Plastic Injection Molder

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MEGN 301: Mechanical Integration and Design

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Table of Contents

Problem Description

In order to reduce plastic pollution, the team sought to build a plastic injection molder - a common machine used for manufacturing plastic. The largest constraints on the project were that the team had a budget of $200 and a semester's worth of work time - about 480 hours. Due to limitations with storage, the molder also needed to be portable or desktop sized. In order to melt different types of plastic, the heating chamber needed to reach a maximum temperature of 250 degrees Celsius.

Design Selection

To begin the design selection process, each member of the team developed a unique design solution. For example, Design Concept One utilizes a lever arm to exert force for extrusion and features heating bands for melting plastics within the heating chamber. Similarly, Design Concept Two also uses a lever arm, however, this design uses heating cartridges in place of band heaters. In contrast to the first two designs, Design Concept Three features an arbor press for producing force and an induction plate for heating the mold and the heating chamber. Design Concept Four sets itself apart from the other designs through the incorporation of a linear actuator, minimizing laborious efforts when injecting. Finally, Design Concept Five makes use of features similar those of a plastic injection molder within industry, such as a reciprocating, tapered injection screw and a hopper that feeds additional material into the heating chamber. With five different designs, the decision matrix below was created to rank each design based on various selection criteria and highlight their distinct characteristics. Such selection criteria

		Concept Number				
		1	2	3	4	5
Selection Criteria	Weight (1-5)	Score (1-5)	Score (1-5)	Score (1-5)	Score (1-5)	Score (1-5)
Cost	5	4	3	4	2	3
Feasability	4	4	4	5	3	2
Manufacturing Time	4	2	2	4	4	4
Safety	1	4	4	4	4	4
Ease of Use	3	5	5	3	5	5
End Product Quality	3	3	3	4	4	5
Production Time	2	4	4	5	4	4
Design Flexibility	2	4	4	4	3	2
Stakeholder Appeal	3	2	2	4	4	5
Producable Pressure	4	4	4	5	1	5
	Total	36	35	42	34	39
	Total Weighted	110	105	131	99	120

include Cost, Feasibility, Manufacturing Time, Safety, Ease of Use, End Product Quality, Production Time, Design Flexibility, Stakeholder Appeal, and Producible Pressure. Each selection criteria received a weighting score of one through five, addressing the varying importance of each category. For example, Production Time held lower importance and received a weighting score of two, while Cost held high importance and received a weighting score of five. After rating each design concept, Design Concept Three ended with the highest weighted score. Several aspects of other designs were then incorporated into this design to create an improved, final design concept. Notably, the induction plate from the original Design Concept Three was replaced with band heaters to better suit the cylindrical nature of the heating chamber. Ultimately, this final design concept allowed for sufficient force to extrude molten plastic and provided a safe and reliable method of heating the heating chamber to a desired temperature.

Initial Prototype Development

The initial prototype development took place in various stages as different components shipped in. The first step was to source an arbor press that would be able to supply enough force to push the molten plastic into the mold. This was initially slated to be a standard arbor press from harbor freight, but thanks to insight from Buddy, the arbor press was sourced at a cost of $0 from the Senior Design Lab. With the arbor press sourced for free, the decision was made to use it and build around some of its quirks. For example, the free arbor press had less clearance beneath the fully extended rack than the model from harbor freight, as well as having less room overall beneath the lever system. With the decision made to use the free arbor press, the team was forced to build a base in order to support the force exerted and prevent the press from tipping forward as the rack pushed the injector. This base would also be able to house the heating chamber, and by threading a metal flange onto one end of the heating chamber, metal to metal contact on the arbor press would eliminate any risks of damage caused by pushing the injector into the heating chamber. In this iteration, it was also discovered that the injector wouldn't fit tightly within the heating chamber due to tolerance issues which were caused by our team's lack of research on the inner and outer diameter of our chamber. Many potential solutions were explored, with our choice being implemented in the refinement stage. On the mold-side of the operation, a CAD model of our final product was sourced and the initial mold design was completed. This initial mold design didn't set any dimensionality of the sprue, or a runner system. At this stage, the CAM operations had also not been mapped out. The aluminum for the two mold halves was then sourced from the Machine Shop and given a machined finish such that the two halves could be used to represent our mold's final size.

Prototype Testing

The team tested the prototype in three phases: heating, melting, and injecting. When the heating chamber was completed, the heating system was tested and the PID controller was tuned to allow consistent temperature control without overshoot. The second phase of testing involved heating plastic to test the melt time and determine optimum settings for plastic melting. The third phase was a complete test of the entire prototype, which focused on testing the amount of plastic needed to fill the mold, as well as developing a procedure for ejecting the part from the mold after solidification.

These tests were conducted intentionally in this order to reduce the likelihood of issues going forward. For example, the heating system was tested before testing the melt time. This allowed us to be sure that the heating temperature would be properly controlled before attempting to melt plastic. Carrying out a series of tests in this way allowed the group to tackle the engineering design problem by breaking it down into several manageable goals (ie. create a heated chamber, melt the plastic, push the plastic from the heating chamber, attach the mold, etc.) which allowed relatively smooth passage from one sub-goal to the next. One important concept in engineering is the idea of failing fast and often. By testing the prototype incrementally, bad designs were iterated upon to improve the overall performance of each subsystem. This greatly improved the final product, as no machine is greater than the sum of its parts; thoroughly testing and refining each part allowed the machine to work smoothly and effectively.

