Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DIE SURFACE COMPENSATION BASED ON THE SPRINGBACK

XIAODA LI, XIANGHUI ZHAN, XIANGYANG LIU, BAOQING DENG
Zhuhai College of Jinlin University, Zhuhai 519075, Guangdong, China

ABSTRACT

To solve the problem about the difference between the design shape and the actual after the sheet metal forming because of the springback, the stamping simulation software can be used to predict the springback values, and according the values, the shape of the die surface can be compensated in the opposite direction to make the forming part fit the design requirement. In the paper, according to the springback valves predicted by KMAS, the R、S and the triangular element coordinate mapping methods are put forward to amend the element node movement. And the amending nodes are used to build the CAD model, which can be the reference of the die surface. In the end, an example was shown to test the validity of the method.

Keywords: *Springback, Die Surface Compensation Method, Coordinate Mapping Method, KMAS, Stamping Simulation*

1. INTRODUCTION

Springback is a common defect in the process of sheet metal forming, leading to deviations between final sizes and expected values of stamping parts [1]. Usually there are two ways to solve the springback problem of stamping parts, the first is the traditional process control method and the second is the springback compensation method which is widely being used today. To get the shape of stamping part meeting design requirements, the die surface needs to be amended according to the size and distribution of springback. The traditional compensation method of die design is through shaving die manually and trying die in punch machine repeatedly in workshop, so it is a time-consuming, laborious and uneconomic process obviously.

In recent years, the computer simulation technology provides an effective solution for this difficulty, and also becomes the main way to solve the problem of springback [2, 3]. Although it has been of great concern and some achievements have been made, the springback simulation and compensation technology is still a weak link in numerical simulation processes and further researches need to be done[4, 5]. Therefore, besides how to predict the springback more accurately with numerical simulation technology, compensation algorithm is a key in the study of springback compensation. In another word, how to amend the shape of mold with the predicted springback and how to convert CAE (Computer Aided Engineering) data format into CAD (Computer Aided Design) which is convenient for numerical control machining after compensation are very critical.

This study is based on the springback prediction of KMAS (King-mesh Analysis System); the die surface compensation procedure is developed independently. Die surface compensation algorithm based on the surface mapping is proposed. And the R 、 S natural coordinate mapping method of quadrilateral element and the triangular coordinate mapping method of triangular element are mainly used in the compensation process. After compensating the nodes, CAD surface is fitted by the discrete nodes with the bi-cubic B spline surface interpolation method.

2. THE METHOD OF DIE SURFACE COMPENSATION

In recent years, by the finite element simulation technology and experiments, there have been the typical compensation algorithms. One is Force Descriptor Method (FDM) used by Karafillis [6, 7] and Wu [8]. The compensation of die surface is calculated by applying an opposite force in contrast with internal force after forming, after 2-3 iterations, the springback errors can be reduced by 90%. This method can be used for any finite element program and is a general method in principle, but its use would be restricted by the convergence difficulties, expect that the stamping is symmetric or has a smaller springback. The other is Displacement Adjustment (DA) proposed by

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Wagoner, etc [9, 10]. The die surface is compensated by the displacement. That is, adjusting displacements of die surface nodes along the opposite direction of springback. This method has fast convergence, less iteration and is applied to general shape stampings.

This method is based on reverse offsets of nodes and the process is as follows: First of all, considering the outer surface of part to be the initial die, finite element analysis of forming and springback simulation are carried out. And then, comparing the model before and after springback, normal deviations of nodes are obtained. Judge whether the deviation is within the accuracy and if meeting the accuracy requirements, discrete data points will be fitted CAD surface. If not meeting, the die surface nodes will be amended according to the result of springback and then the points be fitted the die surface after compensation. Treat the compensated surface as the die and repeat the above process until the shape of stamping part after springback simulation would have met the accuracy requirements. Figure 1 shows the flow chart of die surface compensation.

