Comparison of the positive and negative two points incremental forming quality

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Abstract. The forming method of the positive and negative two points incremental forming is different, so the forming quality will be different. The forming processes on the positive and negative two points incremental forming were simulated numerically by using the Finite Element Analysis software ANSYS/LS-DYNA, and the forming quality was compared and analyzed according to the thickness, profile curve, and equivalent stain. The research shows that the thickness, equivalent strain and contour accuracy of the positive two points incremental forming are better than that of the negative two points incremental forming. Therefore, the forming quality of the positive two points incremental forming is better.

1. Introduction

The incremental forming technology of the sheet metal parts is an economic and efficient sheet metal flexible processing technology. Compared with the traditional forming process, the sheet metal parts can be formed without expensive molds [1], which has high flexibility and easy operation, and then can meet the requirements of the product diversification and personalization in today's society [2]. The forming technology has developed rapidly in the past 20 years and is widely used in various fields such as aerospace, vehicle manufacturing, medical treatment and art.

The incremental forming technology of the sheet metal parts is the process of gradually accumulating the three-dimensional model of the parts at each two-dimensional layer along the Z axis and the forming tool performs the local plastic forming on the two-dimensional layer, so that the forming of the sheet metal part gradually to be realized [3]. According to the different direction of the bottom of the formed part relative to the sheet pane, it can be divided into the positive incremental forming and the negative incremental forming [4]. The diameter of the forming tool head, direction of the forming
force, axial feed, feed speed, forming angle, sheet property and other parameters have an effect on the sheet forming quality[5]. Therefore, in the same environment and process parameters, this paper makes a comparative study on the forming quality of the positive and negative two points incremental forming by using the finite element analysis from the thickness, equivalent strain, and contour accuracy.

2. Positive / Negative two points incremental forming

The forming system of the positive two points incremental forming mainly consists of the CNC machine, extrusion tool, guide post, pressing plate and support mold, as shown in Figure 1a. The forming principle is that the pressing plate and supporting plate are used to clamp four sides of the sheet, so that the sheet can move up and down along the guide post, and then the extrusion tool head presses the sheet point by point according to the predetermined toolpath. The forming system of negative two points incremental forming mainly consists of the CNC machine, extrusion tool, pressing plate and supporting mold, as shown in Figure 1b. The forming principle is that the pressing plate is used to clamp four sides of the sheet, and then the extrusion tool head presses the sheet point by point according to the predetermined toolpath.

![Figure 1. Forming method: (a) positive forming, (b) negative forming](image)

Siddiqi et al.[6] introduced the forming principles of two forming methods of the positive and negative incremental forming, and designed a fixture of the positive incremental forming. Otsu M. et al.[7] used two methods of the positive incremental forming and the double-sided incremental forming to compare their forming accuracy, thickness distribution and residual stress, and obtained that the shape of the formed part based on the positive incremental forming is closer to the target shape, and the absolute value of the residual stress is small. Ben Khalifa N. et al.[8] studied the forming mechanism of the positive and negative incremental forming, and combined with the use of active media to produce concave and convex parts, which can process parts that are difficult to be processed by traditional forming methods. Zhu Hu et al.[9] showed that the positive and negative two points incremental forming sequence have a great influence on forming quality. Formisano et al.[10] compared the forming force, forming limit diagram and thinning rate between the single point positive incremental forming and the single point negative incremental forming, and concluded that the single point positive incremental forming can achieve higher formability and dimensional accuracy than the single point negative incremental forming.

This paper compared the thickness distribution, contour accuracy and equivalent strain between the two points positive incremental forming and the two points negative incremental forming by using the
numerical simulation.

3. Positive / Negative two points incremental forming toolpath generation

In order to study the influence of the positive / negative two points incremental forming on forming quality, the sheet metal model with a thickness of 0.88 mm as shown in Figure 2 was taken as an example to analyse the positive CNC incremental forming and negative two points incremental forming, respectively.

![Figure 2](image)

**Figure 2.** Sheet metal part: (a) façade, (b) obverse

In this paper, UG NX8.0 was used to generate the forming toolpath of the positive two points incremental forming and negative two points incremental forming. In the machining mode, select the "mill_contour" mode, a ball-end cutter with a diameter of 10 mm, specify the part as the containing block, and take the outer surface (Figure 2a) and inner surface (Figure 2b) of the sheet metal model as the cutting area, and adopt the contour cutting mode. The layer spacing was set to 1 mm, the spindle speed was 400 rpm, and the feed speed is 600 m / s. The positive two points incremental forming toolpath (Figure 3a) and negative two points incremental forming toolpath (Figure 3b) were generated respectively.

