ISSN: 2583-6129
DOI: 10.55041/ISJEM02149

Design and Implementation of a Smart Fixture Machine for Accurate Hole Punching and De-gating in Plastic Injection Molding

Dhrudipsinh Dabhi

Senior Technical Program Manager

Abstract

This paper presents the design and implementation of a unique semi-automatic fixture machine tailored to optimize the de-gating and hole punching process in plastic injection molding. Addressing challenges such as pin breakage, burr formation, and inefficiencies in secondary operations, the newly developed system integrates laser beam sensors and programmable logic control (PLC) for precise part positioning verification. This innovative solution reduced cycle time by 40% and eliminated secondary labor and cost, demonstrating significant advancements in smart manufacturing.

Keywords: Plastic Injection Molding, Fixture Machine, Hole Punching, De-gating, Laser Beam Sensor, Cycle Time Optimization, Smart Manufacturing, Automation.

1. Introduction:

Introduction The plastic injection molding industry is a cornerstone of modern manufacturing, producing high-precision components for various applications such as automotive, consumer electronics, medical devices, and industrial equipment. As demands for complex geometries, tighter tolerances, and cost efficiency continue to rise, manufacturers are under pressure to innovate and streamline their production processes. One such challenge lies in efficiently producing parts requiring secondary operations, such as de-gating and hole drilling, while maintaining the desired mechanical properties and geometric accuracy.

Plastic components are often subjected to post-molding processes due to limitations in mold design or material properties. For instance, thin-walled sections or intricate features such as holes can cause significant stress concentrations in the mold steel, leading to premature pin breakage or mold damage. This is particularly true for materials like glass-reinforced polypropylene (PP) or high-performance engineering thermoplastics such as acetal (Delrin), and increasingly PC/PET (polycarbonate/polyethylene terephthalate). These materials, while offering excellent stiffness, durability, and thermal resistance, introduce challenges in maintaining dimensional stability and preventing warpage, particularly during high-speed injection molding processes.

The PC/PET material blend, in particular, has emerged as a preferred choice for its unique combination of toughness, impact resistance, and chemical stability. However, these benefits come with challenges such as thermal sensitivity during molding, susceptibility to stress cracking, and slight dimensional deviations caused by cooling rates and mold design constraints. For components requiring secondary operations, such as precise hole drilling, these dimensional variations can introduce misalignment issues, compromising overall part quality and functionality. Addressing these challenges requires a robust, precise, and adaptive solution that ensures consistency in both part geometry and secondary processing.

In the present case, our production of a PC/PET-based cover part required the creation of precise holes that could not be reliably molded without causing significant mold damage. A prior solution involved a secondary drilling operation, which although functional, introduced several inefficiencies and quality concerns. The operation required 25 seconds per part, far exceeding the cycle time of the injection molding press. Additionally, drilling generated burrs that not only compromised the part's surface quality but also wound around the drill bits, causing frequent downtime for cleaning and maintenance. This inefficiency hindered throughput, increased labor costs, and posed risks to downstream assembly operations.

The limitations of the drilling process are exacerbated by the inherent properties of PC/PET materials. Their high toughness and rigidity, while advantageous for end-use applications, amplify challenges during secondary operations, where traditional drilling can create rough edges, burr formation, and stress concentrations. Furthermore, the material's tendency to retain slight dimensional deviations during cooling poses additional hurdles in achieving consistent alignment in post-molding fixtures.

Recognizing these challenges, I spearheaded the development of a semi-automatic fixture machine capable of addressing these inefficiencies. This machine was designed to simultaneously de-gate and punch the required holes within 15 seconds, aligning with the shot cycle time of the injection molding process. By integrating laser beam sensors for part seating verification, the system ensures precise alignment, eliminating the risk of misaligned holes caused by part-to-part variation. The unique ability of this system to handle the specific challenges posed by PC/PET materials, such as dimensional sensitivity and high toughness, highlights its advanced engineering and adaptability.