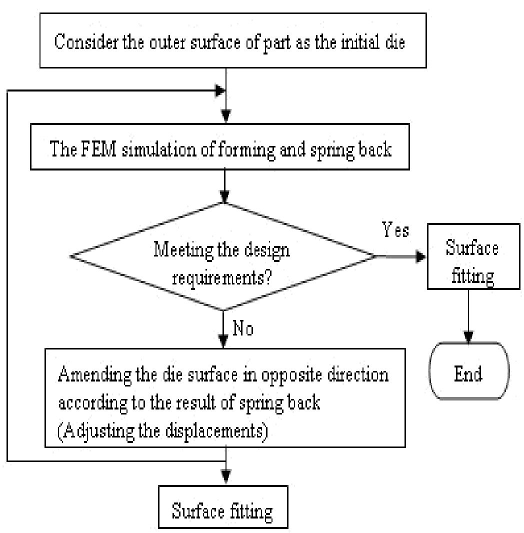

Figure 1: The Flow Chart Of Die Surface Compensation

3. THE DISPLACEMENT ADJUSTMENT OF DIE SURFACE NODES

3.1 The Process Flow

If the spring back of each node has been obtained accurately by numerical simulation, the next step is to consider how to use this result to modify the mold and get stamping parts meeting design requirements. In order to amend the finite element node of initial die surface in opposite direction according to the springback, boundary nodes of each surface patch and all internal nodes need to be projected to sheet elements after forming. Then the springback of each projection point on surface patch is calculated by interpolation with the springback value of projection element node. Finally, the coordinate of the projection point is amended by adding the interpolated springback value in opposite direction. All nodes on surface patches can be amended in turn by using the above method. The process is shown in Figure 2.

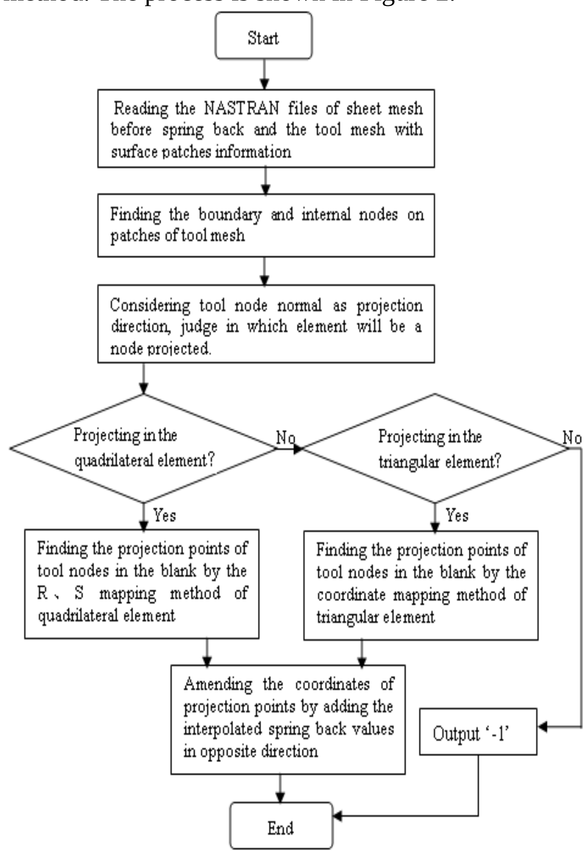

Figure 2: The Flow Chart Of Amending The Die Surface Nodes

3.2 The Main Algorithm

The R、S natural coordinate mapping method of quadrilateral element:

To find the projection element of die node n_s in blank, the four nodes g_1, g_2, g_3, g_4 of the blank element are mapped to the plane β which is through the node $n_s(x_0, y_0, z_0)$ and perpendicular to the element normal along the node normal; the equation of plane β is:

$$(x - x_0) \cdot r_{jx} + (y - y_0) \cdot r_{jy} + (z - z_0) \cdot r_{jz} = 0 \quad (1)$$

Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The mapped nodes are p_1, p_2, p_3, p_4 , the elements before and after mapping are shown in Figure 3, the projection point of die node n_s in the blank is $p_n(x_p, y_p, z_p)$.

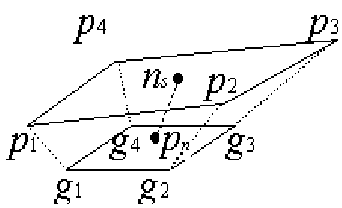

Figure 3: The Schematic Diagram Of Quadrilateral Element Mapping

Use coordinate transformation to transform p_k to the local coordinate system which is shown in Figure 4 and judge whether the transformed point h_s is in the region of quadrilateral element. Finally, h_s is mapped to the natural coordinate system.

