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Design Analysis and Optimization of a Two-Cavity Injection Mould Tool for a Consumer Durable Motor Housing

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Abstract - This paper presents the systematic design, geometric analysis, and optimization of a high-precision, two-cavity injection moulding tool for an indigenous motor housing component used in consumer-durable washing machines. Injection moulding represents approximately 70% of plastic components manufacture globally. This research applies engineering best practices, empirical calculations, and systematic tool layouts to transition a 3D CAD design into a highly productive, mass-manufacturable tooling system. Polypropylene (PP) was selected as the parent material. The paper systematically covers the detailed design of core and cavity inserts, parting line selection, side-core actuation mechanisms, structural calculation matrices, and detailed tool manufacturing cost estimations.

1. INTRODUCTION & PROJECT SCOPE

It is difficult to imagine the modern world without plastics. In present-day life, plastics have become an essential part of everyday use, with applications ranging from common household articles to advanced scientific and medical instruments. Designers and engineers increasingly prefer plastics because they provide unique combinations of properties that are not commonly available in other materials, including light weight, resilience, corrosion resistance, color stability, transparency, ease of processing, and good design flexibility. Moulding is the most commonly used method for plastic fabrication. Through this process, plastic materials can be shaped into different forms by applying suitable heat and pressure under controlled conditions.

1.1 Background of the Project

Motor housing is a critical component used for positioning and enclosing the electric motor in a consumer-durable washing machine. This product is a newly developed indigenous design, created with fresh concepts by the design team at Bilva Moulds Pvt. Ltd. as part of the initial research and development process. In the subsequent stage, a fully developed 3D CAD model and functional prototype were prepared to evaluate assembly metrics and verify operational envelopes. Considering economic factors, design requirements, and typical high-volume production applications, injection moulding has been selected as the most appropriate process for the mass manufacture of these motor housings.

1.2 Objectives of the Work

The core objective of this work is to maximize production throughput and component quality through rigorous tool engineering analysis. The concrete milestones are detailed below:

- Design optimization of the component considering mould design restrictions for design to manufacturability (DFM).
- Design of a robust Two-Cavity Injection Mould for the Motor Housing component to satisfy production volume metrics.
- Execution of solid modeling, precise 2D drafting, and structural layout definitions using advanced CAD platforms.
- Adherence to empirical formulas found in world-standard handbooks, standards, and tool manufacturing industry best practices.
- Optimization of the feeding, venting, side-core slide actuation, and cooling networks to drop manufacturing cycle and lead time.

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1.3 Present Work

The initial stage of the work includes the study of geometric profiles, surface-quality requirements, material specifications, and expected in-service conditions of the component. The design process involves the selection of a suitable parting surface, provision of shrinkage allowance, draft considerations, gate-location selection, venting arrangement, mould balancing, and appropriate ejection-system design.

A two-plate mould design-has been adopted for producing the component, as it allows direct feeding through a sprue gate in single-impression mould. In this arrangement, gate is removed from component after ejection, which makes the process simple and suitable for intended production requirement.

Tool design includes design of core and cavity inserts, along with side-core assembly. mould base is designed according to DME standards after analysing the component and carrying out basic calculations such as component weight, shot weight, and required clamping force.

Cost estimation of the injection-moulding tool is also carried out to determine the probable manufacturing cost of the mould.

