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Design and Development of a Pneumatically Actuated Gravity Casting Machine for Aluminum Component Manufacturing

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Abstract.

Gravity casting using permanent metallic molds is widely adopted in small- and medium-scale foundries for producing aluminum components; however, the manual mold assembly and part-removal steps that characterize conventional practice impose physical constraints on cycle consistency, operator ergonomics, and achievable throughput. This paper presents the design and development of a pneumatically actuated Gravity Casting Apparatus Machine intended to overcome these limitations in the production of aluminum motorcycle accessory components at DTech Engineering, Ltd. The design process followed a structured engineering approach comprising problem identification, functional requirement formulation, CAD-based conceptual modeling using Autodesk Fusion 360 learning edition, component and material selection, and mechanical design calculation. The resulting machine integrates eight principal subsystems: a rigid base plate, precision S45C steel rail shafts, a pneumatically driven movable base plate, a two-part permanent mold fabricated from 40 mm iron plate, an automated ejector plate, a pneumatic air cylinder operating at 6 bar, a structural support table, and an electrical control panel with solenoid-based sequencing. Design calculations addressed pneumatic actuator sizing, rail shaft deflection under mold loading, thermal expansion of mold components, and structural safety factors. Material selection was governed by the dual requirement of mechanical rigidity and resistance to thermal deformation from the molten aluminum environment. Implementation of the machine reduced cycle time from 3.0 minutes per part to 1.24 minutes per part, confirming the validity of the design approach. The study provides replicable design guidelines for foundries seeking to modernize gravity casting operations through low-cost pneumatic automation. Quantitatively, the cycle time decreased by 58.7%, from 3.00 min/part to 1.24 min/part, increasing the estimated production capacity from 20.0 to 48.4 parts/h. The selected 100 mm bore and 25 mm rod double-acting cylinder provides theoretical closing and opening forces of 4.71 kN and 4.42 kN, respectively, at 6 bar.

Keywords: Gravity casting; machine design; pneumatic; permanent mold; aluminum casting; ejection mechanism; foundry automation

INTRODUCTION

Metal casting is among the oldest and most versatile manufacturing processes, enabling the production of components with complex geometries from a wide range of metallic materials. Within the family of casting processes, gravity casting with permanent metallic molds, commonly referred to as permanent mold casting or gravity die casting, has established itself as a preferred route for medium- to high-volume production of aluminum components [1], [2], [3]. The process exploits gravity to fill a reusable metal mold cavity, yielding products with superior dimensional consistency, finer surface finish, and better mechanical properties than those obtained from expendable-mold processes such as green-sand casting [4], [5].

Despite these inherent advantages, a large proportion of foundries operating at small and medium scale continue to rely on manual mold handling. In a typical manual gravity casting cell, an operator physically assembles the two mold halves before each pour, holds them together during solidification, and then manually separates them and extracts the solidified part. This sequence introduces several inefficiencies: cycle time is operator-dependent and therefore variable; repetitive force during mold opening and closing contributes to operator fatigue; and the absence of a mechanical ejection system means that part removal is slow and may damage the casting surface or parting region. Collectively, these factors limit the production rate achievable from a given quantity of molten aluminum and increase non-value-added time within the casting cycle [5], [6], [7].

Efforts to address these limitations have taken various forms in the literature. Patent disclosures describe tilting-platform machines that control the hydrostatic head during filling [2], automatic production lines that integrate pouring, mold opening, and conveying stages [3], and toggle-based clamping devices driven by pneumatic muscles that achieve higher clamping force in a more compact package [8]. PLC-controlled pneumatic sequencing has also been demonstrated as a low-cost route to reliable automatic operation of gravity die casting cells [9], while pneumatic technology has been applied to casting production lines in related metal-processing applications [10]. Nevertheless, published design literature for compact, single-station pneumatic gravity casting machines suitable for small foundries remains limited, and detailed accounts of actuator sizing, rail guidance, thermal deformation management, ejector geometry, and productivity validation are rarely reported in sufficient depth to guide independent replication. In addition to these automation-focused sources, the design rationale is also anchored in standard references on permanent mold casting, aluminum casting, machine design, pneumatic actuation, and safety requirements [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22]. An early aluminum gravity casting mold patent was also considered as background for the permanent-mold configuration [1].