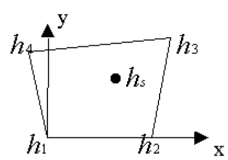

Figure 4: p_k Are Transformed To The Local Coordinate System

According to the feature of FE isoparametric element, the following relationship is established:

$$x = \sum_{i=1}^{4} N_i \cdot x_i$$

$$y = \sum_{i=1}^{4} N_i \cdot y_i \qquad (2)$$

$$N_i = \frac{1}{4}(1 + r \cdot r_i) \cdot (1 + s \cdot s_i) \qquad (3)$$

Substitute equation (3) into equation (2):

$$x_0 = \frac{1}{4}(1-r)(1-s)x_1 + \frac{1}{4}(1+r)(1-s)x_2 + \frac{1}{4}(1+r)(1+s)x_3 + \frac{1}{4}(1-r)(1+s)x_4$$

$$y_0 = \frac{1}{4}(1-r)(1-s)y_1 + \frac{1}{4}(1+r)(1-s)y_2 + \frac{1}{4}(1+r)(1+s)y_3 + \frac{1}{4}(1-r)(1+s)y_4 \qquad (4)$$

Arranging the above equation:

$$a_1 + a_2 \cdot r + a_3 \cdot s + a_4 \cdot r \cdot s = 0$$

$$b_1 + b_2 \cdot r + b_3 \cdot s + b_4 \cdot r \cdot s = 0 \qquad (5)$$

And:

$$a_1 = x_1 + x_2 + x_3 + x_4 - 4 \cdot x_0$$

$$a_2 = x_2 + x_3 - x_1 - x_4$$

$$a_3 = x_3 + x_4 - x_1 - x_2$$

$$a_4 = x_1 + x_3 - x_4 - x_2$$

$$b_1 = y_1 + y_2 + y_3 + y_4 - 4 \cdot y_0$$

$$b_2 = y_2 + y_3 - y_1 - y_4$$

$$b_3 = y_3 + y_4 - y_1 - y_2$$

$$b_4 = y_1 + y_3 - y_4 - y_2 \qquad (6)$$

The r and s can be solved by equation (5) and that there is one to one mapping between (x_0, y_0) and (r, s) when $r, s \in (-1,1)$ can be proved in mathematics, so a set of r, s values are uniquely determined. The projection coordinate of $p_n(x_p, y_p, z_p)$ can be obtained by equation (4).

$$x_p = \sum_{i=1}^{4} N_i \cdot x_i$$

$$y_p = \sum_{i=1}^{4} N_i \cdot y_i$$

$$z_p = \sum_{i=1}^{4} N_i \cdot z_i \qquad (7)$$

And x_i, y_i, z_i are components of the 4 element nodes in three directions x, y, z before the mapping in the overall coordinate system According to the springback of each point in quadrilateral element, the springback of mapping point $\Delta p_n(\Delta x_p, \Delta y_p, \Delta z_p)$ can also be obtained by using the shape function N_i.

$$\Delta x_p = \sum_{i=1}^{4} N_i \cdot \Delta x_i$$

$$\Delta y_p = \sum_{i=1}^{4} N_i \cdot \Delta y_i$$

$$\Delta z_p = \sum_{i=1}^{4} N_i \cdot \Delta z_i \qquad (8)$$

And $\Delta x_i, \Delta y_i, \Delta z_i$ are the springback values of the 4 element nodes in three directions x, y, z before the mapping in the overall coordinate system. So the mapped node coordinates $P(X, Y, Z)$ needed are as follows:

$$X = x_p - \Delta x_p$$

$$Y = y_p - \Delta y_p$$

$$Z = z_p - \Delta z_p \qquad (9)$$

The coordinate mapping method of triangular element:

Generally, it is hard to describe shapes of the surface in some parts which are complex and have dramatic change, but triangular elements can

Journal of Theoretical and Applied Information Technology
30th November 2012. Vol. 45 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

describe shapes more completely. The calculating method which is called the coordinate mapping method of triangular element is similar to that of quadrilateral, so the process is not repeated any more.

4. THE SURFACE FITTING

The die compensation based on numerical simulation technology offers the possibility of optimizing die shape. The geometric information is established on the data structures of numerical simulation which are nodes and elements of FE, so this information can not be directly applied to the mold CAD and need to be converted into CAD data formats. In this article, the bi-cubic B spline surface interpolation method is applied to reconstruct die surface [11].

