Component design concept of hydraulic gear pressing machine for plastic bottle waste recycle

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Abstract. Continuous increment of plastic bottle waste creates new problems of space-consuming both in landfills and the ocean. Hence, plastic bottle waste recycling process and volume reduction are needed. This paper proposes a component design concept of a pressing machine to press plastic bottle wastes for volume reduction purpose. The proposed design essentially brings a concept of combining hydraulic and gear power to produce the pressing mechanism. Some boundary conditions were applied, such as force magnification, weight, and dimension; thus, the machine can be portable because of small scale dimension and light weight. Furthermore, the machine can be used as a demonstration machine for education purpose.

1. Introduction

The amount of plastic bottle waste is increasing linearly with daily consumption. In a day, the total amount of waste produced in Indonesia was reported to reach 407,073 meters cubic in 2017 and 412,047 meters cubic in 2018 [1]. From the total waste produced, plastic bottles contribute up to 2% with a total mass of 9,589 kilograms. The implementation of recycling the waste is still a challenge [2,3]. The pressing machine was granted to solve the problem by reducing plastic bottle waste volume. However, the big dimension of the currently available pressing machine needs to be replaced with the smaller ones.

Pressing machine commonly adopting a hydraulic system for the mechanism. It enables the user to produce high force with a small input force in the mechanical linkage utilizing Pascal's law [4]. This law concludes that the limitation of the force that a machine can exert is the area to which the pressure is applied, where the small force on a small area would create a proportionally larger force on a larger area [4]. Another mechanism can be found is the gear mechanism. It functionally transmits rotary motion from one shaft to another with the advantages of energy efficiency from gear ratio [5]. An important consideration of using a gear mechanism is located on the choice of radius and number of teeth. Radius or the gear can directly affect the force magnification due to gear ratio while the number of teeth affects the force transmission considering teeth are the portion of the gear that makes contact with another gear [5].

The objective of the present work is to develop a component design concept of mini pressing machine which combines hydraulic and gear mechanisms for plastic bottle waste volume reduction. The combination allows the production of high force from the hydraulic mechanism and high torque that is transmitted by friction forces at points of tangency between gears mechanism [6,7]. To accomplish the purpose of making small dimension, the proposed machine is designed with some boundary conditions,
such as force magnification, weight, and dimension; thus, the machine can be portable because of small scale dimension and light weight. This concept design of a pressing machine is expected in the future to be realized in reducing plastic bottle waste to solve environmental problems.

2. Research methodology

2.1. Problem definition
Boundary condition applies in designing a hydraulic gear pressing machine that specifically focuses on its dimension, weight, and magnification.

- Force output magnification is 50 times force input.
- Dimension 1 x 1 x 1 m.
- Mass range 10 – 15 kg.

The synthesis process should follow the boundary condition when determining the components of the pressing machine. The design process of the pressing machine was carried out using the engineering design process as shown in Figure 1. The schematic design of the pressing machine can be seen in Figure 2.

![Figure 1. Design procedure of pressing machine.](image)

2.2. Design concept
A common pressing machine possesses a dimension of 1300 x 800 x 1300 mm. By considering those big dimensions, the proposed pressing machine is restricted to a maximum dimension 1 x 1 x 1 m with a dimension volume reduction of 68%. The magnification was set to have 50 magnification to produce a higher output force with a small input force, which means it is only required 2 N to press a plastic bottle that requires 100 N until it crushed. That magnification can be adjusted by using the hydraulic-gear mechanism.

The material chosen for each component was determined based on the strength and density to meet the boundary condition. Refer to the strength density chart, the strength of a material is directly proportional to its density where high strength material has high density [8]. According to the chart, the materials used for the rack and pinion gear is Cast Carbon Steel (7800 kg/m3), the shaft is AISI Steel cold Drawn (7870 kg/m3), the dies, and Frame are AISI 347 Annealed Stainless Steel (8000 kg/m3).

3. Results: synthesis and analysis
In the present work, a combination of hydraulic and gear mechanisms is considered, which result in producing a high output force with a small input force. The concept design of the proposed pressing machine can be seen in Figure 3. In Figure 3(a), the assembled drawing of the proposed pressing machine is shown. The hydraulic jack used for the design process is shown in Figure 3(b), which is then connected with the rack and pinion gear mechanism (Figure 3(c)). Figure 3(d) shows the front view of the machine’s frame.
Figure 2. Schematic figure of hydraulic gear pressing machine design.

Figure 3. Hydraulic gear pressing machine assembly; (a) assembled machine, (b) hydraulic jack, (c) rack and pinion gear mechanism, (d) dies and frame.

Since the pressing machine consists of several components, in the below, a brief explanation of each component is given.

3.1. **Hydraulic jack**

The hydraulic mechanism can produce a high output force that is needed to meet the target of 50 times magnification. The modification is located at the spur gear that is changed into linear gear that is matched with the jack. This linear gear act as the extension that is connected with the small gear.

