Numerical simulation of flexible blank drawer formation

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Abstract. This paper presents a finite element model for a technology of Flexible Blank Drawer Formation (FBDF) for the forming process. In order to verify the feasibility and versatility of the FBDF technology, we performed numerical simulations for multi-point saddle-shaped parts, and for convex curved surface and hemispherical parts. We analysed the effect of different forming methods on wrinkling and cracking, stress and strain distribution as well as circulating and spring back. Also, we studied the effect on the FBDF result caused by the chucking power, blank drawer force, friction coefficient and material parameters. The results showed that under the same conditions, the parts formed by FBDF technology showed uniform stress and strain distribution with little spring back. The blank drawer force can efficiently restrain the defects such as wrinkling and crack.

1. Introduction

As a common sheet metal forming technology, the press forming often causes wrinkles and cracks in the material sheet. By applying the blank holder forming technology, the instability problem can be limited to some extent. The present blank holder forming technologies include the traditional rigid blank holder technique [1], Variable Blank Holder Force (VBHF) technology [2, 3], piecewise rigid blank holder technique [4], elastic blank holder forming technique [5] and multi-point blank holder forming technique [6, 7]. All of these are in the passive control of sheet flow. For example, while forming such curved parts as automobile panel, because of the different sheet flow at every position, wrinkles and cracks may occur, and it is hard to achieve the formed parts with uniform stress and strain distribution. On the other hand, the present blank holder forming techniques have a common problem, that a mold can be used only by designing a corresponded blank holder mechanism. For sheet metal forming with different size and shape, different blank holder mechanisms need to be designed, leading to increased manufacturing cost and extended product development circle. All these problems need to be resolved to meet the requirement of flexible manufacturing in modern industry [8-10].

In this paper, we introduced a Flexible Blank Drawer Forming (FBDF) technology and its device. By using blank drawer technique instead of flexible blank holder technique, the device of FBDF can be used in conjunction with the whole model or multi-point model. As a result, it can simplify the mold structure, reduce the manufacturing cost and shorten the development period of product. Our simulation results indicated that with the FBDF technology, the defect such as wrinkle and crack can

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be efficiently reduced, and the flexible manufacturing of large curved surface can be realized with high efficiency and low cost.

2. Experimental arrangement
The device of Flexile Blank Drawer Forming (FBDF) is mainly composed of several clamping and pulling mechanisms and a support frame. The pulling mechanism is a horizontal hydraulic cylinder whose position ends are connected with the clamping mechanism and cylinder ends are connected with the support frame. The material sheet is clipped surrounding the clamping mechanisms and the blank drawer force is applied in four directions. The force can be adjusted according to the size and shape of forming parts. The hydraulic cylinder is big enough and it is conducive to the material loading and unloading operation. Press the upper mold and then the sheet metal is formed. The clamping mechanism has flexible features, as it is capable of moving and swing. Moreover, the blank drawer applied by the pulling mechanism can effectively suppress the defect of wrinkle and crack.

The FBDF device is designed according to the PASCAL’s law. The control system is very simple since a hydraulic value can control several pulling mechanisms and produce uniform blank drawer force. Meanwhile, different blank drawer force and clamping force can be applied according to deformations at different parts of sheet metal. Due to the telescopic feature of pulling mechanism, curved parts in various shapes can be obtained by only replacing the mold cavity.

3. Finite element modeling
Thanks to the rapid development of finite element analysis method and computer technology, the element simulation during forming process has become an effective tool to value the quality of metal sheet forming technique. In order to verify the validity and versatility of blank drawer forming technique, have established the finite element for multi-point mold forming of saddle-shaped parts, and for whole mold forming of convex curved surface as well as hemispherical parts. The numerical simulation has been conducted and analyzed as following.

Considering the complexity of the Flexile Blank Drawer Forming (FBDF) device, and to save calculating time and reduce memory occupancy, simplified the forming device of saddle-shaped parts to ¼ finite element model. The multi-point model is indicated by a series of punches; the stretching mechanism is simplified as a clamp and constraints are applied on the clamp to achieve stretching function.