4.1 The Parameterization Of Data Points

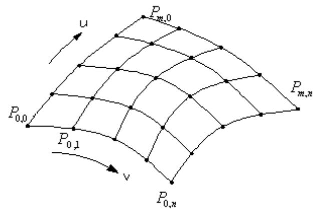

Figure 5: Surface Patches And The Number

In this paper, the parameterization of build-up chord length is used to make data points parameterized. And data points in the direction of U (V) are parameterized by the following equation:

$$\begin{cases} u_0 = 0 \\ u_i = u_{i-1} + |\Delta p_{i-1}| \quad i = 1, 2, \cdots, n \end{cases} \tag{10}$$

Figure 5 shows the surface patches and the number, and Δp_k is the forward difference vector, $\Delta p_k = p_{k+1} - p_k$ is the chord-vector. Firstly, the corresponding standardization node vectors of each row of data points are identified. Secondly, the arithmetic average of all node vectors with the same subscript is obtained and the value is used as the corresponding node value in node vectors of the parameter direction.

$$\begin{cases} u_0 = \cdots = u_3 = 0 \\ u_{m+3} = \cdots = u_{m+6} = 1 \\ u_{i+3} = \dfrac{1}{n+1} \sum_{j=0}^{n} u_{i+3,j}, \quad i = 1, \cdots, m-1 \end{cases}$$

$$\begin{cases} v_0 = \cdots = v_3 = 0 \\ v_{n+3} = \cdots = v_{n+6} = 1 \\ v_{j+3} = \dfrac{1}{m+1} \sum_{m=0}^{m} v_{i,j+3}, \quad j = 1, \cdots, n-1 \end{cases} \tag{11}$$

To some extent, the interpolation curve generated by the parameterization of build-up chord length can be seen as the rough and the tangent vector norm is closer to the unit length. And the curve smoothness is better.

4.2 The Determination Of Tangent Vector

In the process of surface reconstruction, tangent conditions are used, so the sectional curve (u line) endpoint tangent in the direction of u and the longitudinal isoparametric curve (v line) endpoint tangent in the direction of v need to be provided and also the twisting vectors of data points at corners. The Bessel method is used to determine the tangent, the following expression is:

$$\dot{p}_i = \frac{\Delta_i}{\Delta_{i-1} + \Delta_i} \frac{\Delta p_{i-1}}{\Delta_{i-1}} + \frac{\Delta_{i-1}}{\Delta_{i-1} + \Delta_i} \frac{\Delta p_i}{\Delta_i} \tag{12}$$

The geometric meaning is that the parabolic curve is obtained through three points p_{i-1}, p_i, p_{i+1} with the corresponding parameter u_{i-1}, u_i, u_{i+1} and $\dot{p}_i$ is the tangent of p_i. Similarly, $\dot{p}_0$ and $\dot{p}_n$ are the first and the end point tangent of the parabolic curve.

$$\dot{p}_0 = 2\frac{\Delta p_0}{\Delta_0} - \dot{p}_1$$

$$\dot{p}_n = 2\frac{\Delta p_{n-1}}{\Delta_{n-1}} - \dot{p}_{n-1} \tag{13}$$

After the tangent and interpolation points in the directions of U (V) are provided, the NURBS surface can be obtained by using ACIS development kit.

5. THE EXAMPLE

In order to verify the feasibility of the algorithm, the die surface compensation of the stamping part shown in Figure 6 is calculated. Performance parameters of the stamping parts material: Yield Strength $\sigma_s = 110.3Mpa$, Hardening Index n = 0.248, Hardening Coefficient $k = 540Mpa$, Young's modulus $E = 210Gpa$, Blank thickness $t = 0.5mm$.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure 6: The CAD Model Of The Part

The simulation of stamping is carried out by using KMAS software and a *.rst file is obtained. And then the file is imported into the springback module and the result of springback can be acquired. The comparison of the actual part and the part after springback simulation is shown in Figure 7.

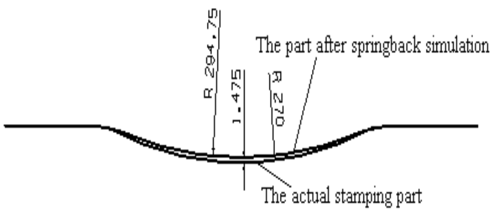

Figure 7: The Comparison Of The Actual Part And The Part After Springback Simulation

Importing the results before and after springback and the tool information into the compensation program, the compensated nodes and the fitted surface are shown in Figure 8 and Figure 9.

