DEVELOPMENT OF A TOOL ALIGNMENT SYSTEM IN SHEARING PROCESS

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INTRODUCTION
Advances in miniaturization and weight reduction of various industrial products have demanded component parts that have both higher accuracy and quality. Small holes can be produced not only by shearing, but also with an EDM, laser, and etching. Shearing, however, is expected to be widely used because of its high productivity and machining stability.

In general, it is well recognized that the clearance most significantly influences the machining accuracy of the shearing process. However, it is quite difficult to maintain an even clearance for a same product, that is to say, to align the position of the punch and die accurately. The clearance is usually given as a value relative to the thickness of the workpiece. Therefore, when the thickness of workpiece is large, a degradation in the machining accuracy caused by tool position misalignment could be neglected. Due to the increasing demand of thin shearing products, however, it would be unwise to neglect the tool position misalignment.

For this reason, methods using static capacitance [1], wire electric discharge grinding (WEDG) [2] and image processing, which the authors helped develop [3, 4], were devised as a technique for aligning the shearing tool position accurately and maintaining an even clearance. These methods, though, correct the alignment in advance of the shearing process and cannot respond to a tool position misalignment that occurs during the shearing process. It is conceivable that a tool position could change during the shearing process because the shearing process excels at mass production.

In this research, a small punch press on a trial basis was designed to not only align the tool position in advance using image processing, but also to detect a tool position misalignment during the manufacturing process by monitoring the machining force proposed newly. Punching of circular holes was performed and the effectiveness of the system was examined.

THE SMALL PUNCH PRESS
Figure 1 shows the structure of the small punch press used in the experiments. The dimensions of the punch press are 651 mm high x 354 mm wide x 228 mm deep. A commercially available motor-driven cylinder that can apply a load up to 800 N is used as an actuator. The alignment of the shearing tool position is fine-tuned by fixing the die set on a positioning stage. The positioning stage is composed of XY and θ stages, which correspond to the alignment of various-shaped tools. The maximum shearing force of this punch press is limited to 686 N due to the maximum load of the positioning stage.

METHOD OF INITIAL ALIGNMENT
Figure 2 shows an expanded sectional view of
the tool image acquisition system for the alignment of the shearing tool position before the shearing process. The tool images are respectively obtained in the punch side and die side, as shown in Fig. 3. The center coordinates of the tools are measured by executing an image processing technique using commercially available software. Next, the position of the die is fine-tuned using the measurement results and using the XY stage as stated above. The position of the die is determined through sequential comparison with the measurement results. It should be noted that this image acquisition and processing method can measure the center position of a circle with an accuracy of more than ±1 μm according to previous tests.

METHOD OF MONITORING MISALIGNMENT

Lateral Force

A schematic diagram of the acting force on the tools in the initial stage of the shearing process, which is described in Maeda’s paper [5], is shown in Fig. 4. Here, the acting force of the X component, that is, the lateral force $F_x$, is represented by

$$ F_x = -F_d + \mu(P_s + H) \tag{1} $$

Consider the equilibrium of the Z component force and the moment about point $P$. They are obtained by

$$ P_d - P_f + \mu(F_d - F_f) = 0 \tag{2} $$

$$ -P_f x_D - P_d (C(\theta) + x_d + \mu(t-s)) - F_f y_p + F_d (t-s + y_d - \mu C(\theta)) - H (x_d - x_f) + \mu(t-2s) = 0 \tag{3} $$

Let $P_f = P_d = P$ and $F_f = F_d = F$, then the lateral force becomes

$$ F_x = -\frac{C(\theta) + x_d + x_f - \mu(C(\theta))}{t-s + y_d + y_f - \mu C(\theta)} P \tag{4} $$

Now, assume that a punch with external diameter $D_p$ and a die with internal diameter $D_d$ are used, with a gap distance $\varepsilon$ and center angle $\phi$. Then, the clearance $C(\theta)$ in angle $\theta$ is represented by

$$ C(\theta) = \frac{1}{2} [(D_d - D_p)^2 + 4\varepsilon^2 + 4(D_d - D_p)\varepsilon \cos(\theta - \phi)]^{0.5} \tag{5} $$

Consequently, it is apparent that the summation of lateral force $F_x$ from angle $\theta = 0$ to $2\pi$ becomes zero at a distance of center position $\varepsilon = 0$. This is no different from the acting force of Y component, that is, lateral force $F_y$. Therefore, it can be expected that a tool position misalignment caused during the process can be detected by monitoring the lateral force.