This paper addresses that gap by documenting the complete design and development process for a pneumatically actuated Gravity Casting Apparatus Machine developed for DTech Engineering, a manufacturer of aluminum motorcycle accessory components. The novelty of this study lies in the integration of a low-cost pneumatic mold opening-closing system, a mechanically actuated ejector plate, and a compact rail-guided single-station configuration specifically intended for small- and medium-scale foundry operations. The objective is to present a reproducible design methodology covering functional requirements, CAD configuration, component selection, material justification, design calculations, productivity quantification, and practical validation, so that the approach can serve as a reference for foundry engineers facing analogous manual-casting limitations.

METHODS

Design Approach

The design process followed a structured product development methodology comprising five sequential phases: (i) problem identification and field observation, (ii) functional and technical requirement formulation, (iii) conceptual design and CAD modeling, (iv) component and material selection with supporting calculations, and (v) design verification against stated requirements. Field observations at DTech Engineering's gravity casting workshop established the baseline performance of the manual process and identified the specific operational constraints that the machine design was required to resolve. Autodesk Fusion 360 was selected as the CAD platform for three-dimensional modeling and assembly simulation owing to its integrated parametric modeling, assembly-checking capability, and ease of design iteration. The development sequence was therefore aligned not only with field observation but also with established manufacturing design references for casting process planning and machine-element verification [11], [12], [15], [17], [18].

Machine Design Requirements

Functional requirements were derived from the field-observed deficiencies of the manual process and from the production targets set by DTech Engineering. The machine was required to:

1. Accommodate the existing two-part permanent mold geometry without modification to the mold cavity.
2. Open and close the mold halves with sufficient clamping force to prevent flash formation during aluminum pouring.
3. Eject the solidified part automatically upon mold opening, eliminating manual extraction.
4. Guide mold movement along a defined linear axis to maintain cavity alignment across repeated cycles.

5. Operate at a sustained production rate that demonstrably reduces cycle time relative to the manual baseline.
6. Withstand the thermal environment generated by repeated contact with molds preheated to casting temperature and by proximity to molten aluminum at approximately 660–700 °C.
7. Be constructed from locally available materials to minimize procurement lead time and cost.
8. Be operable by a single operator with minimal physical exertion.

These requirements directly shaped component selection, material specification, and actuator sizing in subsequent design phases.

CAD Modeling and Machine Configuration

The machine assembly was modeled in Autodesk Fusion 360 as a parametric three-dimensional model comprising eight principal subsystems. The overall configuration positions the mold assembly on a horizontal plane, with one mold half fixed to the base plate and the second half mounted on a pneumatically driven movable base plate that translates along two parallel rail shafts. The ejector plate is integrated into the fixed mold half and actuated mechanically by the relative motion of the movable plate during the opening stroke. The pneumatic cylinder is mounted centrally between the rail shafts and connected to the movable base plate via a clevis joint. The electrical control panel is mounted on the support table frame and houses the solenoid valve, pressure regulator, and safety interlock circuitry. Front-view and isometric-view drawings generated from the CAD model were used to verify spatial envelope, accessibility for maintenance, and operator ergonomics before fabrication.

Table 1. Main design and operating specifications of the pneumatically actuated gravity casting machine

Parameter	Specification
Main components	Base plate, rail shaft, movable base plate, main mold, ejector plate, pneumatic cylinder, support table, and electrical control panel
Machine configuration	Compact single-station horizontal-parting gravity casting machine
Mold	Two-part permanent mold made from 40 mm thick iron plate
Mold reference length	300 mm for thermal expansion analysis
Movable assembly load	Approximately 15 kg total; 75 N assumed on each rail shaft
Rail shaft	S45C steel, 25 mm diameter, 400 mm effective span
Guidance system	Bronze sleeve bushing with 0.02–0.05 mm radial clearance
Pneumatic cylinder	Double-acting cylinder, 100 mm bore and 25 mm rod diameter
Operating pressure	6 bar / 0.6 MPa

Parameter	Specification
Theoretical actuator force	4.71 kN closing force and 4.42 kN opening force
Temperature condition	Mold: 150–250 °C; molten aluminum: 660–700 °C
Cycle time	Manual: 3.00 min/part; machine: 1.24 min/part
Estimated productivity	Manual: 20.0 parts/h; machine: 48.4 parts/h

Component and Material Selection

Material and component selection was governed by three primary criteria: mechanical performance under cyclic loading, resistance to thermal deformation, and local availability. The key selection decisions are summarized below and their technical justification is developed in Section 3. The final selection was cross-checked against casting materials references for mold thermal stability and aluminum foundry practice [13], [14], [16].