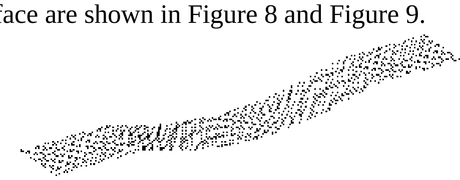

Figure 8: The Compensated Nodes

Figure 9: The Fitted Surface

Using the just amended surface to be the die surface, the forming and the springback are calculated again by the same process parameter. The comparison of the actual part and the simulation result after die compensation is shown in Figure 10.

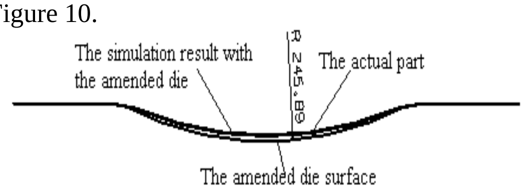

Figure 10: The Comparison Of The Actual Part And The Simulation Result After Die Compensation

It can be seen from the comparison diagram that the simulation result with the amended die and the actual part are almost coincide with each other. So the part meeting the precision requirement can be obtained by using the die compensation algorithm.

6. CONCLUSIONS

Based on the springback prediction of KMAS, the die surface compensation procedure is developed independently including the reverse compensation program of die surface nodes and the implementation of the surface fitting algorithm. The compensation method is to amend the die in the opposite direction with the calculated springback. So the surface mapping algorithm is put forward. In order to obtain the modified node coordinates, firstly, tool nodes need to be projected to the blank along the node vector. Secondly, the springback of projection points are calculated by interpolation according to the projection relation, and then the springback values are added to the projection points coordinates in the opposite direction. In this process, the R、S coordinate mapping method is mainly adopted. The bi-cubic B spline surface interpolation method is applied to reconstruct die surface in the fitting process. The example of the arc-shaped work piece is used to test the reliability of the program and the results prove that the program can be an effective tool to solve the springback problem in the mold design.

ACKNOWLEDGEMENTS

Thanks to Professor Ping Hu providing useful guidance. This work was supported by a grant from the National Natural Science Foundation of China (No. 19832020)， the School Project ‘Study on the die surface compensation technology based on springback in the field of stamping field’ and the teachers’ training program ‘Hundred Project’ of Zhuhai College of Jilin University.

REFRENCES:

[1] Z. Tekiner, “An experimental study on the examination of springback of sheet metals with several thicknesses and properties in bending dies”, Journal of Materials Processing Technology, Vol. 145, No. 1, 2004, pp. 109-117.

[2] LP Lei, SM Hwang, BS Kang, “Finite element analysis and design in stainless steel sheet forming and its experimental comparison”,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Journal of Materials Processing Technology, Vol. 110, No. 1, 2001, pp. 70-77.

[3] J. Weiher, B. Rietman, K. Kose, S. Ohnimus, "Controlling springback with compensation strategies", *The 8th International Conference on Numerical Methods in Industrial Forming Processes*, American Institute of Physics, June 13-17, 2004, pp. 1011-1015.

[4] D. Yang, et al. (Eds.), NUMISHEET2002, vol. 2, Benchmark Problems and Results, Jeju Island, 2002.

[5] YM Huang, TC Chen, "An elasto-plastic finite-element analysis of sheet metal camber process", Journal of Materials Processing Technology, Vol. 140, No. 1, 2003, pp. 432-440.

[6] AP Karafillis, MC Boyce, "Tooling design in sheet metal forming using springback calculations", International journal of mechanical sciences, Vol. 34, No. 2, 1992, pp. 113-131.

[7]AP Karafillis, MC Boyce, "Tooling and binder design for sheet metal forming processes compensating spring back error" , International Journal of Machine Tools and Manufacture, Vol. 36, No. 4, 1996, pp. 503-526.

[8]L Wu, "Tooling mesh generation technique for iterative FEM die surface design algorithm to compensate for springback in sheet-metal stamping", Engineering Computations, Vol. 14, No. 6, 1997, pp. 630-648.

[9] W Gan, R H Wagoner, "Die design method for sheet spring back", International Journal of Mechanical Sciences, Vol. 46, No. 7, 2004, pp. 1097-1113.

[10] W. Gan, R. Wagoner, K. Mao, S. Price, F. Rasouli, "Practical design methods using FE modeling applied to sheet parts and dies", Journal of Materials Processing Technology, Vol. 126, 2004, pp. 360-367.

[11] L. Piegl, W. Tiller, The NURBS Book, Springer, Berlin, 1997.