Gripper Design for Automatic Trimming System in Forging Process

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Abstract — Labor shortage is one of the most common yet critical problems in industrial sectors. Using robotics and automation to replace human labor is one of the most effective solutions. In this research, robotic technology is implemented in the trimming process which is one of the key steps in faucet manufacturing. The system is designed to be able to deal with uncertainties of the shape of flash that are occurred due to the impression-die forging process. A gripper with specific jaws is designed to suit the workpiece. A vision system is used to identify the position and orientation of the workpieces. As a result, with the gripper and the vision system, the workpieces can be grasped, transferred, and loaded into the trimming machine at high success rate in comparison to human labor. In this paper, the design procedure of the gripper and performance of the gripper are emphasized.

1. Introduction
Forging is one of the most important manufacturing processes of mass production of metal parts. Forging is a process where metal is pressed, pounded or squeezed under great pressure into high strength parts known as “forgings”. The process is normally performed at high temperature by preheating the metal part to a desired temperature before it is worked. It is important to note that the forging process is entirely different from the casting process, as metal used to make forged parts is never melted and poured. [1] The forging process can create parts that are stronger than those are manufactured by any other metal working process. Therefore, forgings are mostly used in applications that reliability and human safety are critical. Nowadays, three types of forging methods are used to mass production of the metal parts. Impression-die forging is one of the most reliable method. However, for the disadvantage, the forged workpieces will have flash, which is excess material. It needs to be removed by trimming process (See Figure 1).
Trimming process is a process for cutting the flash and remove it from the workpieces. A punch die is used to press on the workpieces through trimming die in order to remove the flash (See Figure 2).

Traditionally, trimming process requires human operators involved with loading workpieces into the trimming machine and machine operation. However, trimming process is harmful to the operators due to the sharpness of the flash that has been removed. In this research, a robotic system with specifically designed gripper and vision system is developed in order to replace the human operators. As a result, the performance and safety level of the system will increase.

This paper focuses on the design of the gripper that is appropriated with forging workpieces. The gripper is mounted on a robot arm’s end-effector in order to grasp and handle the workpieces accurately. According to the uncertain shape of the flash, to design the gripper which is capable of manipulating workpieces with shape variations of the flash is a challenging problem.

A number of research works were conducted in the design and applications of robot gripper. In regard to the mechanism design, Krishnaraju et al. (2015) [2] designed three-fingered gripper and Martínez (2015) [3] designed a two-fingered gripper. Both prototypes are designed based on impactive gripper type that aim for grasping parts with various shape. However, modification of jaws are essentially required in order to use with the forging parts in this project. From the previous work conducted by the authors, Vongbunyong et al. (2018) [4] developed an automatic handling method for valves trimming system. The system consisted of a robot arm, a gripper, and vision system. The workpieces are simpler according to the shape of workpiece which is symmetry. As a result, the grasping position can be determined more easily. This research takes the concept from this previous work and improve the grasping performance by designing a more complex gripper.

This paper is organized as follows: Introduction and literature review (Section 1), Methodology (Section 2), gripper design (Section 3), experiments Results (Section 4), and Conclusion (Section 5),
2. Methodology

2.1. System Frameworks

The problem in handling the forging workpieces is resolved by using a robotic system. The gripper is designed to be capable of handling all workpieces with flash shape uncertainties. The gripper is one of the most important parts of the entire system as it directly contact with the workpiece while grasping (design procedure, see Section 3). The performance of the gripper and the vision system affects the system’s performance.

In summary, the robotic system in this research consists of 5 primary modules as follows: (a) a gripper module, (b) industrial robot module, (c) vision system module, (d) trimming machine, and (e) conveyor belt. The robot controller of the industrial robot is the master of this system. Controller is connected with the slave modules, gripper and vision system modules with I/O and TCP/IP protocol, respectively. The system diagram is presented in Figure 3.

![Figure 3. System Diagram](image)

2.2. Primary Modules

(a) Gripper is a parallel air gripper (MHL2-10D2Z) [5] is used in this project because of its lightweight (430g) and long stroke (96 – 156 mm at close and open position) in order to support forged workpieces. The jaws of the gripper are made of metal (SCM4) for durability. The gripper connected with the end-effector the robot arm.

(b) 6-axis articulated robot (Nachi MZ04) [6]: this model is selected due to specification of the high speed movement, high accuracy with ±0.02 mm position repeatability, workspace with 541 mm reach, and 4 kg payload.

(c) Smart camera (OMRON FQ2-S20100F) [7] has a built-in processor that can process images and communicate with the robot controller via a TCP/IP protocol. The vision system for detecting the workpieces are programmed by using FQ Touch Finder Simulation software. It will sent information about position of workpiece to robot controller.

(d) Trimming Machine (MecolPress) is able to generate force of 150 metric ton with capacity of 1,000 piece/hr. The 4 trimming dies on a rotating table of the machine can rotate to support the forged workpieces. This machine is controlled by the robot controller which is connected via a Programmable Logic Controller (PLC).