From initial testing, the team determined that the cycle time was going to be longer than initially expected. In the heat transfer calculations, it appeared that 300 watts would be plenty to effectively heat the chamber/mold assembly and melt the plastic. However, in testing it was found that 300 watts was only barely enough to melt the plastic, and the melt time was about 40 minutes. In addition, it was determined that no external heat would be needed to warm the mold. Initially, it was unclear whether the mold would be too cold to produce a good surface finish, but in testing it was found that the interface between the mold and heating chamber is a good enough thermal connection that the mold was heated through conduction with the heating chamber, allowing for a very good surface finish.

Prototype Refinement

The first step of our prototype refinement was machining the inner diameter of the heating chamber in order to remove the welded strip and to reduce the friction that would be exerted on our plunger. This was done using the lathe and a drill bit that fit exactly within the chamber. The following step was to increase the diameter of our plunger. This was done by welding a washer onto the end of the rod, and then machining it down to the same diameter as the new interior of our heating chamber. After this, the CAM was updated with the help of staff within the machine shop and the two mold halves were created. It was seen that the two mold halves held pressure perfectly, so out of concern of forcing an explosion, air channels were machined into one of the halves to allow for air to escape as plastic filled the mold. The final refinement step was tuning the PID Controller and the heating bands. Issues also arose as heating bands burned out. Using one heating band would mean that there would be an extensive delay between starting to melt the plastic and being able to inject into the mold.

Final Prototype

Our team's final working prototype consisted of an arbor press mounted to a wooden frame, a heating chamber with one heating band, a nozzle screwed onto the heating chamber, two mold halves that get bolted together then attached to the nozzle, and an injection rod that gets inserted into the heating chamber. The original final prototype only used one heating band as the second heating band had burned out. However, over Thanksgiving break, a second heating band was sourced and implemented into the final prototype that was demonstrated during demo day. In the end, our final prototype fulfilled the problem the team set out to solve: create a cheap, portable, plastic injection molder that works with a variety of recyclable plastics. As far as our own set design criteria, the team came in under our $200 budget and under the 480 man hour time restriction. Additionally, our plastic injection molder was able to handle a variety of plastics, was within the 12 cubic feet size constraint, and was powered by a standard house outlet. The only criteria not met was our goal to limit overall design weight to 30 pounds and to achieve a fast melting time. Despite this, our prototype was still portable at 50 pounds and produced an exceptional surface finish on the injected part. Overall, the final prototype performed well in comparison to other project prototypes within the class and was able to meet the expectations of the team. The detail and time spent on the mold paid dividends in producing a high quality output and ensuring a quality surface finish. The adjustability of the design allowed the heating chamber temperature to be tweaked in order to ensure ideal melting conditions for a variety of plastics.

Future Work

Although the prototype achieved the desired goals, it is by no means a final product. Further refinement of the prototype would entail using extra band heaters and PID controllers to ensure the entire heating chamber and nozzle were heated more uniformly and quickly. Adding more power into the equation would reduce the rather long cycle time. Insulation around the heating chamber would also aid in reducing the time needed to melt plastic. It would also be more ideal if there were heaters around the nozzle. The nozzle hole for the final product would need to be smaller, as its current size allows plastic pellets to fall through. The plunger rod should also be shortened for ease of placement into the heating chamber, especially when more plastic is used than in testing. To make the end product easier to use, further testing would need to take place to find and document the ideal melting temperatures and times for the common plastics; better yet, the user control interface would allow the user to choose a plastic, and the controller would automatically set the temperature and a timer to melt the plastic then notify the user that the plastic should be injected. A heat resistant glove would also need to come with the final product in order to make removing the mold safer. A better interface between the nozzle and mold would also need to be designed so that that the plastic injection molder could be more versatile in the molds used; although it wasn’t an issue with the current mold, it does place limits on the size and shape of the plastic part, as at least two holes need to be specifically placed in the mold to allow for bolts that attach to the nozzle. Since safety was not the most highly valued design criteria in the prototype, warning labels and a physical cage around the heating chamber would need to be attached in order to mitigate hazards related to the heating chamber.

Lessons Learned

The team learned the value of the Scrum/AGILE design process. Specifically, how the sprint cycles help drive the project rather than loading all the work near the deadline. One lesson our team learned early that benefitted the progression of our project was that it can be more important to meet a sprint's deadline than it is to have the sprint completed perfectly. For example, in the initial stages where calculations were prioritized, the team was able to perform more "rough" calculations and apply a larger factor of safety. This helped us save time initially and allowed us to order our parts earlier and thus begin construction earlier. Another important lesson the team learned was focusing on a more simple, but adaptable design. That way, should any one component fail, the project could be adapted so that one component wouldn't ruin the success of the entire project.