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A die design method for springback compensation based on displacement adjustment

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ABSTRACT

Springback is a major problem in sheet forming processes. This problem can be corrected by adjusting the tooling shape to the appropriate shape and/or active process control. In this paper, the focus will be on tooling shape design, of which compensation magnitude and compensation direction are the two important aspects. A new method, which takes compensation direction into account based on displacement adjustment, has been developed. The method, which we call "comprehensive compensation method" (CC) is general for it considers the fact that large rotation and displacement would occur during springback, which is more common for automotive panel stamping due to the application of advanced high strength steels (AHSS) and the complexity in automotive panel structure. An angle compensation factor was introduced to determine the compensation direction. Compared to the three existing methods, which compensate in different directions, the new method has a higher precision especially for complex panel with advanced high strength. Additionally, the suitability and application of those four methods is also discussed, along with the origin of the differences.
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1. Introduction

Springback can be considered a dimensional change which happens during unloading, due to the occurrence of primarily elastic recovery of the part. It causes deviation from the designed target shape and produces downstream quality problems and assembly difficulties. To reduce springback, several approaches have been employed. Most of them focus on adjusting the main process parameters such as blankholder pressure, optimizing drawbead geometrical parameters, etc., to increase sheet tension during bending; some other approaches may also be taken to utilize sheet material properties to its advantage, such as changing the one-step stamping scheme to multi-stage stamping scheme, optimizing material properties of the sheet, etc. These approaches are effective with the advantage of not being required to adjust the tooling shape, but they cannot altogether eliminate springback completely, and may create other problems such as tearing or wrinkling; also based on trial-and-error method, they are found to be time-consuming. To limit trial and error procedures, numerical simulation methods have been used in sheet metal stamping in a wide range to evaluate springback and optimize the design [1–4], although strong nonlinear behavior in sheet metal stamping process makes it a problem to predict springback accurately. Improving the accuracy of springback prediction is an important topic that is beyond the scope of this paper.

Instead of reducing springback, the other approaches tend to adjust tooling shape to compensate for springback. Compared with those approaches mentioned above, which aim to eliminate springback, these approaches of adjusting tooling shape compensates springback to gain the desired product, it means that springback remains large, but with the modification of the die-face, the final product shape would closely approximate that of the desired product. It is more cost effective and has the potential to compensate springback completely for even complex parts.

Traditionally, springback compensation would be made using handbook tables based on analytic results for simple 2D formation or has to be carried out by trail-and-error for complex 2D shape and 3D shape, which is also time-consuming. To improve efficiency of springback compensation, Karafillis and Boyce [5,6] proposed the "Force Descriptor Method (FDM)" which is based on finite element simulation with an iterative scheme. However, its application suffers from lack of convergence unless the forming operation is symmetric or has very limited geometric change during springback [7,8], and the result is a little conservative [9,10]. In three dimensional formation processes, buckling can occur and in some cases the FE calculation will also fail to converge [10]. The "Displacement Adjustment (DA) method", of which compensation magnitude and compensation direction are

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the two important aspects, has been proved in practice to be successful [8]. The DA method is strictly a geometrical method, based on the intuitive idea to displace the geometry of the forming shape in the direction opposite to the geometrical error. The rate of convergence of DA method is faster compared with FDM, and is not limited to operations having particular symmetry, die shapes, or magnitude of the springback shape change [8]. However, no theory behind the DA method is present, tests of industrial case also show that the effectiveness of the method depends on various parameters including the part geometry, material and process settings [11,12]. To set the process of springback compensation on solid physical and mathematical grounds, Cimolin et al. [13] proposed a new method, in which a set of shape function bases has been employed to express the displacements of both the die and the sheet. The method reduced the size of the inverse problem to deal with. However, the number of function evaluations is too high for complex geometries. More work has been done to improve the precision of springback based on DA method [14–16].

The algorithm of DA method is based on an iterative scheme, as proposed in [8]: $C^{j+1}=C^j-(S^j-D)$. Here the first compensated geometry is referred to as C^1 and with this geometry a new FE simulation is started. By compensating C^1 with the shape deviation between the resulting springback product S^1 and the desired geometry D, the second compensated geometry C^2 is calculated. The loop continues until the shape deviation meets the tolerances. It is actually trial-and-error method based on FE simulation and such an iterative method is also time-consuming and costly. Thus, speeding up the convergence rate and consequently reducing the number of iterations is important for iterative DA method, which would be discussed later in this paper.