(e) Conveyor belt connected with the Programmable Logic Controller (PLC) and Robot controller connect to Conveyor belt through PLC same as Trimming Machine. The conveyor will feed workpieces to picking position at the end of conveyor with capacity of 1,000 piece/hr.
3. Gripper Design

3.1. Requirements and constraints
Requirements and constraints for designing the gripper are as follows. The workpiece is made of brass (JIS C3771) weight 125 g. The accuracy required for inserting the workpiece into the die is within ±2 mm. The area on the workpiece that can contact with jaws are holes and surface of body of workpiece. The area that should be avoided is the flash as the shape is uncertain, so that it is unreliable to design the jaw based on it. The forbidden zone is on one side of the workpiece as it needs to be placed on the die. To improve the robustness of the system against shape uncertainty, the gripper must be able to grasp the workpiece even the input position from the vision system is inaccurate (see Figure 4).

3.2 Design principle
The gripper used in this research is impactive gripper type (jaw and friction grippers). The impactive gripper is a mechanical gripper grasping objects by using the friction force acting between active surfaces of the object and gripper’s jaw. On a contrary, the jaw grippers use the friction force together with the jaws’ geometry to support the object [8].

The reason that impactive grippers are chosen over suction gripper because the limited surface area on the workpiece that the suction can be performed. In addition, the surface of workpiece is covered by graphite powder which can cause the suction pad clogging.

![Figure 4. Analysis Possible active surface for impactive grippers and suction grippers.](image)

3.3 Jaws design
Active surface is the area on the workpiece that will be contacted by the jaws. From the geometry analysis of the workpiece, possible active surfaces are a hole and side flash. Therefore, one jaw will be inserted in the hole and another jaw is for supporting the flash. The jaw design secure the position and orientation of the workpiece for moving to correct position of trimming die (see Figure 5). The cavity at the center of the gripper is designed for securing the position of workpiece. The workpiece will be enforced to stay in that position while the gripper is approaching and pressing on the workpiece (see Figure 6(c)).

The gripper is operated according to the steps shown in Figure 6. Firstly, (a) the jaws are open and (b) the gripper approaches the workpiece by moving down from the top. Next, (c) it will move down to contact with workpiece. Afterwards, when workpiece stay in correct position, (d) the jaws will be closed. As a result, one side of the jaw insert in to the hole and another side support the flash. After position of workpiece fully secured it is ready to be transferred to the target position.
In this research, three variations of jaws sets (see Figure 7) are designed and tested in order to find the most effective design. From a preliminary test, a comparison between three designs is shown in Table 1.
Table 1. Comparison performance of the secure position of gripper each version

| Version | 1 | 2 | 3 |
|---------|---|---|---|
| Technical | Jaw & Friction | Jaw & Friction | Jaw & Friction |
| Image | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |
| Advantage | Secure position & Orientation | Use only one jaw gripper | Secure position & Orientation |
| Disadvantage | 1. One side jaw interrupt workpiece 2. Use two side jaws | 1. Unsure position & Orientation | 1. Use two side jaws |
| Grasping test | 8 from 10 pieces | 5 from 10 pieces | 10 from 10 pieces |

According to the testing result, Ver.1 gripper can secure the position and orientation of workpieces but one jaw interrupts the workpieces while placing on the trimming die. Ver.2 gripper has only one jaw, so that the position and orientation of workpieces cannot be secured properly. Ver.3 exhibits the best performance as the position and orientation of workpieces can be firmly secured. It can grasp workpieces with 100% success rate. As a result, it is selected to further develop.

3.4 Force calculation

\[ F = \frac{mg}{2\mu a} \]

Where
- \( F \) : Gripping force [N]
- \( \mu \) : Friction coefficient between jaw and workpiece
- \( m \) : Workpiece mass [kg]
- \( g \) : Gravitational acceleration (= 9.8 m/s²)
- \( mg \) : Workpiece weight [N]

Gripping force is calculated with a margin of “a” = 4, which allows for impacts that occur during normal transportation, etc. [5]
4. Experiment

4.1 Experiment setup

The experiment was designed to evaluate the performance of the gripper, especially, in regard to the acceptable tolerance of the workpiece’s position and orientation. The maximum acceptable tolerance needs to be identified as it will affect the performance of the entire system. The gripper test setup is shown in Figure 9.

The experiments were done in 4 parts: Test-1 is to test the positional tolerance in x-y axes with 3 mm increment. Test-2 is to test the rotational tolerance about z-axis with 5 degrees increment. (See Figure 10) Test-3 is to test rotation of workpieces each angle and gripper grasp. (See figure 11.) Test-4 is to test continuous grasping workpieces to place on trimming die. (For first and second test, researcher test at laboratory and Third and Fourth test, researcher test at on-site of the factory)

For Test-1 and Test-2, The 10 sample workpieces were selected and the gripper grasped 3 times each. For Test-3 and Test-4, The 100 sample of workpieces were randomly selected in order to exhibit shape variations (i.e. Thickness, contour) of the flash. The sample workpieces are shown in Figure 12.
In this experiment, test about precision of the gripper that can grasp workpieces in all angle even through rotation the workpieces in any direction in the same plane and in this test, researcher define the text ½ PN16 is on the top. (See figure 11.)

