Numerical simulation analysis of flexible blank holder technology applied to a multi-point forming process

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In this paper, the principles of flexible blank holder technology applied to the multi-point forming process is introduced and a finite element model of the multi-point forming device with blank holder is established. Adopting the flexible blank holder multi-point forming process, a numerical simulation research is conducted on the forming process of spherical parts. Through the numerical simulation results, when a different blank holder area is adopted, the forming defects of wrinkling, tension cracks, and spring-back, the stress-strain distribution and the influence of the sheet metal are analyzed and compared, and the effects of the material parameters on the results of flexible blank holder multi-point forming are investigated. The results show that, under the same situation, the formed parts obtained by using a smaller blank holder area have uniform stress-strain and thickness distributions.

Keywords: Flexible blank holder technology, Multi-point forming process, Finite element model, Stress, Strain

Blank holder forming is a common sheet metal punch forming process. At present, the common blank holder forming process include the integral rigid blank holder technology\textsuperscript{1}, regional rigid blank holder technology\textsuperscript{2}, blank holder technology with variable blank holder force (VBHF)\textsuperscript{3,4}, multi-point control blank holder force technology\textsuperscript{5,6}, elastic blank holder technology\textsuperscript{7}, etc. In order to obtain high-quality forming parts, the blank holding groove usually is used to suppress the forming defects such as wrinkling, tension cracks, spring-back, etc. In the blank holder forming process with passive restraint of sheet metal flow, wrinkling and cracking often occur because of the different flow rate of sheet metal in different positions when forming large curvature parts such as train panels and aircraft skin. It is difficult to obtain high quality forming parts with uniform distribution of stress and strain and uniform thickness distribution.

When the blank holder forming process of the integral mold is used, the whole mold must match with the corresponding blank holder mechanism before it can be used. For the sheet work-piece, different blank holder mechanisms need to be designed. This leads to a long product development cycle and an increase in manufacturing costs, which cannot meet the requirements of the flexible manufacturing.

In order to solve the problems mentioned above, Li et al.\textsuperscript{8}, at the Dieless Forming Technology Development Center of Jilin University, proposed the flexible blank holder multi-point forming process. Using discrete blank holder blocks instead of blank holding grooves, and using discrete molds instead of the integral mold. Combined with the flexible multi-point forming device, the product development cycle can be shortened and the manufacturing cost can be reduced significantly. In this paper, a new type of flexible edge forming multi-point forming device is studied. Shaping the target parts to control the blank holder, control parameters such as blank holder force, etc., these methods can effectively improve the production efficiency and quality of forming parts.

Tests conducted during the study demonstrated that the flexible blank holder multi-point forming process can restrain the forming defects of wrinkling, tension cracks, etc. during the forming process of sheet metal, which can obtain high-quality formed parts and the high-efficiency and low-cost flexible manufacturing of large curvature three-dimensional work-pieces can be realized. The schematic diagram of die forming is shown in Fig. 1.

Finite Element Model for Flexible Blank Holder Multi-Point Forming

Finite element model

The finite element model for a flexible blank holder multi-point forming device based on Abaqus of Dassault SIMULIA is shown in Fig. 2.
Taking the spherical parts with the formed curved surface radius of \( R = 800 \text{ mm} \) as the research object, the effective forming area is \( 380 \times 380 \text{ mm}^2 \). The flexible blank holder device is composed of multiple blank holder blocks and blank holding grooves. The blank holding grooves are arranged on both sides of the sheet metal "blank", i.e., the unformed material, which is clamped and fixed at its edge by the blank holder blocks. Because of the stagger arrangement of the blank holding grooves, the finite element model is not completely symmetrical. Only full models can be established.

**Setting of relevant parameters**

In this study, the improved carbon structural steel 08Al was used as the numerical simulation. 08Al belongs to a type of low carbon steel and it is cold stamping sheet steel, which is mainly used in the manufacture of different kinds of cold stamping parts under 6 mm, such as car bodies, cabs, all kinds of instrument and machine cases, etc. Its main material parameters are shown in Table 1, and its real stress-strain curve is shown as Fig. 3.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m(^3))</th>
<th>Poisson's ratio</th>
<th>Young's modulus (GPa)</th>
<th>Yield strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>08Al</td>
<td>7850</td>
<td>0.31</td>
<td>214</td>
<td>230</td>
</tr>
</tbody>
</table>