- Rail shafts: S45C medium-carbon steel, selected for its high yield strength, machinability, and resistance to bending deflection under the dynamic loading imposed by mold traversal.
- Main mold body: 40 mm thick iron plate, selected to provide the thermal mass required for consistent solidification and the dimensional stability needed to maintain cavity geometry across extended production runs.
- Base plates: Structural steel plate, designed with sufficient section modulus to remain flat under the combined weight of the mold assembly and the clamping force.
- Pneumatic actuator: Double-acting air cylinder with 100 mm bore diameter, operating at 6 bar supply pressure.
- Bushing sleeves: Bronze sleeve bushings on the movable base plate, providing low-friction guidance along the rail shafts and accommodating minor thermal expansion differentials.
- Ejector pins and plate: Tool steel, hardened to resist wear from repeated contact with the aluminum casting surface.

Design Calculation Procedure

Calculations were performed to verify that each critical component meets its design requirement with an adequate safety factor. The principal calculations addressed: (a) pneumatic actuator force output and adequacy for mold clamping; (b) rail shaft deflection under the combined weight of the movable assembly; (c) thermal linear expansion of the mold body and its effect on cavity dimension; and (d) structural adequacy of the base plate under the maximum expected load. Where material property data were taken from standard references, the source is cited. Where dimensional parameters were taken from the CAD model or from field measurements at DTech Engineering, this is stated explicitly. The actuator force, beam deflection, stress, and thermal-

expansion checks followed standard mechanical-design and pneumatic-system formulations [17], [18], [19], [20], [21], [22].

RESULT AND DISCUSSION

Proposed Machine Design and Overall Configuration

The Gravity Casting Apparatus Machine developed for DTech Engineering is a single-station, horizontal-parting, pneumatically actuated permanent mold casting machine. The machine occupies a compact footprint consistent with the existing workshop layout. The eight principal subsystems are arranged as follows: the support table provides the structural foundation; the base plate is bolted to the table surface and serves as the fixed reference for all other components; two parallel rail shafts span the base plate longitudinally and guide the movable base plate; the main mold assembly is split between the fixed and movable base plates; the ejector plate is integrated within the fixed mold half; the pneumatic air cylinder is mounted between the rail shafts and drives the movable base plate; and the electrical control panel is mounted on the table frame. The nine-step operating procedure, compressor pressure verification at 6 bar, mold opening and shaft inspection, mold preheating with a gas torch, mold closing via the control panel, aluminum pouring, mold opening with automatic ejection, cavity cleaning, mold reclosing, and periodic rail lubrication every ten cycles, was developed in parallel with the mechanical design to ensure that the machine configuration supports each procedural step without ergonomic compromise. The overall configuration of the proposed machine is shown in Figure 1.

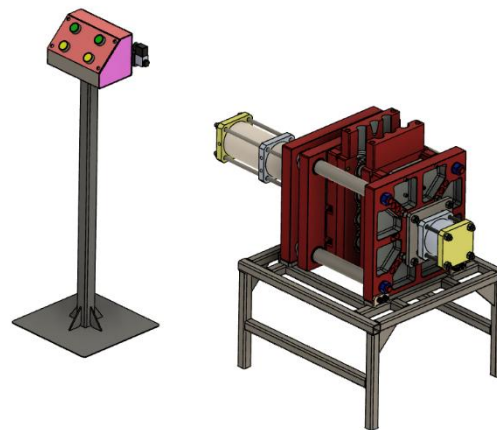


Figure 1. Isometric view of the pneumatically actuated gravity casting machine

Main Machine Components

Base Plate.

The base plate functions as the primary structural foundation of the machine. It is fabricated from flat structural steel plate and machined to achieve the flatness tolerance required for accurate mold alignment. The design prioritizes rigidity to prevent flexural deformation under the clamping load

applied by the pneumatic cylinder, which could otherwise cause misalignment of the two mold halves and result in flash or dimensional error in the casting. The base plate incorporates precision-bored mounting holes for the rail shaft end supports, ensuring parallelism of the two shafts within the tolerance required for smooth movable plate traversal.

Rail Shaft.