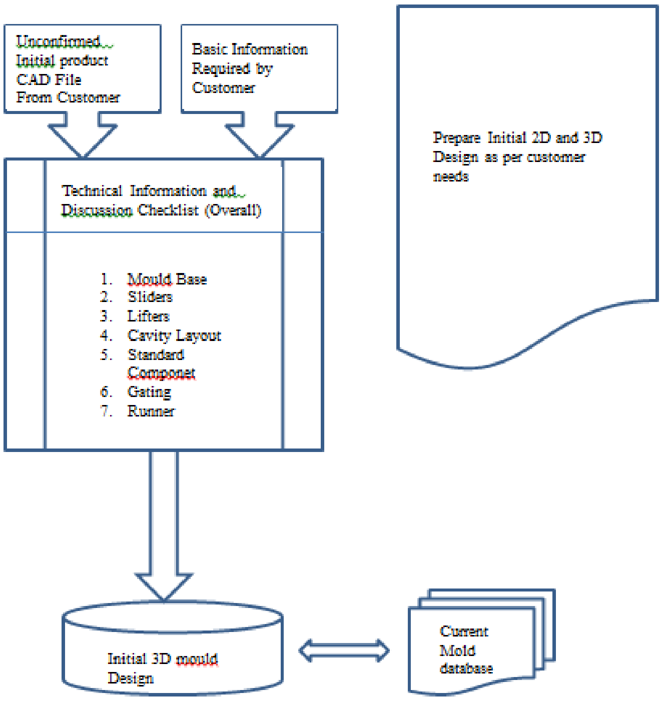

Fig 3.5: Proposed-Design Structure

2. POLYMERIC MATERIAL SELECTION MATRIX

Synthetic large molecules called polymers are formed by joining thousands of small molecular units known as monomers via polymerization. Pure polymers are rarely used in their original form. When suitable additives are incorporated to improve processing, performance, or usability, the resulting engineered material is referred to as plastic. Plastics are classified into thermosets (cross-linked networks that cannot be reshaped after curing) and thermoplastics (long-chain macromolecules that soften repeatedly under heat and solidify on cooling).

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The structural part under analysis requires excellent dimensional stability, impact strength, high fatigue resistance under cyclic load, and low water absorption. Based on these strict requirements, an optimized Polypropylene (PP) Co-polymer was specified.

Table 1: Specified Material & Geometric Profiles

Engineering Metric / Parameter	Value / Specification Base
Material Base Selected	Polypropylene (PP Co-Polymer)
Density Grade	0.89 gms/cc
Shrinkage Allowance Rate	1.0 mm (Volumetric Constraint)
Nominal Wall Thickness	3.0 mm
Component Total Surface Area	132.27 x 10^3 mm^2
Outstanding System Properties	High Impact Strength, Integral Hinge Life, Improved Heat Stability

3. LITERATURE SURVEY & SYSTEM FRAMEWORKS

Mould design is not typically developed purely through intuitive, unstructured design approaches. Instead, it relies on structured knowledge, historical engineering heuristics, and specialized mechanical engineering disciplines. Traditional stand-alone mathematical models often fail to account for the highly complex, interrelated multi-variable design problems present in injection moulding tools.

Advanced systems like IKMOULD (Mok et al.) separate fundamental layout methods from granular technical details, allowing the tool designer to concentrate first on core mechanics before running downstream optimization. Similarly, the Intelligent Cavity Layout Design System (ICLDS by Hu and Masood) underscores that cavity configuration directly dictates parting line selection, feed system layout, and cooling efficiency. Modern industrial practice (Nitin Namdeo et al.) relies heavily on the technical discussion checklist as an overarching standard template to build a 3D solid block framework. Ejector pin arrays and complex internal routing must be derived explicitly based on standard DME or HASCO mould component databases.

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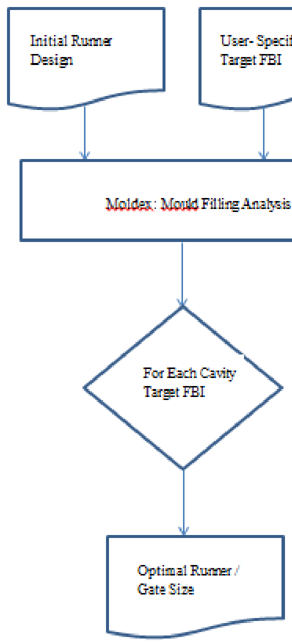
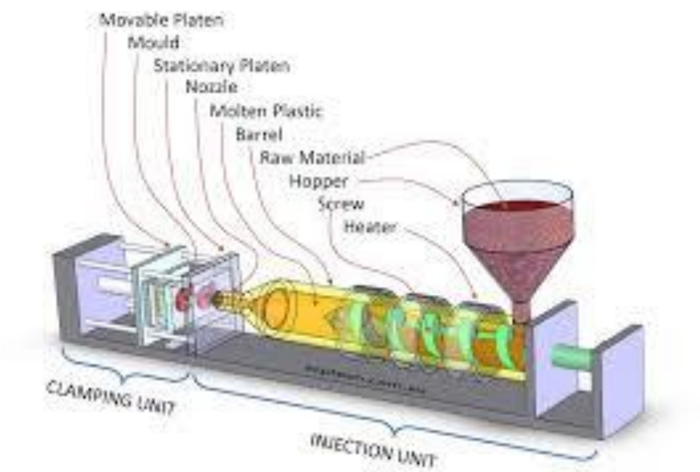


