be 6.13 N/mm. To verify this value, it was applied to the 10 kg ingot, and the resulting friction force was calculated to be 367.8 N, equivalent to approximately 37.49 kg. This confirms that the minimum spring constant is sufficient for securely clamping the full range of ingots used in the system.

Considering a safety factor of 2, the final required spring constant was set at 12.26 N/mm. However, based on available spring catalog specifications, a spring with a constant of 12.35 N/mm was selected. To ensure safe and reliable operation, periodic inspection of the vice units is recommended to detect and address any loosening during service.

3.2.2 Chain and Attachments

The total length of the input device chain was determined based on the maximum ingot length and the number of ingots the system needs to accommodate. The chain length was calculated to be 2400 mm, allowing for a 100 mm gap between each ingot. To support three clamping vices, three attachments are required on the chain. Based on this configuration, the chain pitch was selected to be compatible with available specifications from the manufacturer's catalog.

The total conveyed mass, including a safety factor of 1.5, was calculated as 45 kg. Assuming cycle time of 40 seconds to get a slightly higher speed that can be adjusted later using a motor inverter, the required chain speed was calculated as 3.6 m/min.

To tentatively select a suitable chain, the chain load was calculated using Equation (1).

Substituting the values: W = 45 kg, f_1 = friction coefficient for chain rollers rolling on rail + friction coefficient for three base chain plates sliding on rail = 0.12 + 3 × 0.12 = 0.48, K_v= 1, G = 9.81 m/s², the resulting chain load F was calculated as: F = 0.212 kN

A chain with allowable roller load and attachment load values exceeding the calculated force F was selected. An additional parameter considered was the available space for mounting the vice on the chain attachment. To meet this requirement, a chain with a 50 mm pitch was chosen. To calculate the maximum chain load for the vertically moving chain (F_{m1}), Equation (6) was used.

$$F_{m1} = ((W + M) \times C) + \frac{W_T}{2}) \times \frac{G}{1000} \quad ...(6)$$

where W_T is the take-up load (total mass on driven side). Substituting the values into Equation (6):

W = 45 kg, M = chain weight per meter + weight of attachments per meter + weight of vices per meter = 3.5 + (0.07 × 2) + (3.5 × 2) = 10.64 kg, C = center distance =0.9144 m, W_T = 54 kg, G = 9.81 m/s², the maximum chain load for the vertically moving chain (F_{m1}) can be calculated as: F_{m1}= 0.76kN

The final chain selection was made to ensure compliance with Equation (3). Based on the selected chain, the appropriate sprockets were also chosen. The motor power (P)required to drive the vertically moving chain is calculated using Equation (7).

$$P = \left(\frac{F_V + F_{m1}}{60}\right) \times V \times \frac{1}{\eta} \quad ...(7)$$

where F_V denotes the friction force required to move the vice along the cam while R_V represents the force needed to compress the springs in the vice during clamp and unclamp of the ingot. F_V is defined in Equation (8).

$$F_V = \mu_V \times R_V \quad ...(8)$$

where μ_V is the coefficient of rolling friction between the cam and cam follower, and R_V is the maximum reaction force at a compression of 30 mm, corresponding to the cam height. By substituting μ_V = 0.2 and R_V = 1482 N into Equation (8), the resulting force F_V is calculated to be 0.3 kN.

Substituting F_V = 0.3 kN, F_{m1}= 0.76 kN, and an efficiency of η = 60% into Equation (7), the required motor power is calculated as: P = 0.106 kW.

Since inverter-based speed control is necessary, a three-phase inverter-compatible motor with a power rating of 0.2 kW was selected. To satisfy the required maximum chain speed of 3.6 m/min, ensuring the desired feed rate, a gear ratio of 1:270 was chosen. The sprocket size was determined based on available catalog data, with a selected pitch circle diameter of 196.28 mm.

3.2.3 Mechanical Stopper

The mechanical stopper, illustrated in Figure 4, is used to halt the conveyed ingot at the loading point of the input device. It is designed to allow the moving lever to pivot in only one direction. As shown in Figure 4, when the vice passes the stopper while capturing the ingot, it pushes the moving lever in the indicated direction. After the vice has passed, the moving lever returns to its original position with the help of springs and the stopper mechanism, thereby resetting the system to stop the next incoming ingot.

3.2.4 Cam

Two cams are mounted on the steel structure, one on each side, to make contact with the cam followers attached to the vice, which moves along with the chain and is guided by support rails. The cam profile plays a critical role in the operation of the input device, as it controls the clamping and unclamping actions of the vice.