There are 4 contact pairs in the flexible blank holder multi-point forming device, including the blank holder block and the blank holding groove, the blank holding groove and sheet metal blank, sheet metal blank and the elastic cushion, the elastic cushion and mold, respectively. The Coulomb friction value is used to define the interactions between each contact pair. The friction coefficient between sheet metal blank and the elastic cushion, and between the elastic cushion and the mold were set to be 0.10. The friction coefficient between blank holder block and blank holding groove, and blank holding groove and sheet metal blank was set to be 0.30. For sheet metal parts, because the thickness is much smaller than the...
overall size, an S4R Shell element was used for the mesh partition. For the large strain parts, including the blank holder block, the blank holding groove, and the elastic cushion, etc., a C3D8R entity element was adopted for the mesh partition. In order to increase the computation speed, the R3D4 element is used to divide the surface of multi-point mold.

**Numerical Simulation of the Blank Holder Area**

The flexible blank holder multi-point forming device is composed of blank holder block, blank holding groove, elastic cushion, mold, etc. The schematic diagram of the flexible blank holder device with different blank holders is shown in Fig. 4. The blank holder block is an important part of the flexible blank holder multi-point forming device, and the size of the blank holder block directly reflects the size of the blank holder area under the blank holder force. On the premise of the unchanged size of effective forming area, the effect of the size of blank holder block (blank holder area) on the forming result was analyzed. Blank holder blocks with two different sizes were used for the numerical simulation and the restraining effect of forming defects such as wrinkling, tension cracks, etc., as well as the stress, strain and thickness distribution were compared and analyzed. The detailed parameters for each device are given in Table 2.

**Analysis of wrinkling defects**

‘Light maps’ of two forming parts with different blank holder areas are shown in Fig. 5. From the figure, it can be observed that, when the area of a single blank holder block is $24 \times 20$ mm$^2$ in the blank holder area of the formed part, evident indentation can be observed that is produced by the blank holder.

<table>
<thead>
<tr>
<th>Part name</th>
<th>Material</th>
<th>Model name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank holder block</td>
<td>08AL</td>
<td>24×10</td>
</tr>
<tr>
<td>Blank holding groove</td>
<td>65Mn Spring steel</td>
<td>395×10×3</td>
</tr>
<tr>
<td>Sheet metal</td>
<td>08AL</td>
<td>406×406×1.5</td>
</tr>
<tr>
<td>Elastic cushion</td>
<td>polyurethane rubber</td>
<td>406×406×10</td>
</tr>
</tbody>
</table>

Table 2 — Part sizes and material parameters for each model

![Fig. 4 — Schematic of the flexible blank holder device with different blank holders](image)

![Fig. 5 — Light maps for different models](image)
When the blank holder area of a single blank holder block is $24 \times 10 \text{ mm}^2$, the indentation produced by the blank holder block almost disappears. The transition area between the blank holder area and the forming area is smooth, and the quality of the formed parts is better.

The heights of the sheet metal edges when the blank holder areas of the single blank holder block are $24 \times 20 \text{ mm}^2$ and $24 \times 10 \text{ mm}^2$ are shown in Fig. 6. The height of the sheet metal edge refers to the vertical coordinate extracted along the edge direction of the sheet metal component (OX direction) after forming. From the figures, it can be seen that when the blank holder area of a single blank holder block is $24 \times 10 \text{ mm}^2$, which coincides with the arc edge of the actual formed spherical parts. When the blank holder area of a single blank holder block is $24 \times 20 \text{ mm}^2$, the height of the sheet metal edge varies greatly, which is consistent with the wrinkling defects in the actual formed spherical part. It can be seen that a proper reduction of the blank holder area improves the flexibility of the blank holder device. During the forming process, it can easily deform with the deformation of the sheet metal, which will thereby restrain the forming defects of wrinkling, tension cracking, etc, and formed parts with high quality can be obtained.