In this research, the complicated equipment was simplified to use the finite element simulation package of Abaqus. The 08Al steel, usually used as automotive coverage, was adopted and the materials parameters are listed in Table 1. The deformable shell element S4K was selected to discrete. Four-node quadrilateral shell element with rigid S4K was chosen as element cushion. The friction coefficient was of general contact and the penalty function method was applied. The friction coefficient between clamp and sheet was set as 0.8, and other friction coefficient was set as 0.1. The sheet dimension was 360 mm×360 mm×0.5 mm. The multi-point model consisted of 30× 30 punches, with the punch radius of 5 mm. The dimension of elastic pad was 300 mm×300 mm×10 mm.

The convex surface blank drawer forming device is simplified to a finite element model, in which OX and OY are two symmetrical axes of the sheet. The stretching mechanism is simplified as a clamp and constraints are applied on the clamp to achieve stretching function.

The main material is 08Al sheet plate, and the deformable shell element S4K is selected to discrete. Four-model quadrilateral shell element with rigid S4K is used for entity model and clamp. The friction coefficient between clamp and sheet is set to 0.8, and the rest is set to 0.1. The curvature radius of convex surface parts is 500 mm, and the gap between each surface is 8 mm. The dimension of sheet is 360 mm×360 mm×0.5 mm, and the effective forming area is 300 mm×300 mm.

The used material is 1010 steel and 2024 aluminum, with parameters listed in Table 1. The deforming shell element S4K is selected to discrete upper and lower mode, and four-model quadrilateral shell element with rigid S4K is chosen for the clamp. The friction coefficient between clamp and sheet is set to 0.8, and others are set to 0.1. The radius of upper mode is 150 mm, and the
dimension of sheet is 400 mm×400 mm×1 mm.

### Table 1. Material parameters.

| Material     | Poisson ratio | Young’s modulus, GPa | Yield stress, MPa | Density, Kg •M³ |
|--------------|---------------|----------------------|------------------|-----------------|
| 08Al steel   | 309           | 608                  | 0.35             | 140300          |
| 1010 steel   | 232           | 397                  | 0.35             | 140100          |
| 2024-O al    | 348           | 627                  | 0.35             | 151800          |

### 4. Results and discussion

To testify the validity and versatility of Flexible Blank Drawer Forming (FBDF), we have performed numerical simulation for the multi-point model forming process of saddle-shaped parts. Both blank holder forming and blank drawer forming are studied to compare the effects of different forming techniques on the forming results. While using the blank holder forming technique, the blank holder pressure is 3.8 MPa and 8 MPa. While using the blank drawing forming technique, the clamping pressure is 3.8 MPa and 8 MPa, and the blank drawer force applied by each clamp is 1200 N.

While both the blank holder pressure and the clamping pressure are 3.8 MPa, as can be seen, the part formed by blank holder technique has obvious wrinkles in both the flange region and the effective forming zone. Also, because the edge pressing ring keeps balance during the whole forming process, obvious defect occurs in the blank holder force transmission region. Especially in the central force transmission area, the sheet may crack easily due to the large curvature change. On the contrary, the part obtained by blank drawer technique displays no defect of wrinkle or crack, neither in the flange region nor in the effective forming zone. The formed part has smooth surface as well as good quality.

When the blank holder pressure and the clamping pressure are 8 MPa, as can be seen, the part obtained by blank holder forming technique still shows wrinkle defects in the flange region and the effective forming zone. Meanwhile, slight crack defect occurs. As comparison, with the same clamping pressure, the part obtained by using blank drawer technique has smooth transition without wrinkle or crack defects both in the flange area and the effective region.

It is speculated that, with the blank drawer technique, the blank drawer force effectively suppresses wrinkling defect. Meanwhile, in the holding area of the clamp, due to the flexible characteristics of the discrete gripper, the sheet in the flange area can change shape in coordinate with clamp and thus the high quality forming parts can be obtained.