The two rail shafts are the kinematic backbone of the mold opening and closing mechanism. Each shaft is manufactured from S45C medium-carbon steel, a material widely used in precision linear motion applications for its combination of high tensile strength (minimum 570 MPa), good machinability, and corrosion resistance adequate for the foundry environment [23]. The shafts are ground to h6 tolerance on the outer diameter to match the bore of the bronze sleeve bushings fitted to the movable base plate, ensuring smooth, low-friction linear motion without perceptible lateral play. The shaft diameter was determined by deflection calculation (see Section 3.6) to ensure that mid-span deflection under the weight of the movable assembly remains within the alignment tolerance of the mold cavity.

Movable Base Plate.

The movable base plate carries one half of the mold and translates along the rail shafts under the action of the pneumatic cylinder. It is fitted with two bronze sleeve bushings, one per shaft, which provide the bearing surfaces for linear motion. The bushing material was selected for its self-lubricating properties and its ability to tolerate the elevated ambient temperature of the casting environment. The movable plate incorporates a pattern of tapped holes for mold mounting, with the hole pattern designed to be compatible with the existing mold body dimensions so that the mold can be transferred to the machine without modification.

Main Mold Assembly.

The mold comprises two halves, designated the fixed half and the movable half, each fabricated from 40 mm thick iron plate. Iron plate at this thickness provides the thermal mass required to absorb the heat of the incoming molten aluminum and to maintain a sufficiently uniform temperature distribution across the cavity surface to produce consistent solidification. The 40 mm section also provides the structural rigidity needed to resist the hydrostatic pressure of the liquid aluminum without elastic deformation that would open a gap at the parting line. The two halves close with a precision-machined parting face that, when clamped by the pneumatic cylinder, prevents flash formation. The cavity geometry is machined into the inner faces of the mold halves to produce the target motorcycle accessory component profile. A critical design challenge identified during the development process was the potential for thermal deformation of the mold body after extended production runs: differential thermal expansion between the mold and the rail shaft system

could alter the effective stroke of the movable plate and compromise parting-face contact pressure. This was addressed by specifying a thermal expansion clearance in the bushing bore and by including a periodic lubrication requirement in the operating procedure [9].

Ejector Plate.

The ejector plate is a purpose-designed component integrated into the fixed mold half. Its function is to push the solidified casting clear of the mold cavity as the movable plate retracts during the opening stroke, eliminating the need for manual part extraction. The ejector plate is driven by the relative motion between the fixed mold half and the movable plate: as the movable plate travels away from the fixed half, a mechanical linkage translates this motion into an axial displacement of the ejector pins, which bear against the back face of the casting and eject it from the cavity. The ejector pin geometry and layout were designed to distribute the ejection force uniformly across the casting cross-section, avoiding stress concentrations that could deform or crack the still-warm aluminum component. In the present design, the ejection force acts in the direction normal to the casting back face, while the movable mold half retracts in the opposite opening direction. This arrangement reduces manual prying and helps prevent local casting damage during removal.

Pneumatic Air Cylinder.

The pneumatic cylinder serves as the primary actuator of the machine and is the component most directly associated with cycle time reduction compared with the manual process. A double-acting pneumatic cylinder with a 100 mm bore diameter was selected and operated at a supply pressure of 6 bar (0.6 MPa). The theoretical actuation force was determined from the relationship between operating pressure and effective piston area, as expressed in Equation (1).

$$F = P \times A = 6 \times 10^5 \text{ Pa} \times \frac{\pi(0.1)^2}{4} \text{ m}^2 \approx 4,712 \text{ N} \quad (1)$$

On the retraction (opening) stroke, the effective area is reduced by the rod cross-section; assuming a 25 mm rod diameter, the retraction force is approximately:

$$F_{ret} = P \times \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4} \right) = 6 \times 10^5 \times \left(\frac{\pi(0.1)^2}{4} - \frac{\pi(0.025)^2}{4} \right) \approx 4,418 \text{ N} \quad (2)$$

These forces exceed the practical requirement observed during the production trial because the mold remained closed without significant parting-line opening during pouring. A formal pneumatic safety factor can be calculated as $SF = F_{available}/F_{required}$, where $F_{required}$ depends on the projected cavity area and maximum liquid-metal head. Because the projected cavity area and pour-head

height were not preserved as separate numerical records in the available dataset, the exact pneumatic safety factor should be reported in future work once these mold-specific values are documented.