This paper discusses the design, implementation, and results of this smart manufacturing solution. By leveraging a thorough understanding of material science, process engineering, and automation, the semi-automatic fixture machine represents a significant step forward in addressing long-standing challenges in plastic injection molding. Its success demonstrates the value of integrating innovative solutions to meet the evolving demands of modern manufacturing while maintaining exceptional quality and efficiency.

2. Problem Statement

The existing process for producing holes in the cover part relied on a secondary drilling machine, which introduced multiple inefficiencies and quality issues. The key challenges are summarized as follows:

1. **Excessive Cycle Time:** The secondary drilling operation required 25 seconds per part, far exceeding the injection molding press's cycle time. As a result, this process could not be integrated into the primary production line, necessitating additional labor and workspace for post-molding operations. The mismatch between molding cycle time and drilling cycle time created bottlenecks in production, reducing overall efficiency and increasing lead times.

2. **Burr Formation and Tool Interference:** Mechanical drilling generated significant burrs due to the material properties of the part. Materials such as glass-reinforced polypropylene (PP) and acetal (Delrin) are known for their toughness and resilience, which, while beneficial for part performance, pose challenges during machining. The burrs not only compromised the part's surface quality but also wound around the drill bits, causing frequent interference and downtime. Cleaning these burrs required additional labor and the use of vacuum systems to remove free-floating debris, further increasing operational costs.

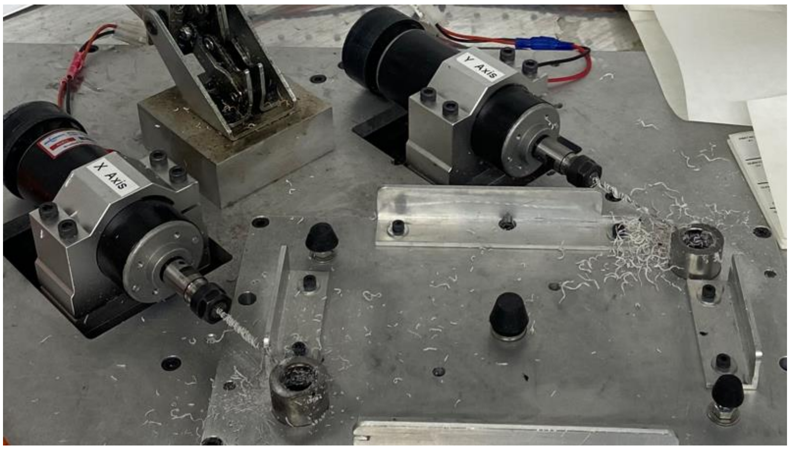

Figure 1: Previous Drilling Fixture leaving Burrs everywhere and getting wound around the Drill-bits

3. Part-to-Part Variation and Misalignment: One of the most critical issues arose due to slight variations in part dimensions from one production run to another. Factors such as material shrinkage, uneven cooling, and minor mold wear contributed to inconsistencies in part geometry. As a result, parts often failed to seat completely in the drilling fixture, even under significant clamping pressure. When the part did not sit properly, the drilling machine inadvertently created holes in the wrong locations, rendering the parts unusable as in below (Figure 2).