Fig.3.6: Analysis Process of Moldex-Expert Auto runner Functions

4. CORE TOOL ENGINEERING & MATHEMATICAL LOGIC

The step-by-step tool design follows explicit scientific methods and empirical relationships derived from recognized tool engineering parameters. The choice of tool layout metrics must balance structural resistance against machine constraints.



4.1 Structural Integrity of Cavity Inserts

To prevent geometric distortion or flash formation from the high pressures exerted by the molten plastic stream, the minimal wall thickness (t) of the rectangular cavity inserts is calculated using the following thin-plate elastic deflection formula:

$$t = [(c * P * d^4) / (E * y)]^{(1/3)}$$

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Where 'y' represents the maximum allowable elastic deflection of the insert sidewalls (safely constrained to 0.005 cm), 'P' is the maximum internal cavity pressure (kg/cm^2), 'd' is the total depth of the cavity profile, and 'E' represents the Modulus of Elasticity of the insert tool steel.

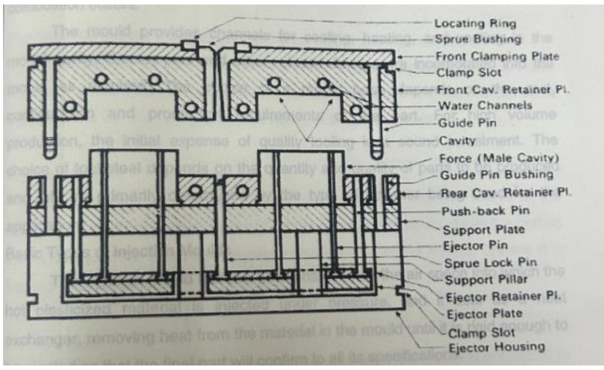

Fig 4.1: Basic Impression of core & Cavity

4.2 Clamping Tonnage Assessment

The clamping unit of the injection moulding machine must exert sufficient locking force to hold the parting plane securely closed against internal opening forces. The baseline calculation is governed by the relation:

*Required Clamping Force = Projected Cavity Area (including feed lines) * Maximum Cavity Pressure * Number of Cavities*

To provide a robust factor of safety and ensure perfect mould seal during the holding and packing phase, the machine clamping capacity is selected to be approximately 15% higher than the calculated opening force.

4.3 Housing Configuration and Sizing

Based on the component geometric limits, insert thickness calculations, and standard tool metrics, the plate dimensions were optimized as follows:

- **Cavity Retainer / Housing Plate:** 76 mm x 296 mm x 296 mm
- **Core Retainer / Housing Plate:** 46 mm x 296 mm x 296 mm

5. Mechanical Subsystems of the Two-Plate Mould

The tooling configuration has been customized into a standard two-plate, single-daylight injection mould frame, optimizing structural robustness.

5.1 Feeding and Venting Architecture

The melt delivery network incorporates a tapered sprue bush, primary and secondary balanced cold runners, and narrow gates to connect the machine nozzle directly to the two impressions. The sprue bush is engineered with an internal included taper between 2 and 4 degrees, paired with a downstream sprue puller pin and cold slug well. This layout traps the highly viscous, cold front edge of the advancing polymer stream, keeping it from clogging the narrow gate orifices.

5.2 Side-Core Cam Slide Actuation

The motor housing design exhibits three complex external undercut recesses that obstruct simple vertical demoulding. To resolve this, a robust slide-core mechanism is integrated into the core bolster unit. The slides are mechanically actuated during the opening stroke via finger cams. To maximize pin life and prevent mechanical jamming, the finger cam inclination angle is engineered between 15 and 25 degrees. Solid insert heel blocks (wedge blocks) clamped behind the slides tightly lock them into position during injection, securely counteracting the explosive cavity pressure.