![Figure 3](image)

**Figure 3.** Forming toolpath: (a) positive forming, (b) negative forming

4. The model for the positive / negative two points incremental forming

According to the model of the part to be formed, the support mold for positive CNC incremental forming and negative CNC incremental forming was generated. Suppose the concave surface of the sheet metal model was the upper surface and the convex surface was the lower surface as shown in Figure 4a. Take the size of the concave shape as the outer surface dimension of the positive support mold, construct the positive support mold in the UG NX8.0 modeling mode, as shown in Figure 4b. Take the shape and size of the convex surface as the shape and size of the inner surface of the negative support mold, the negative support mold was constructed in the UG NX8.0 modeling mode, as shown in Figure 4c.
In the FEM analysis, the sheet metal part model, positive support mold and negative support mold shown in Figure 4 were taken as examples, and the ANSYS / LS-DYNA finite element analysis software was used to simulate the CNC incremental forming process of sheet metal. The thickness, contour accuracy and equivalent strain are compared and analyzed. The analysis process uses the Belytschko-Wong-Chiang algorithm. The sheet is selected from 1060 aluminum sheet with a thickness of 0.88 mm, and the element type is SHELL163 space shell element. The extrusion tool selected the W10Mo5Cr4V2 high-speed steel spherical tool with Φ10 mm, and its element type is SOLID164 body element. The material of the positive support mold is the W6Mo5Cr4V2 high-speed steel, the material of the negative support mold is GCr15 bearing steel, and the element type is SOLID164 body element. The mechanical properties of each material are shown in Table 1.

| Material     | Density /kg*m⁻³ | Elastic Modulus /Gpa | Poisson's ratio | Yield stress /Mpa | Tangent modulus /Gpa | Tangent modulus /Gpa | Hardening coefficient |
|--------------|------------------|----------------------|-----------------|-------------------|----------------------|----------------------|----------------------|
| Al1060       | 2700             | 55.94                | 0.324           | 153.6             | 2.9                  | 2.9                  | 0.19775              |
| GCr15        | 8160             | 218                  | 0.30            | ----              | ----                 | ----                 | ----                 |
| W6Mo5Cr4V2   | 7810             | 212                  | 0.29            | ----              | ----                 | ----                 | ----                 |

The support mold, sheet, and tool were meshed respectively. The support mold is meshed with a 4 mm free tetrahedral method, the sheet was meshed with a 1.5 mm mapping method, and the tool is meshed with a 1.5 mm free mesh method, as shown in Figure 5.
sheet in X, Y, Z direction and around X, Y, Z axis. The rotation in the direction limits the rotation of the extrusion tool head around X, Y, Z axes and the movement in Z axis direction. The four sides of the sheet metal and the X, Y, Z axis directions of the support mold and the six degrees of freedom around X, Y, Z axes of rotation are restricted, and the extrusion tool is restricted around the X, Y axis. The contour toolpath are generated with 1 mm layer spacing, and then put the x, y, z coordinates of the toolpath points into the Excel for data processing. The time t adopts a step difference of 0.001. After completion, reposition the x, y, z coordinate points and the corresponding time t is saved in txt file format. Using the function of array reading in ANSYS software, the text is read into T, Xp, Yp, Zp arrays which are established in advance, so as to complete the loading process of the finite element simulation.

6. Finite element analysis results
The finite element analysis and post-processing software LS-PrePost is used to post-process the numerical simulation results, and the numerical simulation models of the sheet metal parts with two forming methods of positive and negative two points incremental forming are obtained. Figure 6a and Figure 6b respectively show the numerical simulation thickness distribution of the positive and negative two points incremental forming. The thickness distribution interval of the positive two points incremental forming is [0.4326 mm, 0.8808 mm], and the thickness distribution interval of the negative two points incremental forming is [0.3919 mm, 0.8806 mm]. By comparing the thickness distribution of two forming methods of the positive / negative two points incremental forming, it can be seen that the thickness of the positive / negative two points incremental forming is not much different, but the forming quality of the positive two points incremental forming is slightly better.

![Figure 6. Thickness distribution: (a) positive forming, (b) negative forming](image)

Figure 7a and Figure 7b show the numerically simulated equivalent strain diagrams of the positive / negative two points incremental forming. The positive two points incremental forming is mainly distributed in [0.330, 0.7489], and the equivalent strain of the negative CNC incremental forming is mainly distributed in [0.3624, 0.8152]. It can be seen from the comparison that the equivalent strain distribution of the positive two points incremental forming is more uniform, so the forming quality of the positive two points incremental forming is better.
Figure 7. Equivalent strain: (a) positive forming, (b) negative forming

Figure 8 shows the comparison between the node coordinates of the positive two points incremental forming and the theoretical design contour on the $X = 0$ section. Figure 9 shows the comparison between the node coordinates of the negative two points incremental forming and the theoretical design contour on the $X = 0$ section. Figure 10 shows the Z-deviation of the positive / negative two points incremental forming. The comparison shows that the forming quality of the positive two points incremental forming is better.

Figure 8. Positive forming profile curve

Figure 9. Negative forming profile curve
7. Conclusion
The thickness of the formed parts obtained by the positive two points incremental forming is slightly better than the negative two points incremental forming; the equivalent strain of the positive two points incremental forming is more uniformly distributed than that of the negative two points incremental forming; the contour dimension accuracy of the positive two points incremental forming is better than that of the negative two points incremental forming.

8. References
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