In both the clamping and unclamping regions, constant velocity follower motion is employed. Based on this motion, the cam profile was designed, as illustrated in Figure 5. The corresponding displacement profiles are shown in Figures 6 and 7. Figure 6 depicts the displacement in the unclamping area, while Figure 7 shows the displacement in the clamping area. The total displacement of the cam follower is 30 mm, which corresponds to the maximum travel of the movable jaw of the vice.

The cam–follower system must also be subjected to periodic inspection to identify potential mechanical loosening during operation.

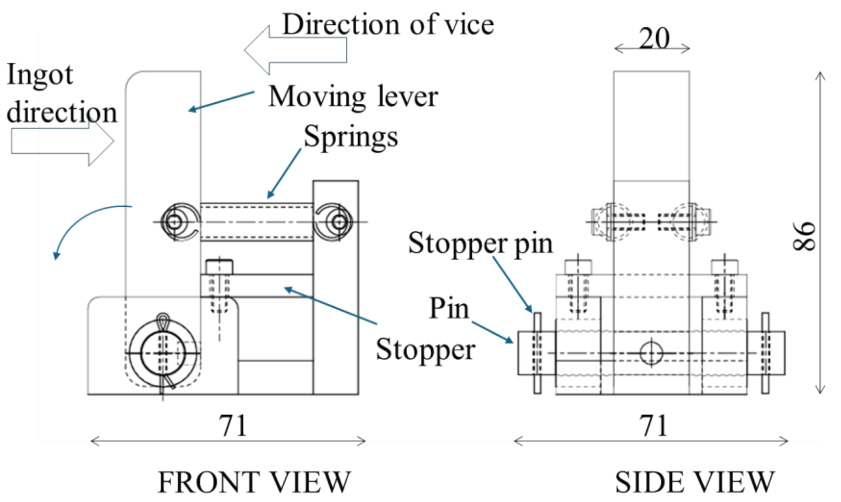


Figure 4 – Mechanical stopper

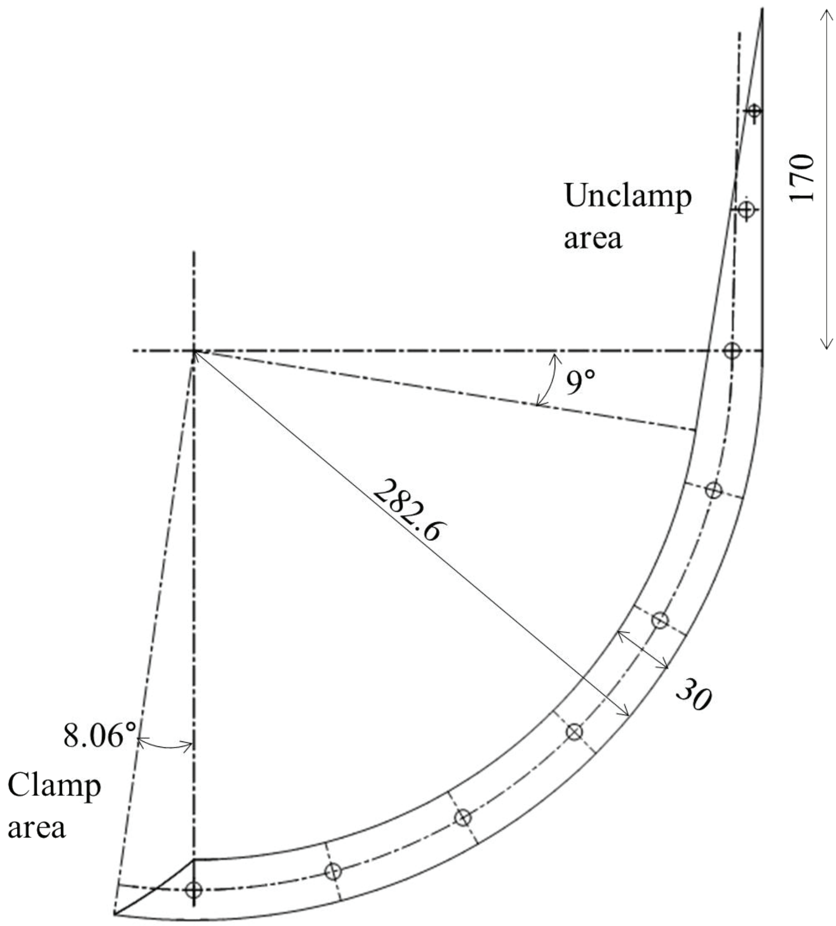


Figure 5 – Cam profile

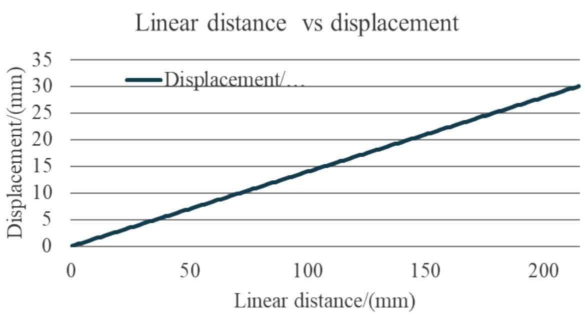


Figure 6 – Displacement at unclamping area

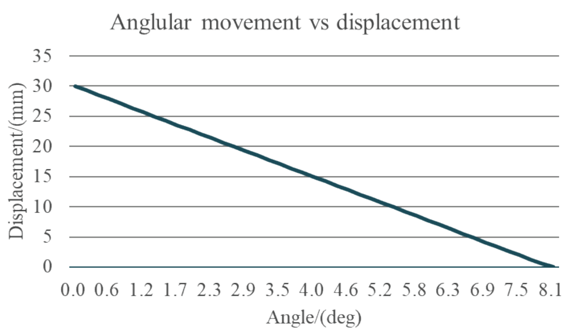


Figure 7 – Displacement at clamping area

3.2.5 Base Plate

