Design and development of injection moulding machine for manufacturing laboratory

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Abstract. This paper presented the design process and manufacturing of a benchtop and inexpensive injection moulding machine for use as learning and teaching equipment in a manufacturing laboratory. The design use a vertical plunger type of injection equipped with clamping system. The maximum volume of barrel is 290 cc combined with injection plunger 60 mm provides ideal capacity for lab. The design concept process and preliminary test result are discussed. The flow rate increases with increase of motor speed and the packing time decrease with increase of motor speed. At 2500rpm the flow rate is 0.42m/s and pack time is 15 second.

1. Introduction
Commonly used materials in teaching the process of producing near net shape components in manufacturing lab are low cost materials such as plastic and polymer-composite although sometimes low-melt temperature metals or alloys and ceramics are used as well. All these materials can be produced, machined, fabricated and assembled by equipment such as, CNC machining, 3D printing, casting, and injection moulding machines. The injection moulding process is primarily a sequential operation that results in the transformation of plastic pellets into a moulded part. Identical parts are produced through a cyclic process involving the melting of a pellet or powder resin followed by the injection of the polymer melt into the hollow mould cavity under high pressure Common process to produce polymeric components is by using injection moulding machine. In injection moulding process, polymer melts must have high viscosity and cannot simply be poured into a mould like metal die casting. Instead a large force must be used to inject the polymer into the hollow mould cavity. The process of clamping, injection, cooling and ejection are essential knowledge for practical activities in manufacturing lab. The commercial injection moulding machine can provide that knowledge at ease however not all manufacturing labs have sufficient budget or space for it.

Many research have been carried out to improve the process of injection moulding based on theoretical, computer based simulation models and experimental trials [1]. Specific optimisations have been done to the machine for specific manufacturing product, such as a brake booster valve body, bird cage and automotive part [2-4]. The work on optimization that employed Taguchi method for minimizing warpage and sink index in injection moulded thermoplastic was carried out by Erzurumlu et al. In their study they considered mold temperature, melt temperature, packing pressure, rib cross section and rib layout angle and material PC/ABS, POM, and PA66. Other optimization approach that
is artificial neural network and fuzzy logic have been used for initial process parameter setting that provides proper setting for good quality molded parts [5-6].

This work aims to provide the needs of proper knowledge of injection moulding process for undergraduate students learning in a manufacturing lab by developing a machine that is relatively low cost. This machine is expected to provide similar experience as commercial injection moulding machines in addition to research needs.

2. Design Concept

The injection moulding machine is designed for lab work purposes with main considerations for inexpensive, small size, capable of producing small number of products for prototype testing, able to accommodate up to medium size specimens, and have similar operational procedure as in commercial large injection moulding machine. In order to accommodate those constrains, the injection moulding machine is designed as a benchtop size, vertical type and having four main components that can be modified for experimental works.

Three concepts of vertical type are considered and sketched roughly in figure 1. Concept 1 utilize screw component to inject the heated plastic to die, while concept 2 and concept 3 uses plunger. The different between concept 2 and 3 is on movement of the plunger. Concept 2 utilize hydraulic instead of motors as in concept 3. In concept 3, the injection pressure is controlled by the speed of motor using motor speed drive. A simple decision making tool is employed and odd numbers from 1 to 9 are used to denote the magnitude value presented in table 1. Based on the weighted decision in table 1, concept 3 has the highest rating for material, manufacturing process and product result. These criteria will be most likely to be able to simulate the condition of injection moulding as in an commercial environment. Thus, concept 3 was selected for prototyping development.

![Figure 1. Alternative concepts of vertical injection moulding machine.](image-url)
Table 1. Weighted decision matrix for conceptual design of injection moulding machine.

|                | Concept 1 |             | Concept 2 |             | Concept 3 |             |
|----------------|-----------|-------------|-----------|-------------|-----------|-------------|
|                | Magnitude | Score Rating | Magnitude | Score Rating | Magnitude | Score Rating |
| Material       | 7         | 0.15 1.05   | 3         | 0.15 0.45   | 9         | 0.15 1.35   |
| Construction   | 3         | 0.20 0.60   | 9         | 0.20 1.40   | 7         | 0.20 1.40   |
| Manufacturing  | 9         | 0.10 0.90   | 5         | 0.10 0.50   | 9         | 0.10 0.90   |
| process        |           |             |           |             |           |             |
| Time to produce| 5         | 0.20 1.00   | 7         | 0.20 1.40   | 7         | 0.20 1.40   |
| Product result | 7         | 0.20 1.40   | 7         | 0.20 1.40   | 9         | 0.20 1.80   |
| Cost           | 9         | 0.15 1.35   | 5         | 0.15 0.70   | 7         | 0.15 1.05   |
|                |           | 6.30        |           | 6.05        |           | 7.90        |

The four main sub-assemblies for concept 3 are drawn with CATIA as in figure 2. It was designed such that these sub-assemblies can be modified later to accommodate experimental parameters. Components such as motors, barrels, heater, clamper and plungers are usually needs some adjustments during experimental work. Similar experimental works by Dimla et. al.[8] is able to be performed using this machine by adding a cooling channels.

![Figure 2. Four main sub-assembly of injection moulding machine (a) motor (b) main pillar (c) switch panel (d) LCD panel (e) heater (f) barrel (g) clamper.](image)

The machine weighs 73 kg and has 35 x 60 cm footprint with height of main pillar at 95 cm. The total production cost of the machine is about Rp. 10 million (US$750). The highest cost contributors are motors, controllers and heater while frame and machining is relatively inexpensive due to the precision works is not so high. The results of construction work can be seen in figure 3(b) that compared side by side with CAD rendered drawing figure 3(a).
3. Preliminary Test Results and Discussion
In order to test the performance of injection pressure and its flow rate, a simple mould was developed. The mould is designed with two outputs to evaluate the time to pack. The simple mould together with its test result is shown in figure 4. Figure 4(c-d) shows the relation between motor speed that control injection pressure and time to pack the mould with liquid plastic. While average flow rate is calculated based on it volume and time. It is considered in good moulding area of injection capacity.

Figure 3 Injection moulding machine (a) CAD drawing using CATIA (b) photograph of injection moulding machine.

Figure 4. Testing results (a) simple mould (b) plastic product, (c) flow rate (d) time to pack.
4. Conclusion
This paper presents the design and development of an injection moulding machine for manufacturing lab that have features of low cost, bench top size, and have similar processes as in commercial injection moulding machine. The design concept and preliminary test of the prototype were discussed and validated in terms of its performance. The machine is well suited for use in undergraduate teaching labs as well as research needs.

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