The non-iterative variant which we called the one-step DA method, points at another way to solve the problem above, as described in the following equation: $C=D-\alpha(S-D)$. The idea is that the compensated forming geometry C would springback exactly to the desired geometry D. Due to nonlinearities in forming process, compensation factor α is applied to revise the shape deviation between the springback product S and desired geometry D. The value of α, ranging from 0.7 to 2.5 in practice [12], is different for each forming process and cannot be predicted effectively. It depends on material, process and geometrical parameters, and can be directly calculated for the analytical model for simple geometry [10]. But in most cases of industrial application, it is impossible to get the desired product by just employing one parameter α for each point due to the nonlinear nature of the problem, but it is feasible to employ an improved global compensation factor to consider the effect of material, tension force and curvature of geometry.

When more attentions are paid to the iterative DA method and the compensation factor for one-step variant, the other important aspect of DA method the compensation direction, is neglected. In the DA method developed by Gan and Wagoner, the shape deviation is defined as the difference of y coordinates between the target and the springback shape [8]. Springback compensation is made opposite to the stamping direction, which brings up the question of convergence especially for side-wall area, since these features would mostly springback to the x direction, and here we call it the "reverse stamping (RS) method". The method by using the total distance instead of the y difference would work better and has been applied in industry [17]. That is, in the method, which we call as the "reverse displacement (RD) compensation method", springback compensation would be made along the direction connecting corresponding nodes of the spingback shape and the desired product. While in the case where node of the geometry is not available, especially in reverse engineering, the springback compensation would rather be made in the normal direction [14,18,19], which we would term the "reverse normal (RN) compensation method". No more work has been done to discuss what the effect compensation direction would have on the precision of springback compensation.

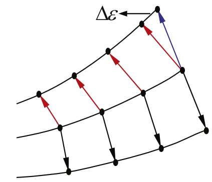

Fig.1. Error $\Delta\varepsilon$ between actual position and assumed position after compensation.

Calculating the desired die geometry from the springback shape is in virtually an inverse problem, which shows strong nonlinear nature. It is nontrivial since the transformation from the modified geometry of the die to the final piece obtained from it implies a very complex FE simulation. The DA method is actually a geometrical method that avoids the solution of complex FE model. In general, the nodal position after springback compensation along a certain direction may differ from the actual nodal position for the desired die geometry, position error of the nodes $\Delta\varepsilon$ would exist, which is neglected in most cases, as shown in Fig. 1 [20].

In fact, different compensation directions would result in a much different position error and have great effect on the precision of the results, which will be discussed later in this paper. When the compensation direction coincides with the direction for the desired die geometry, the position error $\Delta\varepsilon$ would be reduced and the precision of results would be improved; for the iterative DA method, it means a reduction on the iterations. On the contrary, much deviation from the actual compensation direction would bring about a lower precision result, and may also compromise the effect of the compensation factor. Thus, a modified DA method, which takes the compensation direction into account is developed in this paper. The method is general in that it considers the fact that large rotation and displacement would occur during springback, which is more common for automotive panels stamping; hence the term "comprehensive compensation (CC) method" is applied.

2. The modified DA method for springback compensation

The principle of DA method is to measure the shape deviation between the spingback shape and the desired product, and compensation would be made in the direction opposite to shape deviation. The methods that compensate along different directions would lead to different results. However, no rational explanation was given for those methods.

2.1. Explanation for current methods

Generally, springback process involves material nonlinearity, contact condition nonlinearity and geometrical nonlinearity, which would cause much difficulty to make an accurate FE simulation for springback. However, only small local plastic deformation would occur during springback and have no obvious effect to the result for springback calculation, deformation in the unloading process would be regarded as totally elastic. To deal with the problem of contact condition nonlinearity, springback scheme with tools removed, hence, avoids contact calculation, has been applied. The approach proved to be successful with little difference compared with the scheme considering the nonlinear contact condition. In most applications of springback simulation,

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