The size of the base plate was determined by considering the total thickness of the furnace wall, including both the steel plate and refractory materials. In standard practice, furnace walls typically have a thickness of 300 mm to 350 mm to maintain a low external surface temperature. Based on this, the base length was set to 400 mm, ensuring that the opening for inserting ingots extends beyond the wall thickness. The width was chosen to be 590 mm to provide stability for the unit and to facilitate easy installation. To enhance the rigidity of the entire assembly, the plate thickness was set to 16 mm.

4. Fabrication and Final Product

All steel structures were first fabricated, after which the conveyor and input device were assembled. The complete system was then tested under all possible operating conditions. Figure 8 shows the assembled conveyor, Figure 9(a) shows the assembled input device, and Figure 9(b) captures the unit during testing.

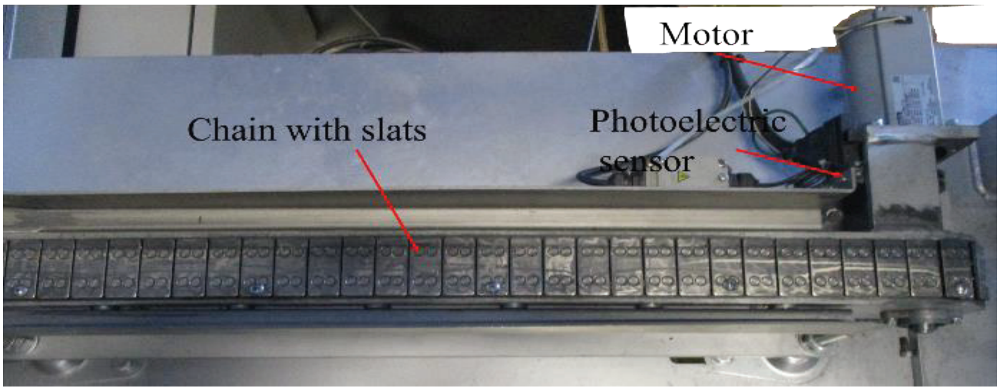
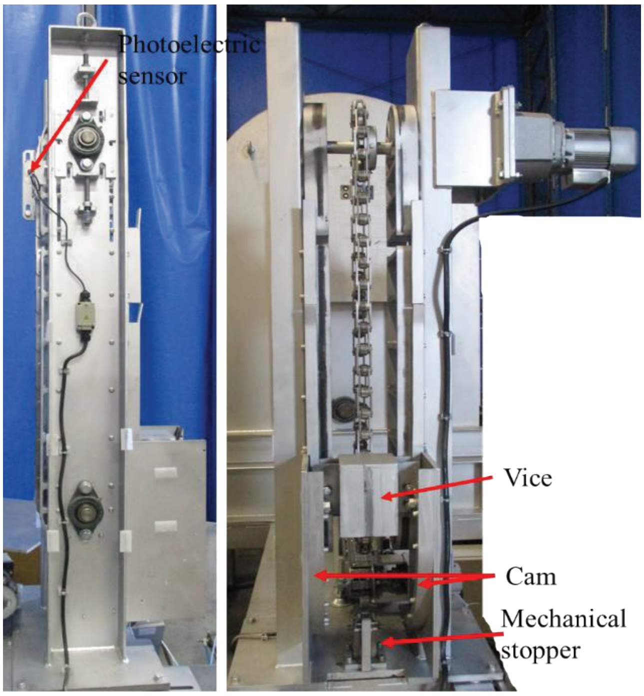
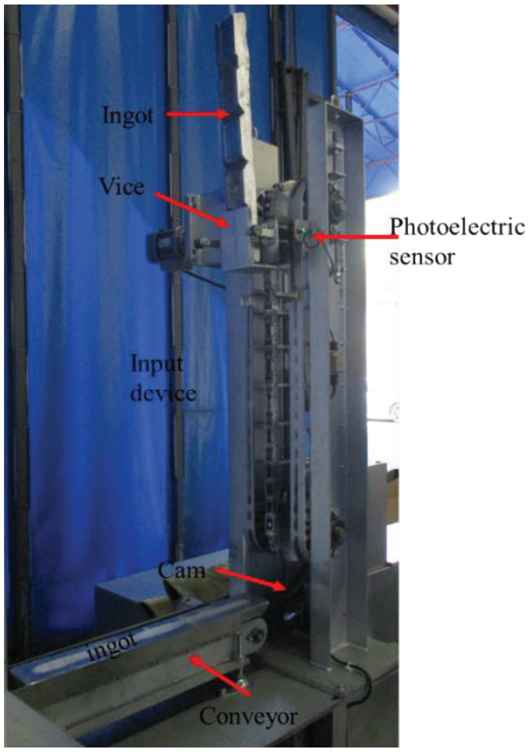