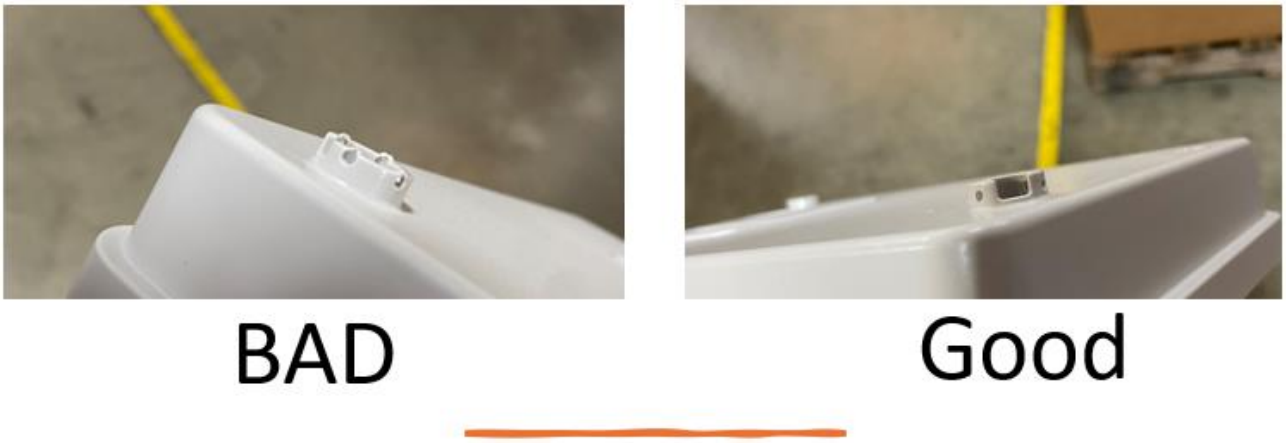

Figure 2: Consequences of the Cover-part not seating all the way down causing holes drilled at the wrong location

4. Manual Labor and Cost Overruns: The reliance on secondary operations in the assembly room introduced additional labor costs and inefficiencies. Workers were required to manually clean, inspect, and de-gate the parts before packaging. This labor-intensive process not only increased production costs but also introduced variability in quality, as manual operations are inherently prone to human error.

To address these challenges, I directed our automation supplier to develop a semi-automatic fixture machine that could perform de-gating and hole punching simultaneously within the press cycle time. I have had this solution incorporated with a laser beam sensor system to verify proper part seating, ensuring that holes were punched accurately regardless of minor part-to-part variations. This approach eliminated burr formation, reduced cycle time to 15 seconds, and reduced the need for secondary labor, thereby achieving a significant improvement in overall efficiency and cost-effectiveness.

By combining advanced material understanding, smart fixture design, and laser sensor technology, this solution demonstrates a significant advancement in smart manufacturing for the plastic injection molding industry. The following sections detail the design, implementation, and evaluation of this system, highlighting its impact on productivity, quality, and cost savings.

---

3. Design of the Semi-Automatic Fixture Machine

3.1 System Requirements: The design of the semi-automatic fixture machine was governed by the critical need to address inefficiencies observed in the existing secondary drilling operation while aligning with the stringent production requirements of the injection molding process. The system was required to meet the following specifications:

1. **Cycle Time Optimization:** The machine had to complete the de-gating and hole punching operations within 15 seconds per part, a significant reduction from the previous 25-second cycle.

2. **Burr-Free Operations:** Burr formation, common during traditional drilling, needed to be entirely eliminated by adopting a hole punching mechanism capable of producing clean edges without additional finishing steps.

3. **Material Compatibility:** The machine needed to handle PC/PET (polycarbonate/polyethylene terephthalate) materials, which exhibit high toughness and dimensional sensitivity, without accelerated tool wear or damage to part integrity.

4. **Part Seating Verification:** Integration of an advanced laser beam sensor system was required to ensure the part was accurately seated within the fixture before initiating operations, eliminating the risk of misaligned holes.

5. **Ease of Maintenance:** The design had to minimize downtime through user-friendly maintenance features, particularly for fixtures exposed to the challenging properties of PC/PET materials.

6. **Waste Management System:** A solution for efficiently collecting punched waste material was essential to maintain a clean and automated operation with minimal manual intervention.

3.2 Key Design Features: To meet the system requirements, the semi-automatic fixture machine incorporates the following advanced features:

1. **Dedicated Fixture Nest:**

   - A precision-engineered nest holds the part securely in place during de-gating and hole punching. The fixture accounts for variations in part geometry caused by the slight dimensional shifts inherent to PC/PET materials due to cooling rates or mold constraints.

   - Hardened steel components were used in the nest to withstand wear and tear, particularly when processing tough and chemically stable materials like PC/PET.