3.2. **Rack and pinion gear**

Rack from jack extension is in contact with the small pinion gear while another big pinion gear connects to rack dies. A combination of two gear allows the force up to be going down and vice versa. The advantage of a combination of the small and big gear is to give a double downward movement. Some considerations are taken into account in determining the material. The material property used in a big gear and small gear is cast carbon steel because it has high yield strength, low cost, and high ductility.

3.3. **Shaft**

The shaft was designed as the cantilever of the small and big gear and also as the buffer of the big rack and small rack. To lock the shaft, it uses the two domes of nuts that the face of the nuts will be welded to the body and the nuts. The material used for shaft is AISI Steel 1015 as it has higher yield strength compared with Cast Carbon Steel that is used for rack and gear.

3.4. **Container**

The container was designed to have a dimension of 30 cm x 14 cm x 12 cm (see Figure 4). The die with the container can keep 4 plastic bottles with position horizontally. The material that is used for the
container is AISI 347 Annealed Stainless Steel. The inner surface may need to be hardened and coated to improve its lifespan and corrosion resistance [9,10].

![Figure 4. Dimension of container in cm.](image)

3.5. **Frame**
The frame uses AISI 347 Annealed stainless steel as described in Figure 5. This material can also resist the corrosion problem. More advantage of using this material is the lower cost of material grade and to reduce the thickness of material that makes the body is lighter.

![Figure 5. Pressing machine frame.](image)

Based on the rough calculation of gear torque transmission, the proposed design is able to crush four plastic bottles with a 50 times magnification of applied force owing from the combination of hydraulic and gear mechanism. The final dimension of the pressing machine is 30 cm x 40 cm x 73.39 cm. This gives a total weight of 13.9 kg which can be considered as light enough to be held by the human hand, hence it is portable. The physical properties of the developed pressing machine can be seen in Table 1.

| Properties     | Value                   |
|----------------|-------------------------|
| Mass           | 13.9 kg                 |
| Volume         | 18708 cm³               |
| Dimension      | 5 m x 40 cm x 73.39 cm  |

Table 1. Hydraulic gear pressing machine physical properties.

Figure 5 shows the final shape of the hydraulic-gear pressing machine. The machine work as the user pushes the handle down and load a force on it. This force will act as the input force and be magnified by the hydraulic system. As the force is applied, the jack’s extension will move upward and rotate the small gear attached to it. The big gear rotates as the small gear rotate since it is connected with a shaft. Shaft connection will create the same angular velocity between small gear and big gear, but the diameter difference results in a higher linear velocity of the big gear. This movement will generate a downward motion to the rack gear and its extension to press the plastic bottle inside the container.
4. Discussion

The dimension of the pressing machine presented in this paper, 30 cm x 40 cm x 73.39 cm, shows a 24% volume reduction of a common pressing machine (1300 x 800 x 1300 mm). Because of this, the machine can be considered as a portable machine and also suitable to be used as, e.g., an educational purpose in the class [11]. The gear ratio of 2:1 results in a higher displacement of the dies as the hydraulic jack moves. Target load magnification is reached for arise 50 times of the applied force. An analytical calculation under dynamic loading shows the machine can offer an infinite life depending on the applied load.

As the dimension of the designed pressing machine is small, it has less weight compared to the common pressing machine. The total mass is around 14 kg which is still acceptable to be held by the human hand. However, one might argue that the machine is still quite heavy, thus requires some improvement on the component dimension or material selection.

With the dimension of the container, the machine is capable to press 4 plastic bottles in one process. The slight movement from the hydraulic jack affects the time needed to move the dies downward. Based on the static calculation, this pressing machine can go as low as 2.4 N applied force in order to crush four plastic bottles.

In order to improve the lifespan, surface treatment for increasing the hardness of dies and container as well as coating for improving the corrosion resistance inside the machine need to be considered carefully. This will be done in the future work during the manufacturing process. Moreover, an analytical calculation for the stress concentration at the shaft also needs to be done for avoiding any crack propagation [3]. For the manufacturing process, thermal and mechanical loading need to be taken into account as it could generate surface and subsurface damage altering the mechanical and metallurgical properties of the materials [3,9,10,12].

5. Conclusion

This paper presented a component design idea of a mini pressing machine by combining hydraulic and rack-pinion gear mechanism. The design shows that the machine is quite effective as the force magnitude from the hydraulic jack can be adjusted by the rack and pinion gear mechanism. Moreover, its dimension of 30 cm x 40 cm x 73.39 cm makes the machine can be portable and used for educational purposes in the class. However, the mini pressing machine is still considered quite heavy for having a mass of around 14 kg. Creating a pressing machine with a smaller dimension and high loading transfer rate is the next improvement of this project.

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