Designing piezoelectric actuators for micro deep drawing of rectangular work pieces

Iman Aminzahed¹,a, Mahmoud Mosavi Mashhadi²,b
¹Department of Mechanical Engineering, University of Tehran, Tehran, Iran
²Department of Mechanical Engineering, University of Tehran, Tehran, Iran

ABSTRACT: Micro forming process is a promising micro manufacturing technology for producing micro parts due to its high efficiency, low production cost and good product quality. Deep drawing provides a great application potential for the manufacturing of parts with complex shapes, even in very small dimensions. Using piezoelectric actuator which is implied in this paper can be considered as a novel approach in the field of micro deep drawing. Micro-machines based on piezoelectric actuators are kind of actuators assures even up to several kilo-Newton forces and movement accuracy theoretically in atomic scale. In this paper, scaled investigations are carried out with different scales of rectangular punches and the blank with different thicknesses then appropriate piezoelectric actuators are designed for each scale.

Keywords: Micro deep drawing; Piezoelectric actuator; rectangular work pieces;

I. INTRODUCTION

Micro-electro-mechanical systems (MEMS) technology has been broadened to many application fields, such as telecommunication, medicine, and biotechnology. Micro deep drawing provides a great application potential for the manufacturing of micro parts with complex shapes, in particular for bulk production, as required in many industrial products resulting from micro technology. When scaling down specimen dimension, the ratio of the mean grain size to the specimen dimension is changed, and the size effect occurs. Vollertsen et al. found that scaling effects, which e.g. occur in tribological aspects such as the friction coefficient, which increases with decreasing specimen size [1]. Vollertsen and Hu investigated the tribological size effect in deep drawing and developed an analytical model [2]. Manabe et al. verified the validity of the FE model of surface roughness in the microdeep-drawing process, a new high-precision sequential blanking and drawing setup was developed for the experiment [3]. Hu by using scaled deep drawing found that the friction coefficients increase significantly with decreasing process dimension. This is called tribological size effect, which must be taken into account during the development of micro deep drawing. He investigated the tribological size effect in deep drawing of work pieces with more complicated geometry, i.e. rectangular cups. He performed size dependent FEM-simulation for this process, at which the friction functions from scaled deep drawing of circular parts in previous work are applied. With the comparison of both the simulated and experimental punch force-stroke-curves they showed that the friction functions from deep drawing of circular parts is also valid for the deep drawing of rectangular work pieces [4]. In this paper friction functions from deep drawing of circular parts have been used to simulate the scaled deep drawing rectangular work pieces. In this investigation, scaled simulations are carried out with different rectangular punches (from 1.5 × 0.75 mm² to 20 × 10 mm²) and the blank material Al99.5 with different thicknesses (from 0.015 mm to 0.2 mm). Different blank holder pressure (from 1 Mpa to 2 Mpa) are applied to analyze output parameters of micro deep drawing of rectangular parts such as blank thickness distribution, punch force-stroke-curves, and spring back. Regarding obtained punch force-stroke curves and maximum needed stroke for forming process, the appropriate piezoelectric actuators are designed for each scale of micro deep drawing. The comparison of both the simulated and experimental punch force-stroke-curves which are derived from Hu work [4] validate the results of the simulation.

II. METHODS OF STUDY

Four different punches were used in this investigation. The largest one has a section of 20 × 10 mm² and the smallest one has a section of 1.5 × 0.75 mm². The geometrical parameters of the used forming tools as well as the blanks are scaled according to the theory of similarity [5] and Hu work [4]. The geometry of the forming tools and the blank is shown in Figs. 1. Blank material for all processes is Al99.5 with different thicknesses according to process’s size. A different blank holder pressure from 1 N/mm² to 2 N/mm² is applied for each scale to investigate the effect on output parameters of micro deep drawing for rectangular parts.

Figure 1. Setup and the geometrical parameters for the deep drawing of rectangular parts.
III. FEM SIMULATION OF FORMING PROCESS

ABAQUS 6.12 is used to simulate the forming process. The model is created 3-Dimensional for the deep drawing of rectangular parts. The tool, punch, die, and blank holder are defined as discrete rigid shell and the blank was defined as deformable object. The shell element was used to mesh the blank. For saving computing time, only one fourth of the model was simulated. In order to obtain a successful FEM-simulation for the forming process in both macro and micro range, the size effects must be taken into account. Among them, both the size effect on the properties of the material [6] and the size effect on tribology [7] are the most important ones for the deep drawing process. Without taking them into account, the FEM-simulation for micro deep drawing becomes usually unsuccessful. Since the flow stress is required in FEM-simulation, the tensile tests results were carried out from Hu work [4] in order to acquire the flow curves of Al99.5 in each thickness. The friction between blank and tools in micro deep drawing is larger than in macro deep drawing. The friction functions were validated by the use of FEM in [8], where the simulated punch force vs. stroke curve agrees very well with the experimental curve for deep drawing of circular parts in different dimensions (macro and micro deep drawing). Hu pointed out, that the friction function in deep drawing of circular parts depends on the length of contact area between blank and tools, which is determined by the drawn radius. For the selection of size dependent friction functions, which are necessary for the realization of size dependent FEM-simulation for scaled deep drawing of rectangular parts, an assumptions is employed: The friction functions from deep drawing of circular parts are also valid for deep drawing of rectangular parts, as long as the other process parameters such as blank material and lubricant are the same. Fig. 2 shows the final formed part of simulation.