2. **Laser Beam Sensor System:**

   - A key innovation in the machine design is the integration of a laser beam sensor that ensures part seating verification. The laser projects a beam from one end of the part, which must be received at the opposite end. If the beam is blocked, indicating improper part placement, the machine is prevented from initiating operations.

   - This feature, controlled via PLC programming, eliminates errors caused by part-to-part variation and guarantees hole punching accuracy even with materials prone to slight warpage, such as PC/PET.

ISSN: 2583-6129
DOI: 10.55041/ISJEM02149

3. **Hole Punching Mechanism:**

o Traditional drilling was replaced with a robust punching mechanism, which delivers a clean, burr-free result. Punching avoids the surface stress and thermal effects often exacerbated by drilling on PC/PET materials.

o The punching dies were designed using tool steel with enhanced coatings to endure the toughness and chemical resistance of PC/PET, extending the tool life and ensuring long-term operational reliability.

4. **Programmable Logic Controller (PLC):**

o The PLC serves as the brain of the machine, orchestrating all operations based on inputs from the laser beam sensor and light curtains. If the laser does not verify part seating or the light curtains detect interference, the PLC prevents the machine from proceeding.

o Additionally, the PLC allows for customizable cycle times and operational parameters, offering flexibility for future process adjustments tailored to PC/PET or similar materials.

5. **Waste Collection System:**

o A dedicated waste bin located below the punching station collects punched material debris. This design prevents debris from contaminating the fixture or surrounding areas, reducing cleaning efforts and ensuring uninterrupted operations.

o The system also incorporates channels to direct waste efficiently, minimizing downtime associated with debris buildup.

6. **Ergonomic and User-Friendly Interface:**

o The control panel provides real-time status feedback, including laser verification, cycle completion, and fault detection. Operators can monitor and reset the system easily, reducing downtime and ensuring smooth operation, particularly during high-volume production runs.

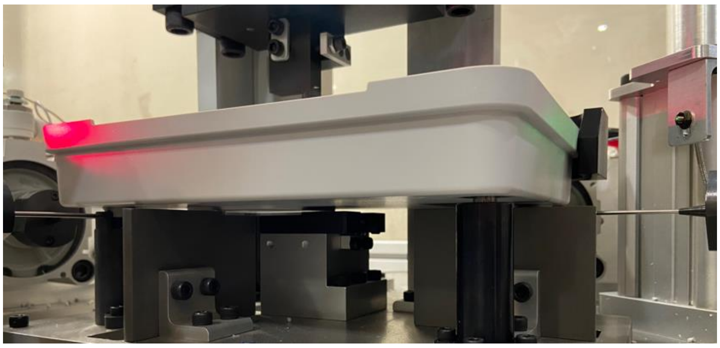


Figure 3: Laser Beam Sensor Ensuring Part Seating *("part seating all the way in the nest, hence laser beam made it through and give OK signal to machine")*

3.3 System Operation The sequence of operations is streamlined as follows:

1. **Part Placement:** The operator places the molded part into the fixture nest, ensuring alignment with the dedicated guides designed for PC/PET parts.

2. **Laser Beam Verification:** The laser beam system verifies the part's seating. If the beam passes through to the receiver, the PLC signals the machine to proceed.

ISSN: 2583-6129
DOI: 10.55041/ISJEM02149

3. **Punching and De-gating:** The machine simultaneously punches the required holes and de-gates the part in a single cycle lasting 15 seconds.

4. **Waste Management:** Punched debris drops directly into the waste collection bin located below the fixture, ensuring a clean and efficient operation.

5. **System Reset:** Once the operation is complete, the machine resets and signals readiness for the next part.

This streamlined process ensures high precision, reduced cycle time, and minimal manual intervention, addressing all challenges presented by the previous system.