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5.3 Balanced Mechanical Ejection

All thermoplastic resins contract volumetricly during cooling. As a result, the component shrinks tightly onto the moving core half. Ejection pins are arranged symmetrically and located at critical high-load areas—specifically at deep ribs, bosses, and perimeter rims—to ensure completely uniform load distribution without inducing stress marks. Return pins utilize mechanical force against the stationary plate to safely return the entire ejector sub-assembly to its home position before the next moulding cycle begins.

6. Metallurgy & Materials Selection Matrix

Mould steel selection directly governs tool life and production consistency. Inclusions or alloy segregation can lead to rapid tool failure or surface pitting during high-gloss diamond polishing. Specific metallurgical grades were selected based on structural demands:

Table 2: Metallurgical Selection for Tooling Elements

Material Class / Grade	Hardness / Treatment Characteristics	Applied Tool Elements
Mild Steel (MS)	Low carbon stock, clean machinability	Top/Bottom plates, Spacers, Housing blocks, Locating ring
Case-Hardened Steel	High wear resistance, hardened surface layer	Leader pillars, Guide bushes, Cams, Wear plates
Silver Steel	Precision ground stock, highly uniform	Straight mechanical ejector pins
OHNS Steel	Oil Hardening Non-Shrink, stable under heat	Push-back pins, Sprue bush, Core pins, Forming punches
P20 Steel	Pre-hardened alloy tool steel, uniform core density	Core and Cavity inserts, Complex split elements

7. COMPUTER AIDED MOULD-DESIGN PROCEDURE

1. Parting Subsystem
   - Recognition & extraction of undercut features, along with-determination of feature-parameters,
   - Determination of parting-direction,
   - Generation of parting lines & parting surfaces,
   - Selection of-mould layout & creation of-core/cavity blocks & inserts
2. Feeding-Subsystem: Design of runners, gates, & mould layout.
3. Cooling Subsystem: Generation of cooling circuit & bubbler system.
4. Ejecting-Subsystem: Creation of ejection devices & actuating mechanisms.
5. Local Tool-Subsystem: Design of side-cores, side-cavities, form-pins, split cores, and corresponding-actuating mechanisms.
6. Mould Base-bsystem: Generation-of mould plates and selection of-mould structure.
7. Ancillary-Component Subsystem: Generation-of standard-ancillary components, such as nuts, slots, and screws.

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7.1 Methodology

This project was-carried out at the Indian Institute of Science. It involved design optimization and mould-tool design of a two-cavity injection mould for motor housing component, as well as for associated motor housing component.

This motor housing component, along with the related motor housing component, is used in a consumer-durable product that is presently under research & development. These two components-together form an assembly intended to house the motor.

1. Component Description

This motor pump housing is used in washing machine of a consumer product. Its main function is to protect the internal electric motor and provide proper-structural alignment for the worm drive, output drum gear, and related cable-supporting features. The work was carried out at Bilva Mould Pvt. Ltd. The project included design optimization and mould-tool design of a two-cavity injection mould for the motor housing component.

2. Design & Geometric Features

A metal insert pin is provided to serve as the rotational axis for the internal cable drum gear. The back face contains a radial wheel-spoke rib pattern, which helps distribute stress uniformly and reduces the possibility of sink marks or warpage during the moulding process. Integral moulded loops are provided along the perimeter to ensure secure fastening to the vehicle door panel or motor mounting plate. In addition, formed routing channels are incorporated on the side to safely guide electrical inputs away from moving mechanical parts.

Fig 7.1: Component Photos

1. Soild Modeling of Component

Solid modelling of the component was-carried out using the high-end CAD software SolidWorks 2020. The component weight, volume, and surface-area were also determined using the same software package. These-data are useful for performing accurate design calculations and further analysis.