Support Table.

The support table is a welded structural steel frame designed to support the complete machine assembly at a working height ergonomically suited to the standing operator. The table legs are fitted with leveling feet to accommodate minor floor irregularities. The frame cross-section and weld configuration were designed to provide adequate stiffness against the dynamic loads transmitted through the base plate during the pneumatic actuation cycle.

Electrical Control Panel.

The electrical control panel houses the solenoid valve for pneumatic direction control, the pressure regulator, indicator lights, operator push-buttons for mold open and mold close commands, and a safety interlock that prevents mold closing if the operator's hands are detected within the mold zone. The panel is mounted on the table frame at a position accessible to the standing operator without requiring body movement away from the pour station. The control logic was implemented using a relay-based circuit with a programmed safety sequence that enforces a minimum dwell time between the close command and the pour-ready indication, ensuring that the mold is fully clamped before pouring commences [15]. The machine consists of eight main subsystems, as identified in Figure 2.

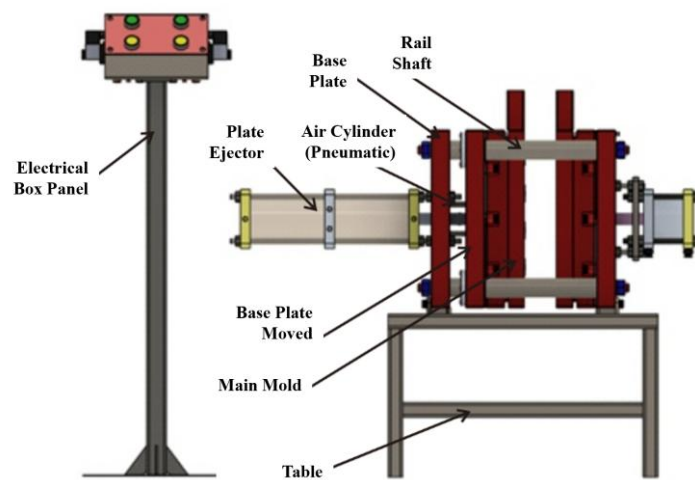


Figure 2. Main subsystems of the gravity casting apparatus machine

Pneumatic Mold Opening and Closing Mechanism

The mold opening and closing mechanism is the functional core of the machine. In the manual baseline process, the operator physically pushes the two mold halves together, holds them closed during pouring and solidification, and then pulls them apart for part removal. This sequence is physically demanding and introduces cycle time variability of $\pm 15\text{--}20\%$ depending on operator fatigue

and attention. The pneumatic mechanism replaces all three of these manual actions with controlled, repeatable cylinder strokes. The closing stroke drives the movable base plate along the rail shafts until the parting faces of the two mold halves are in full contact; the cylinder then maintains the clamping force throughout the pouring and solidification dwell. The opening stroke retracts the movable plate to a defined open position determined by the cylinder stroke length, simultaneously actuating the ejector mechanism. The speed of both strokes is regulated by flow control valves on the cylinder ports, allowing the stroke velocity to be tuned to avoid impact damage to the mold faces at closure and to control the ejection velocity at opening [6], [13].

Rail-Guided Movement System

Precise linear guidance of the movable base plate is essential for consistent parting-face alignment across thousands of production cycles. The two-shaft rail system provides this guidance by constraining the movable plate to a single translational degree of freedom. The S45C shafts are mounted in fixed end supports on the base plate with a center-to-center spacing chosen to maximize the moment of resistance of the movable plate against rotational disturbance from asymmetric mold loading. The bronze sleeve bushings on the movable plate are sized to provide a radial clearance of 0.02–0.05 mm on the shaft diameter, which is sufficient to permit free sliding while limiting lateral play to a value below the parting-face alignment tolerance. Lubrication of the shaft–bushing interface is specified every ten production cycles using engine oil, a requirement derived from the thermal environment of the machine: elevated ambient temperature accelerates lubricant degradation, and the operating procedure was therefore designed to maintain lubrication frequency at a level that prevents bushing seizure [9]. This guidance arrangement is consistent with beam and machine-element design references, where shaft diameter, support span, bushing clearance, and lubrication condition jointly control alignment stability and service life [17], [18], [19].

