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A new iterative method for springback control based on theory analysis and displacement adjustment

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ABSTRACT

Springback is considered to be a manufacturing defect in sheet metal forming. When the tools are released after forming processes, the product will deviate from the desired shape due to its internal stresses. The deviation can be corrected by adjusting the tooling shape and/or optimizing the forming process. This paper will focus on tooling compensation (the forming process optimization is out of the discussion of this paper, although it is also an important method to control springback). Based on the displacement adjustment (DA) method, this paper will present a new iterative method for tooling compensation, which is a named sheet elements compensation (SEC) method. The aim of the SEC method is to overcome the difficulties, which are very common when using existing methods to solve springback problems. Three typical shapes are used to demonstrate the suitability and reliability of the SEC method. Additionally, a comparison between SEC method and existing methods is also implemented, which shows that the SEC method is also efficient in tooling design.

1. Introduction

Stamping is a complex plastic forming process, which possesses the characteristics of large deformation, geometric non-linearity, material non-linearity and contact non-linearity. Many products around us are made by a stamping process, such as aircraft bodies, vehicle bodies, refrigerator doors and so on. When the tools are released, springback will occur and the dimension of products will change, which can lead to quality problems and assembly difficulties. To get accurate products, researchers made some efforts to control springback. Their first approach is to develop methods to reduce springback by optimizing the forming process parameters such as controlling blankholder pressure, redesigning the drawbeads and controlling the forming temperature. More instances about this approach can be found in [1–4]. These methods are very effective to reduce springback, but they cannot eliminate springback completely. Moreover, they can cause other forming problems, such as tearing and wrinkling. Their second approach is to adjust the tooling shape, so that the product will be geometrically accurate enough to the desired shape after springback. This approach cannot reduce springback at all, but it has the potential to compensate springback completely for complex products.

Many springback compensation strategies have been well developed in the past few years [5–20]. Among them, a DA method is proved to be effective and reliable, as it can get a good result in a few steps. The DA method is an iterative algorithm based on FE simulation as shown in Fig. 1, which can be described as follows: (1) measure the shape deviation between the springback shape and the desired shape; (2) modify the coordinates of the control points on the tool surface in the direction opposite to the shape deviation.

The DA method is attractive to researchers due to its effectiveness and reliability. In the existing literatures, many compensation strategies based on the DA method are well developed, aiming at acquiring a faster convergence speed and increasing the robustness of the method.

In the original displacement adjustment method proposed by Gan [6], the shape compensation is only implemented in the y direction, parallel to the tool travel direction. This strategy can simplify the compensation process but may lead to low efficiency, especially for products with large side-wall areas. Weiher [7] modified the strategy by using a total distance between the nodes of desired shape and springback product instead of the y difference, which can achieve a much better result. But the strategy is still not perfect. Too many iterative steps are still needed to find the desired tool shape. Yang [8] discussed the importance of compensation direction to the

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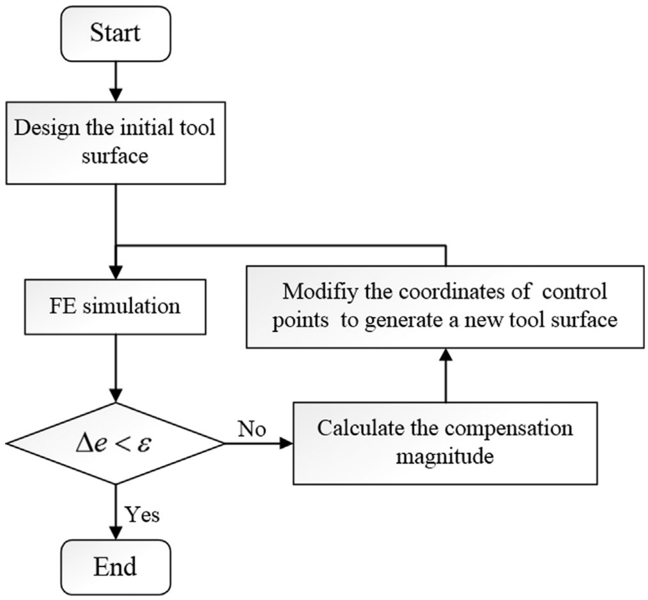

Fig. 1. Procedure of the DA method in tooling design.

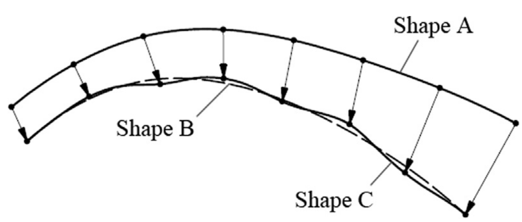

Fig. 2. Compensation defects caused by DA method.

convergence speed. An angle compensation factor is introduced to determine the compensation direction, so that the compensation can reflect the actual movement of the nodes on the surface when springback occurs. The method has been successfully used in simple bending cases. However, the strategy seems still need to be improved when modifying a complex 3D shape, since compensation factor and angle compensation factor are both variables at different nodes.