IV. PIEZOELECTRIC ACTUATOR DESIGN AND DISCUSSION

According to obtained punch force vs. stroke curves and maximum needed stroke for forming process (see Fig. 3), the appropriate piezoelectric actuators are designed for each scale of micro deep drawing. For the scaling factor 1 (see Fig. 3-a) maximum stroke and punch force are respectively 5 mm and 360 N, therefore, a piezoelectric actuator with at least 5 mm displacement and 360 N blocking force is necessary. In general case there is no industrial piezoelectric actuator with 5 mm range of displacement, hence, it is necessary to design a special Amplified piezoelectric actuator to obtain this range of displacement. The Amplified piezoelectric actuator is a mechanical magnified preloaded stack of low voltage piezoelectric ceramics. The mechanical amplification is obtained thanks to an external shell made of stainless steel which magnifies along the short axis of the actuator deformation occurring along the main axis. This frame also protects the actuator against tensile force. This pre stressing and magnifying flex-tensile frame applies an optimal preloading force to the actuator which ensures a longer life time and better performances than traditional mechanical amplifiers based on lever arm and flexure pivot, when dynamically applied. In this paper a combination of both kinds of actuators are used to benefit from the maximum efficiency. The designed actuator includes 2 pieces of P-025.200-PICA Stack Piezo actuators (The specifications of P-025.200-PICA Stack Piezo actuators are shown in Table 1), which are glued together laterally, and one shell frame which is made of stainless steel. Measured stroke and blocking force of this actuator shows respectively around 6.3 mm and 700 N. It means that the displacement is amplified about 10 times (according to Table 1, displacement of each P-025.200-PICA Stack Piezo actuator is 0.3 mm, so two piezo stack which are glued together stroke 0.6 mm); on the other hand the blocking force is decreased about 45 times (according to Table 1, blocking force of each P-025.200-PICA Stack Piezo actuator is 16000 N, so two piezo stack which are glued together have 32000 blocking force). This actuator is appropriate for scaling factor 1 because it satisfies the maximum necessary displacement (5 mm) and punch force (360 N). The same investigation is done to design piezoelectric actuator for the other scaling factors. The design purpose is to satisfy maximum stroke and punch force which are shown in Fig. 3 with trial and error method. Table 2 indicates features and Fig.4 shows dimension of these actuators.
Table 3. The specifications of Piezo stacks which used in designed actuators

<table>
<thead>
<tr>
<th>Piezo stack type</th>
<th>Displacement (0–1000 V) [µm] -10/+20%</th>
<th>Diameter [mm]</th>
<th>Length [mm ±0.5]</th>
<th>Blocking force (0–1000 V) [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-025.200-PICA</td>
<td>300</td>
<td>25</td>
<td>244</td>
<td>16000</td>
</tr>
<tr>
<td>P-010.80-PICA</td>
<td>120</td>
<td>10</td>
<td>107</td>
<td>2400</td>
</tr>
<tr>
<td>P-010.40-PICA</td>
<td>60</td>
<td>10</td>
<td>56</td>
<td>2200</td>
</tr>
</tbody>
</table>

Table 2. The specifications of designed actuators

<table>
<thead>
<tr>
<th>Scaling factor</th>
<th>Piezoelectric type</th>
<th>Piezoelectric number</th>
<th>Maximum Stroke [mm]</th>
<th>Blocking force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P-025.200-PICA Stack</td>
<td>2</td>
<td>6.337</td>
<td>703.9</td>
</tr>
<tr>
<td>0.5</td>
<td>P-025.200-PICA Stack</td>
<td>1</td>
<td>3.207</td>
<td>358.6</td>
</tr>
<tr>
<td>0.1</td>
<td>P-010.80-PICA Stack</td>
<td>1</td>
<td>0.937</td>
<td>56.8</td>
</tr>
<tr>
<td>0.075</td>
<td>P-010.40-PICA Stack</td>
<td>1</td>
<td>0.558</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Figure 4. Dimension of designed actuators (units: mm).

V. CONCLUSION

Using piezoelectric actuator which is implied in this paper can be considered as a novel approach in the field of micro deep drawing. Piezoelectric actuators are more economical and easier to use than any other micro scale actuators. Different size-scaled deep drawings are investigated and different piezoelectric actuators are designed. According to obtained punch force vs. stroke curves and maximum needed stroke for forming process, the appropriate piezoelectric actuators are designed for each scale of micro deep drawing.

REFERENCES