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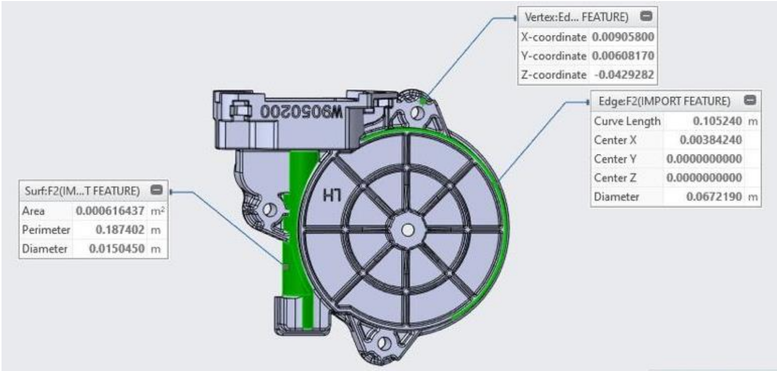

Fig: 7.2: Solid Model Design

2. Material Selection

Suitable-materials are selected for the manufacture and fabrication of each tool component based on its primary function, working requirement, and intended application.

3. Design of Tool

The core and-cavity inserts were developed using software package "Solid Works 2005". Standard-dimensions were selected for cavity plate based on the available design dimensions.

4. Drafting

Two-dimensional drawings of mould components were prepared for-manufacturing purposes.

5. Analysis

Mold flow-analysis was carried out using the Moldex3D evaluation-version available in institute. This analysis was performed to study filling behaviour of the part and to-predict possible air-entrapment regions and weld-line locations. However, due to budget constraints, this analysis may be carried out only if specifically required by the company.

8. COMMERCIAL SIZING AND COST ESTIMATION MATRIX

To verify commercial feasibility and establish financial benchmarks, a strict cost estimation analysis was completed for the raw stock, precision machining operations, heat treatment, and ancillary assembly overheads.

Table 3: Precision Machining Cost Breakdown

Operation Element	Rate per Hour (Rs/-)	Machine Time (Hours)	Total Operational Cost (Rs/-)
Conventional Milling	150	80	12,000
Precision Turning	90	40	3,600
Cylindrical Grinding	180	10	1,800
Surface Grinding	200	50	10,000
Drilling / Reaming	80	60	4,800
Bench Work / Manual	220	70	15,400

Fitting			
Wire EDM Cut	320	30	9,600
CNC High-Speed Milling	500	150	75,000
Spark Erosion EDM	180	20	3,600
Diamond Polishing	180	35	6,300
Final Tool Assembly & Test	250	50	12,500
CONSOLIDATED TOTAL TIME / LABOUR CHARGES	**-**	**595 Hours**	**1,54,600/-**

7.1 Raw Material Base Costs

- **Engineered ABS Resin (Testing / Trials): 86 kg @ Rs. 300/kg =** Rs. 25,800/-
- **Electrode Copper Stock (EDM Sparking): 5 kg @ Rs. 750/kg =** Rs. 3,750/-
- **Mild Steel Plate Stock (MS Base): 90 kg @ Rs. 150/kg =** Rs. 13,500/-

Total Consolidated Material Expenses: Rs. 31,550/-

Table 4: Comprehensive Tool Commercial Quotation Summary

Cost Element Line	Calculation Basis / Derivation	Value (Rs/-)
1. Raw Material Charges	ABS, Copper, and MS Base Stock Costs	31,550
2. Precision Machining Charges	Accumulated Machining & Bench Hours (Table 3)	1,54,600
3. Controlled Heat Treatment	Vacuum Hardening for Inserts	3,000
4. Standard Items & Ancillaries	DME Pillars, Bushes, Springs, & Fasteners	10,000
5. Risk Component Provision	10% of Accumulated Prime Cost	19,915
6. Plant & Toolroom Overheads	15% of Accumulated Prime Cost	29,875
7. Engineering Design Charges	10% of Accumulated Prime Cost	19,915
8. Metrology Precision Inspection	5% of Accumulated Prime Cost	9,957
9. In-Machine Tryout & Debugging	5% of Accumulated Prime Cost	9,957
10. Factory Net Profit Margin	15% of Accumulated Prime Cost	29,872

FINAL COMPREHENSIVE COMMERCIAL PROJECT VALUE: Rs. 3,18,641/-

9. CONCLUSIONS & FUTURE SCOPE

The systematic engineering design of a two-cavity injection mould tool for a consumer-durable motor housing component has been successfully completed. Scientific methods and explicit empirical relationships from standard parameters were utilized.