The stress distribution of the forming parts was obtained by using blank holder forming technique and blank drawer forming technique. As can be seen, the stress distribution of the part obtained by using blank holder forming technique is not even. The stress value in forming area varies from 202 MPa to 480 MPa. Especially in the transition area such as blank holder area and forming area, the stress is concentrated seriously. The maximum stress value appears in the effective forming area and it leads to crack defect. By contrast, the stress distribution of part obtained by using blank drawer forming technique is much more uniform. The stress value in forming area changes within the range of 170 MPa to 270 MPa. Also, the transition at the clamping and forming area is smooth and there is no stress concentration. Thus good-quality forming parts can be achieved.

The strain distribution of forming parts obtained by using blank holder forming technique and blank drawer forming technique. As can be seen, the part obtained by using blank holder technique displays a serious thin sheet near the straight force transmission area, due to the flow less sheet in the flange area. The maximum equivalent strain is 0.589, at which the material sheet is close to rupture. On the other hand, the part obtained by using blank drawer forming technique has the maximum equivalent strain value of only 0.0805, much smaller than that of the part by blank holder technique. With comparison, we can conclude that, using blank drawer forming technique, forming parts with high quality can be achieved, even with the large clamping force, blank holder force or the great curvature of the work piece. By using the blank drawer forming technique, some forming parts which can’t be obtained by using blank holder technique will become feasible.

The displacement diagram of forming parts was obtained by using blank holder forming technique,
as well as blank drawer forming technique. As seen from the picture, the maximum displacement of the part obtained by using blank holder forming technique is 50 mm in the flange area, and 73 mm in the forming area, with the difference of 23. On the contrary, the maximum displacement of the part obtained by using blank drawer forming technique is 73 mm in the flange area, and 75 mm in the formative area, with little difference. Therefore, a conclusion can be drawn that the part obtained by using blank drawer forming technique has a better sheet flow ability. The reason is that while forming, the sheet can have different amounts of displacement according to the mold curvature changes, thus it makes a smooth transition between the flange area and the formative area.

Rebound phenomenon often occurs in the course of forming. The amount of rebound is defined as displacement changes in certain direction after forming. The rebound of the forming parts obtained by using blank holder forming technique as well as blank drawer forming technique. As can be seen, the maximum spring back of the part obtained by using blank holder forming technique is 1.1 mm in OX direction, and 0.31 mm in OY direction. As comparison, the maximum amount of spring back of the part obtained by using blank drawer forming technique is 0.72 mm in OX direction and 0.2 mm in OY direction. Apparently, in blank drawer forming technique, the pre-clamping of the clamp to sheet can effectively cut down the rebound phenomenon.

After studying the numerical simulation of multi-point model forming process of saddle-shaped parts, can conclude that the blank drawer forming technique is more favourable than the blank holder forming technique. By using the blank drawer forming technique, wrinkle and crack defects can be effectively inhibited. Also, the forming parts can be obtained with uniform stress and strain as well as small amount of rebound.

To further testify the validity and versatility of the flexible blank drawer forming technique, carried out numerical simulation for integral mold forming process of convexity surface parts. By using blank holder forming technique and blank drawer forming technique, we studied and compared the effect of different forming technique on forming results. For blank holder forming, the clamping pressure of clamping ring is 4 MPa and 8 MPa. For blank drawer forming, the clamping pressure of each clamp is 4 MPa and 8 MPa, and the stretching force applied by each clamp is 1200 N.

When both the blank holder pressure and clamping pressure are 4 MPa, the forming parts were obtained by using blank holder forming technique as well as blank drawer forming technique. As can be seen, the part obtained by using blank holder technique has obvious wrinkles in the flange area as well as in the effective forming area. This can be attributed to the fact that the blank holder ring is always flat in the whole forming process. The wrinkle defect occurs in force transmission area, especially in four angles. By contraries, the part obtained by using blank drawer forming technique exhibits a smooth surface, without wrinkle either in the flange area or in the effective forming area.