When most attentions are paid to improve the convergence speed and robustness of the DA method, another problem caused by the DA method is usually neglected. As shown in Fig. 2, shape A refers to a tool shape with large amount of nodes, shape B refers to a smooth surface and shape C refers to a rough surface. When using the DA method to modify shape A, keeping the smoothness of the compensated tool surface will be a difficult task. The compensated tool shape is usually similar to shape C rather than shape B, because both compensation direction and compensation magnitude can influence the quality of the compensated tool surface greatly. To get a smooth compensated tool surface, extra optimizations should be implemented.

In Ref. [7], Weiher proposed the smooth displacement adjustment (SDA) method, using polynomial basis functions to keep the compensated surface smooth. But, when the amount of nodes becomes larger, the degree of the polynomial function will be raised and the method will become unstable and inefficient. Lingbeek [9] presented the surface control overbending (SCO) method. Bezier and B-spline surfaces are chosen as approximation surfaces in the SCO method to keep the surface smooth. But, the control points is not exactly on the surface, which means only an approximate result can be found. If the control points deviate too much from the tool surface, the method fails. Additionally, the SCO method only allow 'quasi 2D' shape modifications, such as bending, or the application of torsion and camber. The SCO method is also sensitive to the amount of the nodes. In Ref. [10], Zhang proposed an analytical method, which is established by a combination method of theoretical analysis and numerical simulation. Interpolation processing and Bezier surface blending methods are used to construct the compensated tool surface. But this method can only get a limited precision due to the following facts: (1) the method is established on a simplified material model, in which hardening and Bauchinger effects are absent; (2) the stress–strain history has a great influence on the magnitudes of springback in a sheet metal forming process. Zheng [18] and Liao [19] proposed an analytical method, in which compensation strategies are implemented by correcting the curvature of the shape, but this method just can be used for pure bending cases and the precision of the compensated shape is limited by material models. For complex 3D-shapes, this method still needs to be improved.

As shown above, a good compensation method should have the following characteristics: (1) should have high precision or a fast convergence speed; (2) should be a reliable compensation process; (3) cannot only be used for 2D-shapes, but also for complex 3D-shapes; (4) should contain surface smoothing or regularization strategies. It seems that none of the existing methods mentioned above possesses the four characteristics. In this paper, based on the efforts of all the previous researchers, a new iterative method (SEC) is introduced.

2. The sheet elements compensation (SEC) method

2.1. Principle of the SEC method for bending cases

Most existing compensation methods are based on the conclusion that springback is a result of the displacement and rotation of nodes on the sheet surface. Their compensation strategy is to modify the coordinates of nodes directly along the compensation directions, which can cause non-smoothness of the tool surface especially when compensating a complex tool shape with large amount of nodes.

In this paper, we focus our attention on the sheet elements. So, springback can be considered as an accumulation of the displacement, rotation and deformation of the elements. As shown in Fig. 3(a), when the tool is released, the node p_i' and p_{i+1}' will displace to p_i and p_{i+1}. $\overline{p_i p_i'}$ refers to the displacement magnitude of p_i'. $\overline{p_i' p''_i}$ refers to the compensation magnitude of p''_i. Angle θ_0, denoted by the tangent line of p_i' and p_i, refers to the rotation magnitude of p_i'. Angle θ_1 refers to the plasticity deformation of the sheet element $p_i p_{i+1}$. Angle θ_2 refers to the deformation of the tool surface element $p_i' p_{i+1}'$. Angle θ_3 refers to the deformation compensation of the tool surface element $p''_i p''_{i+1}$. Thus, the motion of coordinates can be described as follows:

$$S(p_{i+1}) = S(p_i) + R(p_i) + D(s_{i+1}) \tag{1}$$

where $S(p_i)$ and $S(p_{i+1})$ refer to the springback magnitude of node p_i and p_{i+1}, $R(p_i)$ refers to the rotation magnitude of node p_i, and $D(s_i)$ refers to the deformation magnitude of the sheet element $p_i p_{i+1}$. In the same way, we can get other equations as follows:

$$S(p_i) = S(p_{i-1}) + R(p_{i-1}) + D(s_i) \tag{2}$$

$$S(p_{i-1}) = S(p_{i-2}) + R(p_{i-2}) + D(s_{i-1}) \tag{3}$$

$$S(p_1) = S(p_0) + R(p_0) + D(s_1) \tag{4}$$

Adding all the equations above together, Eq. (5) can be achieved.

$$S(p_i) = S(p_0) + \sum_{j=0}^{i-1} R\left(p_j\right) + \sum_{j=1}^{i} D(s_j) \tag{5}$$