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Selecting a flat parting plane across the maximum cross-sectional area ensures clean part extraction. By using sliding side-cores driven by finger cams, the tool cleanly forms the three critical undercuts, achieving high productivity while eliminating the risk of dynamic part damage.

Future extensions of this project will involve executing advanced transient thermal mould cooling simulations and active warpage analyses to further shave down total cycle time. Running structural fatigue analysis via FEA models on the high-wear core pins and side slides is also recommended to accurately predict the tool's absolute service lifecycle before baseline wear occurs.

Some investigations recommended-from this work for successful development of the complete product and its corresponding moulds are as follows:

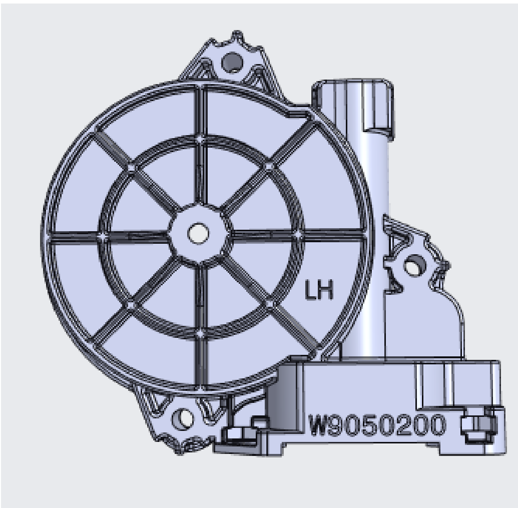
1. During this work, it was observed that some components of the consumer-durable product, particularly at its development stage, were designed without proper consideration of draft.

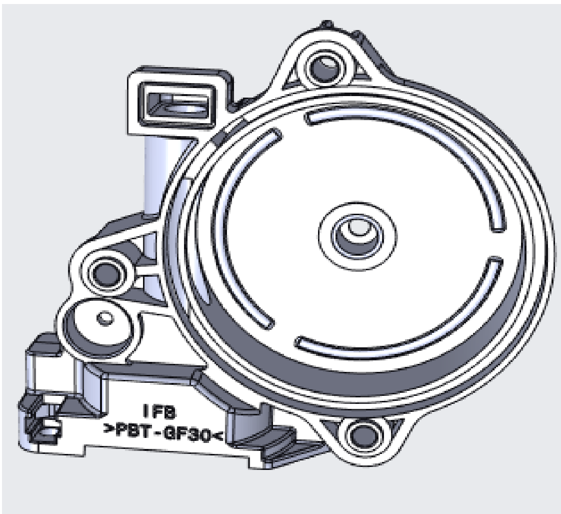
   Application of draft at a later stage in product design may result in alteration of part geometry. When geometry of each part changes, placement of every component must be reconsidered. In addition, exact clearances required for proper functioning of the product must be newly formulated.

2. Injection moulds should be designed for different components of the product by selecting the most advantageous option for all design parameters. Further, mould-flow analysis should be carried-out for all such moulds.
3. Mould-flow analysis can also be extended to cooling analysis and warpage analysis. Results obtained from-these studies can be used-for further optimization-of tool design.
4. Fabrication of the tool and tool try-out should be carried out.
5. Fatigue analysis may be performed for the tool, as it can-provide useful information regarding-expected tool life.