**Stress comparison**

Nephrograms of the stress distributions for formed parts with two different blank holder areas are shown in Fig. 7. From the figure, it can be deduced that when the blank holder area of a single blank holder block is $24 \times 20 \text{ mm}^2$, the stress distribution range of the part being formed is $3.74-264.64 \text{ MPa}$. The stress distribution range is relatively wide. The maximum value of the stress appears in the blank holder area, where the blank holding groove contacts the sheet metal and a stress concentration phenomenon is evident. When the blank holder area of a single blank holder block is $24 \times 10 \text{ mm}^2$, the stress distribution range of the forming parts is $9.80-260.96 \text{ MPa}$. The stress distribution range is relatively narrow. The maximum stress occurs at the four corners of the part being formed, and the stress concentration phenomenon at the blank holder area is no longer evident.

**Strain comparison**

Nephrograms of strain distributions for formed parts with two different blank holder areas are shown in Fig. 8. From these figures, it is evident that when the blank holder area of a single blank holder block is $24 \times 20 \text{ mm}^2$, the strain distribution range of the formed part is $0.0006-0.15$. The maximum strain value appears at the blank holder area where the blank holding groove contacts the sheet metal and there is evidence of strain concentration. When the blank holder area of a single blank holder block is $24 \times 10 \text{ mm}^2$, the strain distribution range of the component being formed is $0.0018-0.04$. The maximum strain occurs at the four corners of the formed part. The maximum value of the equivalent strain is decreased by $73.87\%$ and the strain concentration phenomenon at the blank holder area is no longer evident.

**Comparison of the thickness change**

Nephrograms of the thickness distribution for parts formed with two different blank holder areas are shown in Fig. 9. From the figure, it can be observed that when the blank holder area of a single blank holder block is $24 \times 20 \text{ mm}^2$, the thickness
distribution range of the formed part is 1.442-1.510 mm. The sheet metal in the center of the part being formed flows around the die. The thickness of the component center being formed decreases and the phenomenon of four thickened sides of the formed part is evident. The maximum thickness value is at the blank holder area where the blank holding groove contacts the sheet metal being formed. When the blank holder area of a single blank holder block is 24 × 10 mm², the thickness distribution range of the forming parts is 1.472-1.505 mm. The maximum thickness value is at the blank holder area where the blank holding groove contacts the sheet metal. The minimum thickness is increased by 2.15%, and the maximum thickness is reduced by 0.3%. The tendency for four thickened sides presented on the formed part has been restrained and the thickness distribution is more uniform.

The thickness distribution along the OX direction of formed parts with different blank holder areas are shown in Fig. 10. In the direction of OX, the variation trend of the thickness curve is basically consistent. As the distance increases, the thickness gradually approaches the thickness of the sheet metal. When the blank holder area of a single blank holder block is 24 × 10 mm², the blank holder block has a little inhibition on the flow of the sheet metal. The thickness of the sheet metal in the blank holder area increases significantly. When the blank holder area of a single blank holder block is 24 × 20 mm², the blank holder block has relatively substantial suppression on the flow of the sheet metal. The thickness change of the sheet metal in the blank holder area is limited but thickness change in the transition area is significant. It can be seen that proper reduction of the blank holder area can reduce suppression of the flow of sheet metal and high-quality formed parts can be obtained.

Verification of the practical improvement in formed product quality

Images of the formed parts with two different blank holder areas are shown in Fig. 11. It can be observed that when the blank holder area of a single blank holder block is 24 × 20 mm², the larger blank holder area reduces the flexibility of the flexible blank holder multi-point forming device. During the forming process, only the blank holder block can follow the deformation of the sheet metal. At the edge of the blank holder block, wrinkling defects occurred in the
formed parts. When the blank holder area of a single blank holder block is $24 \times 10 \text{ mm}^2$, the smaller blank holder area improves the flexibility of the flexible blank holder multi-point forming device. In the forming process, the blank holder block and blank holding groove can now follow the deformation of the sheet metal. In consequence, no wrinkling defects occur in the formed parts and high-quality formed products are obtained.

**Conclusions**

In this paper, the principles of a flexible blank holder multi-point forming process are discussed. A finite element model of flexible blank holder multi-point forming, which took $R = 800 \text{ mm}$ as the object of study, was developed and effect of the blank holder block area on the forming results was simulated. The simulation results of the blank holder area for the forming model were verified by theoretical test. The feasibility and versatility of the flexible blank drawer forming process were discussed. The findings demonstrate that when the blank holder area is properly managed, the quality of the produced components can be improved by minimizing the tendency to form defects such as wrinkles and tension cracks. During the forming process, satisfactory deformation of the sheet metal can be easily achieved, and high quality formed parts can be obtained.

**References**