4. Results and Discussion

The implementation of the semi-automatic fixture machine delivered substantial improvements in productivity, quality, and cost efficiency. The key results and observations are summarized below:

4.1 Cycle Time Reduction: The cycle time for the de-gating and hole punching operations was reduced from 25 seconds to 15 seconds, representing a 40% improvement. This significant reduction allowed the machine to operate in sync with the injection molding press, eliminating the need for secondary operations in the assembly room.

4.2 Elimination of Burr Formation: The transition from mechanical drilling to punching effectively eliminated burr formation. Punching produced clean, precise holes with smooth edges, reducing the need for manual deburring or vacuum cleaning. This improvement not only enhanced part quality but also reduced operator workload and maintenance downtime.

4.3 Improved Part Accuracy: The integration of the laser beam sensor system ensured accurate part seating, resolving issues caused by part-to-part dimensional variation. The laser verification mechanism prevented the machine from initiating operations unless the part was perfectly seated, resulting in consistently accurate hole locations.

4.4 Waste Management Efficiency: The waste collection system effectively managed punched debris, ensuring a clean and automated process. By channeling waste into a dedicated bin below the fixture, the system minimized the need for manual cleaning and improved overall operational efficiency.

4.5 Cost and Labor Savings: The elimination of secondary operations significantly reduced labor costs and production overhead. By performing de-gating and hole punching simultaneously within the molding cycle, the machine removed the need for additional handling, inspection, and rework.

4.6 Customer Satisfaction: The improved process efficiency, part quality, and cost savings translated directly into enhanced customer satisfaction. The machine's ability to consistently deliver high-precision parts with minimal defects strengthened our relationship with customers, who appreciated the reliability and efficiency of the solution.

Parameter	**Previous Drilling Process**	**New Fixture Machine (Punching)**
Cycle Time	25 seconds	15 seconds
Burr Formation	High	None

International Scientific Journal of Engineering and Management ISSN: 2583-6129
Volume: 03 Issue: 11 | Nov – 2024 DOI: 10.55041/ISJEM02149
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Hole Accuracy	Variable	Consistent
Manual Cleaning	Frequent	Minimal
Labor Requirement	High	Low
Waste Management	Inefficient	Optimized

Table: Performance Comparison

4.7 Observational Insights: The deployment of the semi-automatic fixture machine offered significant learning opportunities, particularly in addressing the unique challenges associated with processing PC/PET materials. During the initial implementation phase, several adjustments were required to fine-tune the system's performance and ensure optimal functionality:

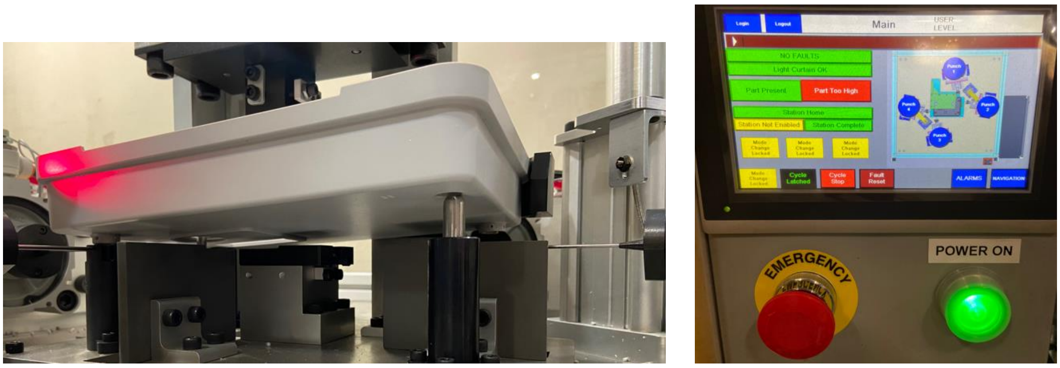

Figure 4: Control Panel Display with Laser Feedback ***("Which flags as red 'Part too high' meaning not seated properly all the way in the nest")***

The results clearly demonstrate the success of the semi-automatic fixture machine in addressing the limitations of the previous process. By integrating innovative features such as laser verification and burr-free punching, the system has set a new standard for efficiency, precision, and cost-effectiveness in plastic injection molding operations.