CAD DESIGNED PHOTOS

10.1 Component Design





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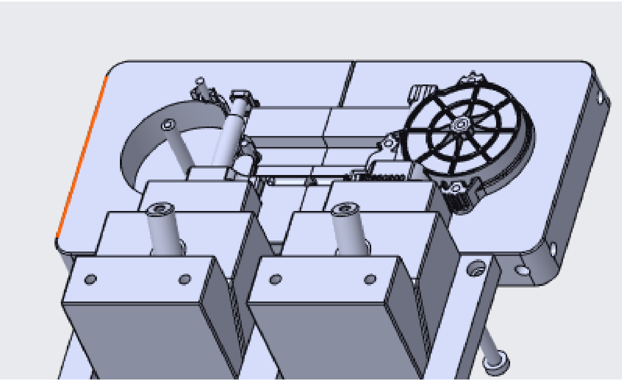
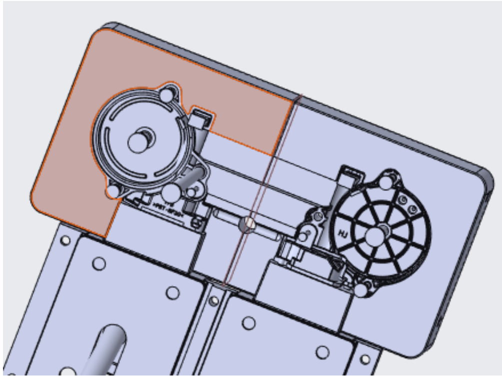
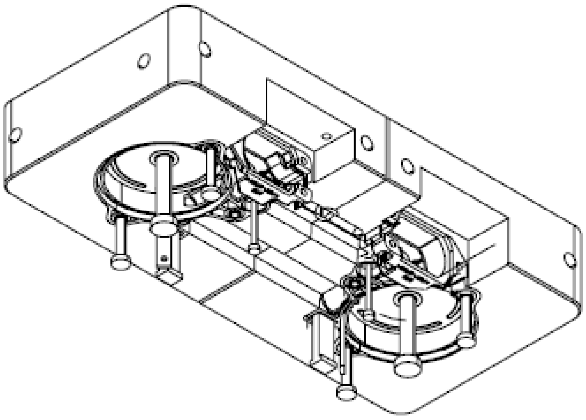
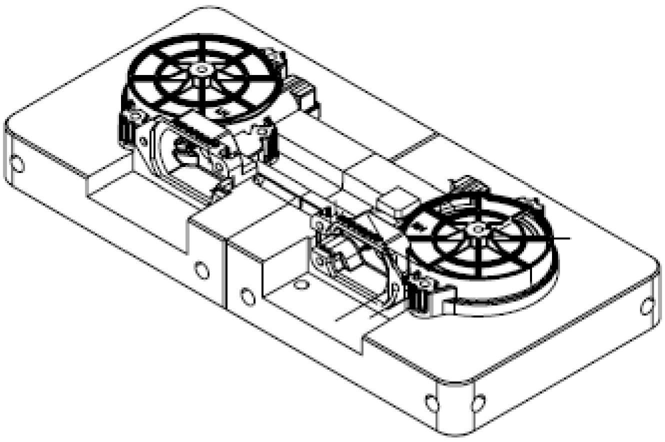
10.2 Fixed half and Moving Half design





10.3 Fixed half and Moving Half CAD Photos





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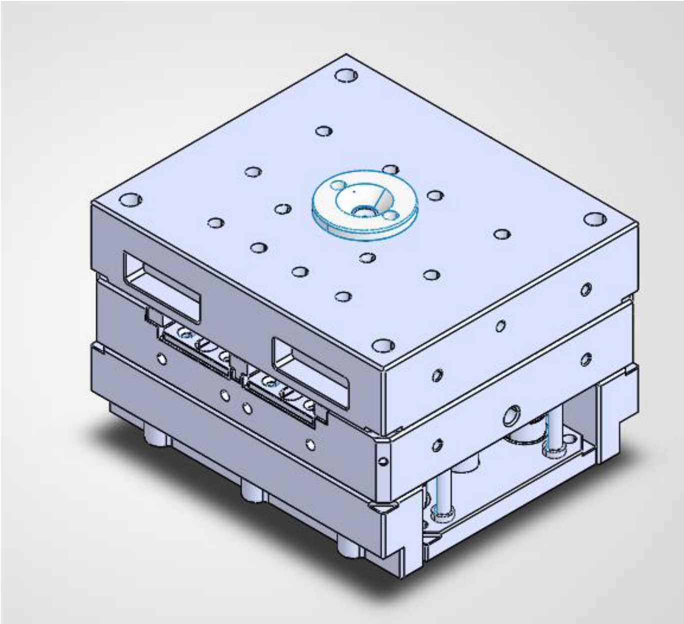
10.4 Fully Designed mould



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