4.2 Experimental results

Table 2. Tolerance in X axis and Y axis. (Test-1)

| Distance (mm.) | -6 | -5  | -3  | 0  | 3  | 5  | 6  |
|----------------|----|-----|-----|----|----|----|----|
| Axis X         | ×  | ×   | ×   | √  | √  | √  | ×  |
| Axis Y         | ×  | √   | √   | √  | √  | √  | ×  |

From the experiment in Test-1, the maximum error that the gripper can successfully grasp the workpiece in x-axis, y-axis are [0, 5] mm, [-5, 5] mm, respectively. If the position and orientation error of the gripper is higher than these tolerance levels, it failed to grasp the workpiece (see Table 2. and Figure 10 (a) for x-axis and y-axis)

Table 3. Tolerance of rotation in Z axis. (Test-2)

| Distance (degree) | -20 | -15 | -10 | -5  | 0  | 5  | 10 | 15  | 20  | 25  |
|-------------------|-----|-----|-----|-----|----|----|----|-----|-----|-----|
| Axis Z            | ×   | √   | √   | √   | √  | √  | √  | √   | ×   |     |

From the experiment in Test-2, the maximum error that the gripper can successfully grasp the workpiece in z-axis [-15, 20] degrees, respectively. If the orientation error of the gripper is higher than these tolerance levels, it failed to grasp the workpiece (see Table 3. and Figure 10(b) for z-axis.)

- Remark : √ = Gripper can grasp the workpiece
  × = Gripper cannot grasp the workpiece
For Test-3 and Test-4, the on-site test was conducted in the factory in order to observe the system while working under the actual environment as the conditions which are different from the lab condition. (See figure 13.)

Table 4. Results of Rotation of workpieces each angle and gripper grasp 100 times each (Test-3)

| NO. | Angle | Quantity of workpiece that can grasp (Pcs.) | Quantity of workpiece that cannot grasp (Pcs.) | Remark |
|-----|-------|-------------------------------------------|-----------------------------------------------|--------|
| 1   | 0     | 99                                        | 1                                             | *1     |
| 2   | 45    | 98                                        | 2                                             | *2     |
| 3   | 90    | 94                                        | 6                                             | *3     |
| 4   | 135   | 95                                        | 5                                             | *4     |
| 5   | 180   | 98                                        | 2                                             | *5     |
| 6   | 225   | 98                                        | 2                                             | *6     |
| 7   | 270   | 97                                        | 3                                             | *7     |
| 8   | 315   | 98                                        | 2                                             | *8     |
| Average | - | 97.125% | 2.875% | - |

From the experiment in Test-3, the gripper can grasp workpieces all of rotation of each angle before moving to trimming die. The gripper can grasp workpieces average 97.125% and the gripper cannot grasp workpieces average 2.875%.

Table 5. Result of continuous grasping workpieces to place on trimming die (100 pcs. 3 time) (Test-4)

| Test | Quantity of workpiece that can grasp (Pcs.) | Quantity of workpiece that cannot grasp (Pcs.) | Remark | Time (Sec)/Piece |
|------|-------------------------------------------|-----------------------------------------------|--------|------------------|
| 1    | 97                                        | 3                                             | *1     | 3.51             |
| 2    | 98                                        | 2                                             | *2     | 3.42             |
| 3    | 96                                        | 4                                             | *3     | 3.65             |
| Average | 97% | 3%                               | -     | 3.52             |
From the experiment in Test-4, the gripper can continuous grasping workpieces to place on trimming die. (100 pcs. 3 time) The gripper can grasp workpieces average 97% and the gripper cannot grasp workpieces average 3%. The average time 3.52 Sec/Piece or about 1,022 Pcs. /Hr. which the objective of this project is 3.6 Sec/Piece or 1,000 Pcs. /Hr.

5. Conclusion
In this research, the impactive gripper used for grasping the workpieces and transferring to the trimming die in trimming machine was developed. This is integration of a gripper, an industrial robot arm, a vision system, a trimming machine, and a conveyor belt. The challenging issue is the uncertain shape of the flash of forged workpieces. The jaw gripper was designed specifically for solving problem of uncertain shape of workpieces and can grasp the workpieces and transfer to the trimming die precisely. From the experiment, the gripper was proved to be able to grasp the workpieces with 100% success rate within the acceptable levels of tolerance. With respect to the on-site test, the gripper can grasp the workpieces with 97% success rate so the gripper can achieve the objective of this project.

For future work, the full system will be developed. The information of the workpieces will be provided by the conveyor system. Eventually, the system will be fully automated and will be implemented in the actual production line.

6. References
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Acknowledgments
We would like to thank you Asahi Thai Alloy Co., Ltd. Thailand, for technical support, financial support, and the demonstration site.