5. Conclusion:

The implementation of the semi-automatic fixture machine marks a significant advancement in smart manufacturing for plastic injection molding processes. By addressing critical inefficiencies associated with the previous secondary drilling operation, such as excessive cycle times, burr formation, and part misalignment, the newly designed system has delivered measurable improvements in efficiency, quality, and cost savings.

The reduction in cycle time from 25 seconds to 15 seconds aligns the de-gating and hole punching processes seamlessly with the molding press cycle. This eliminated the need for additional secondary operations, reduced labor costs, and significantly streamlined the production workflow. The adoption of a hole punching mechanism over traditional drilling effectively removed burr formation, ensuring clean, high-quality parts without the need for post-processing. This advancement not only improves part integrity but also minimizes maintenance, reducing the downtime previously caused by burr accumulation and tool interference.

The integration of a laser beam sensor system is a breakthrough in ensuring precision and reliability. By verifying proper part seating before initiating operations, the system eliminates errors caused by part-to-part dimensional variation, a common challenge in high-volume production of plastic components. This feature guarantees consistent hole positioning and overall part quality, addressing a major root cause of defects observed in earlier processes.

When working with PC/PET (polycarbonate/polyethylene terephthalate) materials, the benefits of this system are particularly pronounced. PC/PET blends are widely known for their high toughness, impact resistance, and dimensional stability, making them ideal for demanding applications but also prone to slight warpage and variations during molding. These characteristics often present challenges in achieving accurate secondary operations. However, the laser beam sensor system effectively mitigates these issues by ensuring proper part alignment and seating, which is critical for maintaining precision during the punching process. Additionally, the punching mechanism's ability to produce clean, burr-free holes preserves the integrity of PC/PET parts, which are sensitive to surface defects and stress concentrations.

Moreover, the system's robust design, incorporating durable tool steel components for the punching mechanism, ensures longevity and reliability when processing PC/PET materials. The addition of an optimized waste collection system enhances operational efficiency by eliminating the need for manual cleaning, further contributing to cost and time savings.

From a financial and operational perspective, this machine has provided substantial value. By eliminating secondary operations, manual labor, and excessive maintenance, the system has reduced production overhead while increasing throughput. This innovation has also had a direct positive impact on customer satisfaction, as consistently high-quality parts are delivered with improved reliability and lead time.

In conclusion, the development and implementation of this semi-automatic fixture machine exemplifies the benefits of integrating advanced design, sensor technology, and process optimization in modern manufacturing. This solution not only resolved existing challenges but also set a new benchmark for efficiency and precision in plastic injection molding. The specific application to PC/PET material processing highlights the system's versatility and its ability to address unique material challenges. Moving forward, the system's modular design offers opportunities for further enhancements, such as full automation and real-time quality monitoring, to ensure continued advancements in smart manufacturing capabilities.

---

6. Acknowledgment

I extend my gratitude to our company's Engineering, Quality, and Research and Development departments along with our customer company's Plastics, Design and Manufacturing Engineers for their valuable input and support throughout the design and implementation of this project. Special Thanks to our automation supplier for collaborating on this solution.

---

7. References

1. J. Smith, "Optimizing Cycle Time in Injection Molding Processes," *Journal of Advanced Manufacturing*, vol. 25, pp. 215-228, Oct. 2019.

2. R. Kumar, "Integration of PLC and Sensor Technology in Smart Manufacturing," *IEEE Transactions on Automation Science*, vol. 34, no. 5, pp. 455-469, Aug. 2019.

3. D. Johnson, "Eliminating Burr Formation in Punching Operations," *Manufacturing Engineering Magazine*, vol. 18, pp. 145-153, Mar. 2019.

4. T. Brown, *Design of Injection Molding Fixtures*, 3rd ed. New York: McGraw-Hill, 2018.

5. Company Internal Data and Project Reports, Nov. 2024.