Figure 8 – Assembled conveyor



(a)



(b)

Figure 9 – (a) Assembled input device, and (b) Testing the unit

5. Results

The ingot bundle consists of 100 individual ingots, each weighing 5 kg, resulting in a total bundle mass of 500 kg. The bundle changeover time was measured to be 10 minutes. At an input device motor operating frequency of 50 Hz (corresponding to 5.6 rpm), the average feeding time per ingot was measured as 14.14 s. When the bundle changeover time was considered, the effective average input time per ingot increased to 20.15 s. This value closely matches the assumed input time, thereby confirming that the targeted ingot mass flow rate to the furnace is achieved under these operating conditions.

For the same motor operating speed, when 10 kg ingots are considered, a 500 kg bundle comprises 50 ingots. Under these conditions, the measured effective average input time per ingot, including the changeover time, was 26.14 s. This value is slightly higher than the assumed input time, resulting in a reduced input mass flow rate to the furnace.

To address this limitation, a frequency margin of 10 Hz remains available for increasing the motor speed. By utilizing this additional frequency range, the ingot feeding rate and, consequently, the furnace input mass flow rate can be further adjusted to meet the required operating conditions.

6. Conclusions

Aluminum ingot feeding systems play a critical role in ensuring efficient and effective melting in aluminum production. This is particularly important for furnaces based on non-oxidation melting technology. In this work, an ingot feeding unit was designed, fabricated, and tested for use in a production environment. The unit demonstrated strong performance and proved to be well-suited for integration into the production facility. Based on the test results, the following features were confirmed:

- The unit can effectively handle aluminum ingots weighing between 5 to 10 kg, with dimensions ranging from 680 – 700 mm in length, 90 – 125 mm in width, and 35 – 50 mm in height.

- Ingots were fed into the molten aluminum bath at a controlled speed of 60 mm/sec, significantly minimizing splashing. This speed can be easily adjusted using the inverter.

- The system is capable of handling up to 900 kg/hour with 5 kg ingots and up to 1800 kg/hour with 10 kg ingots. Capacity can be further adjusted by modifying the feeding speed or increasing the number of vices.

- The furnace opening can be set to 90 mm × 140 mm for 5 kg ingots and 100 mm × 175 mm for 10 kg ingots, effectively reducing heat loss. Additionally, a swinging door can be introduced to further minimize heat emission. These modifications are easily implementable on existing furnaces, as they involve only external steel structures.

- The design offers flexibility for easy installation on existing furnaces without significant modifications.

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