Machining Force Measurement Device

Figure 5 shows the device united with die set used to measure the machining force in the
shearing process. Commercially available force sensors that can measure three components (X, Y, Z) are arranged under the die and measure the shearing force and lateral force acting on the die.

In order to investigate the resolutions of this device, experiments involving applying and removing a load were repeatedly carried out for various loads and in each direction. As a result, it was confirmed that the resolutions of the X and Y directions are about 0.2 N, and the Z direction is about 0.5 N.

PUNCHING EXPERIMENT
Machining Condition
In order to confirm the effectiveness of the new method, the shearing processes were carried out under the following machining conditions. Phosphor bronze (ISO CnSn6) with a thickness of 0.2 mm is selected as the workpiece. A commercially available punch and die made of powder high-speed steel were used as the shearing tools. The external diameter of the punch is 1.000 mm and the internal diameter of the die is 1.060 mm. The blank holding force of the stripper is set at 88 N to become about 20 % of maximum shearing force. The working speed is 1.00 mm/s, the processing temperature is RT and the feed and side bridges are secured at more than 5.0 mm so as not to have an affect on machining accuracy. Additionally, no lubrication was used in order to avoid fears that the punch could slip slightly due to the fluidity or surface tension of the lubrication.

Concerning the punch and die position alignment, the distance between the tool centers was set to be 0.4 μm in the X direction and 0.0 μm in the Y direction, using the initial alignment image processing method (Condition 1). After the several repetitions of punching in this condition, the die was moved 12.5 μm in the -X direction using the micrometer in the XY stage (Condition 2). Punching was then performed several times. Then, the die was moved another 12.5 μm in the -X direction (Condition 3), and several more punching repetitions were carried out. That is to say, expressed in clearance, the maximum clearance is 15.2 %t and the minimum one is 14.8 %t under Condition 1. In the same way, 21.05 %t is the maximum and 8.95 %t is the minimum under Condition 2, and 28.3 %t is the maximum and 2.7 %t is the minimum under Condition 3.

Experimental Results
The machining force measurement results in each direction are shown in Fig. 7. The reason the lateral force in the X and Y directions are not zero is assumed to be due to imperfect alignment, machining and assembling accuracy or elastic deformation of the small punch press.

When attention is focused on the lateral force in the X direction, it is evident that there are differences between Conditions 1 and 2 after about 0.08 seconds. Moreover, in Conditions 2 and 3, the difference becomes clear after about 0.12 seconds. On the other hand, there is almost no recognizable distinct difference in the lateral force in the Y direction and the shearing force (Z direction). Consequently, it is judged that it is possible to detect a tool position misalignment generated during the process to a satisfactory degree.
SEM images of the shape of the shearing plane under Conditions 1 and 3 are shown in Fig. 8. In the top figure, it can be seen that a proportion of the shearing surface and fracture surface are distributed evenly along the outline in Condition 1. On the contrary, in the bottom figure (Condition 3), it can be seen that the proportion of the shearing surface increases from right to left and the machining accuracy isn’t even in the same product.

As a whole, it can be said that monitoring the machining force is an effective method for detecting the misalignment of the tool that occurs during the process and is an important technique for maintaining machining accuracy.

CONCLUSIONS
This paper proposed a method for detecting a tool misalignment that occurs during the manufacturing process. A small punch press on a trial basis was created with two tool alignment methods, one to align the tools in advance and one to monitor the alignment in process. Actual punching of circular holes was carried under several conditions, and the effectiveness and importance of the proposed method were verified.

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REFERENCES