Material Selection Rationale

The selection of S45C steel for the rail shafts is justified by its established use in precision linear motion components in the machine tool and automation industries. Its carbon content of approximately 0.45% provides a good balance between strength and machinability, and its surface can be induction-hardened if wear resistance needs to be increased in future iterations. The selection of 40 mm iron plate for the mold body reflects the thermal and structural requirements of the permanent mold casting environment. Cast iron exhibits thermal conductivity of approximately 50 W/(m·K) and a specific heat capacity of approximately 460 J/(kg·K), giving it the thermal mass needed to absorb the heat of solidification without excessive temperature excursions that would accelerate mold degradation. The 40 mm section thickness was determined by a combination of structural calculation and practical experience with similar mold geometries at DTech Engineering [9].

Design Calculations

Rail Shaft Deflection.

The movable base plate assembly, including the mold half and the cylinder rod connection, was estimated to have a total mass of approximately 15 kg, producing a distributed load on the two shafts. Treating each shaft as a simply supported beam of span $L = 400$ mm and applying the midpoint deflection formula:

$$\delta = \frac{WL^3}{48EI} \quad (3)$$

where $W = 75$ N (half the total weight on each shaft), $E = 200$ GPa for steel, and $I = \pi d^4/64$ for a solid circular cross-section with $d = 25$ mm:

$$I = \frac{\pi(0.025)^4}{64} = 1.917 \times 10^{-8} \text{ m}^4 \quad (4)$$

This deflection is well within the acceptable alignment tolerance for the mold parting face, confirming that the 25 mm shaft diameter is adequate.

Thermal Expansion of Mold Body.

The iron plate mold body is preheated before production and reaches operating temperatures in the range of 150–250 °C. The linear thermal expansion over the mold length $L_0 = 300$ mm is: The calculation used a conservative linear thermal expansion coefficient for iron/cast-iron mold material of $\alpha = 11.0 \times 10^{-6} / ^\circ\text{C}$. Taking the reference mold length as $L_0 = 300$ mm and the conservative temperature rise as $\Delta T = 200$ °C, the expected dimensional growth (ΔL) is 0.66 mm. If the narrower operating interval of 150–250 °C is used, the corresponding expansion is approximately 0.33 mm.

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T \quad (5)$$

This expansion is accommodated by the 0.02–0.05 mm radial clearance in the bushing bore and by the axial float designed into the mold mounting arrangement. Without this provision, thermal growth of the mold body could generate compressive stress in the rail shaft system and cause binding of the movable plate. Therefore, the clearance and mounting allowance were treated as design accommodations for repeated casting cycles rather than as a direct constraint on cavity geometry. Periodic lubrication is also required to reduce the possibility of bushing binding caused by combined thermal growth and aluminum-flash contamination.

Structural Safety Factor of Base Plate.

The base plate was designed with a minimum section modulus sufficient to limit bending stress to below 50% of the yield stress of the structural steel used (yield stress \approx 250 MPa), giving a structural safety factor of 2.0 or greater under the maximum expected combined loading from the mold weight and the pneumatic clamping force.

Design Validation

Following fabrication and assembly, the machine was subjected to a trial production run at DTech Engineering's workshop. The trial confirmed that the pneumatic mechanism opened and closed the mold smoothly at the specified 6 bar pressure, that the ejector plate released the casting without manual intervention, and that the rail guidance system maintained parting-face alignment during repeated operation. The measured cycle time of 1.24 minutes per part, compared with the manual baseline of 3.00 minutes per part, confirms that the design met the primary performance requirement. The thermal deformation management strategy was supported by the absence of bushing seizure or shaft binding during the trial production period. These observations are consistent with the expected behavior of pneumatic clamping and guidance systems reported in related casting automation studies.

The productivity improvement can be quantified as follows: cycle-time reduction = $(3.00 - 1.24)/3.00 \times 100\% = 58.7\%$. The estimated hourly capacity increased from $60/3.00 = 20.0$ parts/h in the manual process to $60/1.24 = 48.4$ parts/h using the developed machine. This corresponds to an increase of approximately 28.4 parts/h or a 142% improvement in hourly production capacity relative to the manual baseline.