When both the blank holder pressure and clamping pressure are 8 MPa, the forming parts were obtained by using blank holder forming technique and blank drawer forming technique. As can be seen, higher blank holder pressure can effectively inhibit the wrinkle defect in the forming part obtained by using blank holder forming technique. When the blank holder pressure increases to a certain value, wrinkles disappear, but slight crack defect occurs in the four corners of force transmission zone. As comparison, the integral forming part obtained by using blank drawer forming technique demonstrates good quality without any defects. Therefore, the blank drawer forming technique can be used to match not only with the multi-point mold, but also with the integral mold.

Furthermore, we applied numerical simulation for integral mode forming process of hemispherical parts.

The clamping pressure indicates the average force applied in unit area on clamp. With a reasonable clamping force, the metal sheet can be held tightly in the forming process. In addition, the clamp with reasonable force can have pre-clamping to the sheet, reduce the rebound and inhibit wrinkling. Thus, the forming parts with uniform stress and strain distribution can be achieved. When the blank drawer force applied by each clamp is 1200 N, the clamping pressure of each clamp is 8 MPa and 16 MPa. The state of the clamp by using blank drawer forming technique is shown in Figure 1. As can be seen, when the clamping pressure of each clamp is 8 MPa, the clamp is pulled. While the clamping pressure
is 16 MPa, there is no such phenomenon.

![Figure 1. State of clamp after forming.](image1)

![Figure 2. Mises stress distribution.](image2)

With the flexible blank drawer forming technique, the blank drawer force is applied to the sheet, which can stretch the sheet, reduce spring back and inhibit wrinkling defect. A reasonable blank drawer force is to make the sheet change. In actual forming process, the clamping force can be adjusted according to the wrinkling situation to reach an optimum value. With the clamping force of each clamp as 2000 N and 3000 N, the Mises stress distribution of forming parts obtained by using blank drawer forming technique is shown in Figure 2. As can be seen, the wrinkling defect appears in the flange area when the blank drawer force applied by each clamp is 2000 N. However, when the force is 3000 N, no wrinkling defect is observed.

The Mises stress distribution of forming parts along X-axis and Y-axis when different friction coefficients are applied. As can be seen, when the friction coefficient between sheet and mold is as small as 0.05, the Mises stress distribution of forming parts is uniform. When the friction coefficient is 0.2, the Mises stress varies more. Usually the sheet surface should be as smooth as possible. In other words, a smaller friction coefficient is better. Since the deformation resistance is small, the better-qualified forming parts can be obtained.

With Flexible Blank Drawer Forming (FBDF) technique, 1010 steel and 2024-O aluminum plates are used to analyze the effect of material parameters on hemispherical parts forming process. When the clamping pressure is 64MPa and the blank drawer force is 3000 N, the forming parts of 1010 steel have no obvious defect. When the clamping pressure is 6 MPa and the blank drawer force is 800 N, the forming parts of 2024-O aluminum also have no obvious defect, as shown in Figure 3. Since the elastic modulus and yield limit of 1010 steel are much higher than those of 2024-O aluminum sheet, the external load capacity needed in 1010 steel sheet forming is much higher than that for 2024-O aluminum. Moreover, greater blank drawer force and clamping pressure are needed to form better-qualified forming parts.

![Figure 3. Simulation of hemispherical parts with different materials.](image3)
5. Conclusions
In this paper, introduced the Fexible Blank Drawer Forming (FBDF) technique, established the finite element model of saddle-shaped parts, convexity surface parts as well as hemispherical parts, and testified the feasibility and versatility of FBDF technique. The results showed that with the blank drawer forming technique, the blank drawer force can inhibit the defect of wrinkling and crack in the sheet. Meanwhile, the forming parts have uniform stress and strain distribution, well-flow sheet, small rebound and high quality. When the yield limit and elastic modulus of sheet are higher, the clamping pressure and blank drawer pressure needed in forming is higher as well. In addition, smoother sheet surface can result in better quality of forming parts.

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