Product quality was evaluated qualitatively during the trial. The available observation notes indicate successful release of the casting by the ejector plate, absence of severe mold-opening difficulty, and no visually dominant parting-line opening during pouring. However, quantitative product-quality metrics, such as dimensional deviation, surface roughness, flash thickness, incomplete-filling rate, porosity inspection, and rejection percentage, were not recorded in the available dataset. These measurements should be included in the next validation stage to strengthen the connection between machine performance and casting quality. This qualitative inspection approach is consistent with casting defect-control references, although future work should add quantitative dimensional and rejection-rate records [13], [14], [16].

The available validation record reports the cycle-time comparison but does not preserve cycle-by-cycle time data, the exact number of tested cycles, or the number of accepted and rejected castings. Therefore, repeatability is discussed qualitatively in this manuscript. Future validation should record at least 30 consecutive cycles and report average cycle time, standard deviation, coefficient of variation, and rejection rate.

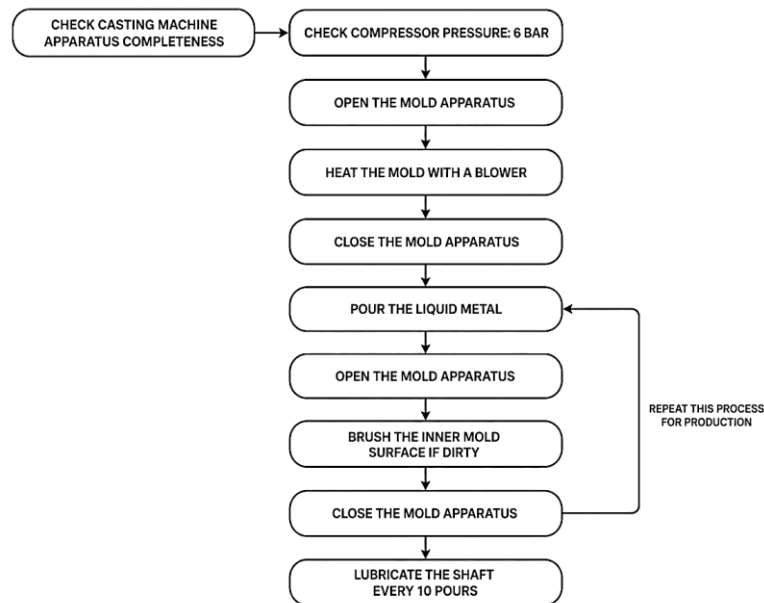


Figure 3. Operating workflow of the gravity casting machine during one production cycle

A design limitation identified during the trial was the sensitivity of the mold cavity surface to contamination from residual aluminum flash and combustion products from the preheating torch. The operating procedure addresses this through a mandatory cavity cleaning step after each cycle, but future design iterations could incorporate a compressed-air blow-off nozzle integrated into the mold opening sequence to reduce cleaning time. Additionally, the current design does not include active mold temperature control; a thermocouple-based monitoring system and a water-cooling circuit in the mold body would improve solidification consistency and are recommended for future development. Another limitation is that the validation was based on production-observation data rather than a controlled statistical test plan; therefore, quantitative repeatability and casting-quality capability should be treated as future validation needs.

CONCLUSION

This study has presented the complete design and development process for a pneumatically actuated Gravity Casting Apparatus Machine for aluminum component manufacturing at DTech Engineering. The machine integrates eight principal subsystems, namely the base plate, S45C steel rail shafts, movable base plate, 40 mm iron plate mold assembly, ejector plate, 100 mm bore pneumatic cylinder at 6 bar, support table, and electrical control panel, into a compact, single-station casting cell that eliminates the manual mold assembly and part-removal steps of the conventional process. Design calculations confirmed the adequacy of the 25 mm rail shaft diameter against deflection, quantified mold-body thermal expansion in the range of approximately 0.33-0.66 mm depending on the assumed temperature interval, and showed that the

pneumatic actuator delivers theoretical closing and opening forces of approximately 4,712 N and 4,418 N, respectively. Trial production results validated the productivity benefit of the design, reducing cycle time from 3.00 to 1.24 min/part, equivalent to a 58.7% cycle-time reduction and an estimated capacity increase from 20.0 to 48.4 parts/h. The qualitative trial also indicated successful automatic ejection and stable mold movement; however, future work should include cycle-by-cycle repeatability data, dimensional inspection, flash measurement, defect evaluation, and rejection-rate analysis. The structured design methodology and engineering rationale documented in this paper provide a replicable reference for foundry engineers seeking to implement low-cost pneumatic automation in small- and medium-scale gravity casting operations.

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