RECENT ADVANCES IN INDUSTRIALLY APPLIED NUMERICALLY AIDED SPRINGBACK COMPENSATION

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Abstract

Springback is a common and intrinsic phenomenon of every deep drawing operation. For various reasons the application of high strength steels and aluminum in automotive industry is still increasing. Unfortunately, these materials tend to larger springback than mild steels. Therefore it is more difficult to guarantee the accuracy of the part shape without a proper springback compensation. Several countermeasures can be applied to minimize springback, but it is not always possible to reduce springback sufficiently. Additionally, the overbending technique has been developed to counter springback by modification of the tool shape. This method gives satisfactory results for a whole class of parts which are very susceptible to springback. In this paper an improvement, the smooth displacement adjustment (SDA) method, is presented. Basically the shape deviation of the part is calculated and subsequently approximated by an L2-projection of sufficiently smooth global analytical functions. Due to the restriction to analytical functions the computed shape deviations can be easily transferred to the tool surface in order to compensate them. The use of the new method is demonstrated on an industrial part. The paper ends with conclusions and recommendations.
Key words: Springback compensation, virtual prototyping

1. Introduction

The geometrical inaccuracies due to springback after deep drawing operations are the reason for high efforts in tool and process development. This is amplified by the ever increasing application of HSS steels and aluminum. Their high yield stress to Young's modulus ratio results in more springback. Also the larger part sizes nowadays add up in making springback an urging problem. Different techniques have been developed to cope with the problem of springback. Process parameters like blankholder force or drawbeads can be applied and stiffeners or beads in the part improve the stiffness of the part. The most complex technique is the complete modification of the tool geometry to compensate the springback by overbending the part. This is an expensive and time intensive method largely based on workshop knowledge [1].

Springback is inevitable in each stage of the production process where the material undergoes changes that affect its geometry, geometrical stiffness and residual stresses. Therefore it is not only a phenomenon occurring during the deep drawing operation, but also during the subsequent trimming, flanging and hemming operations. Parts with satisfactory geometries after the first forming operation may finally become geometrically inaccurate. Generally, springback is compensated in the forming operation in which the inaccuracy arose. However, springback due to trimming has to be compensated in the previous forming operation. Springback is strongly dependent on the part geometry and the materials used and therefore it is not possible to give a general

rule of thumb for its compensation. Specific strategies can only be applied for parts which are geometrically similar. With the help of numerical simulation the amount of springback can be predicted and adequate countermeasures can be verified before the tools are even built. The accuracy with respect to its final geometry however is generally of insufficient quality. Improvements can possibly be found in the application of higher order elements and advanced contact and friction algorithms. Nonetheless is it very beneficial to develop compensation tools for springback from the point of view of industry.

In this paper an overview of the existing springback control strategies will be given. The new smooth displacement adjustment method (SDA) as an extension of the displacement adjustment method (DA) is presented. This method is based on the use of a continuous displacement function to compensate the tool geometry including the addendum and the blankholder. The advantages of such a description are discussed and illustrated on the basis of an industrial part.

2. Strategies for Springback Compensation

Springback compensation is defined as the modification of the original tool geometry such that the resulting geometry after springback comes closer to the target geometry derived from the CAD construction. A number of different approaches to control springback have been described in literature. Well-known methods are the spring forward (SF) [2] and displacement adjustment (DA) method [3,4].

The basis for the modification of the tool geometry is the part after forming either in reality or after numerical simulation of the springback. The result is then compared with the target geometry. In the DA-method the deviation between the two geometries is calculated first. The resulting field is multiplied with some certain compensation factor and then used as a shape modification. Depending on the geometry and the material this factor is found to be between –1 and –2.5. A sequential application of the DA-method enhances the compensation result significantly.

The SF-method starts with the forces acting on the punch at the end of the forming simulation. These forces are applied to the target geometry in a subsequent elastic FE-calculation resulting in a geometry which compensates springback. In the SF-method it is implicitly assumed that residual stresses do not influence the springback behavior. This method is confined to compensate springback in the first forming operation whilst the DA-methods can also be applied to springback as the result of all previous forming steps.

2.1. The displacement adjustment method

The DA-method is an intuitive method that has been used by deep drawing engineers for a long time. An iteration of the DA-method starts with the definition of the target position of a material point in the part $\mathbf{t}$ and its actual position after springback $\mathbf{s}$. The compensated material point $\mathbf{c}$ is then defined by:

$$\mathbf{c} = \mathbf{t} + a(\mathbf{s} - \mathbf{t}), \tag{1}$$

with a being an appropriate compensation factor. It strongly depends on the material and the geometry and is determined by trial and error. Usually its value is in the range

from -1 to -2.5. Based on the geometry of the part after the first compensation another iteration can be started to improve the result. This is repeated until convergence is reached [3].

The reason for the success of the DA-method stems from the fact that the deformation caused by springback is mainly elastic and linear with respect to modifications of the tool geometry. Therefore the deformations caused by springback can be canceled out by additional deformations due to the tool geometry. Note that in most parts a compensation factor $a = -1.3$ is used. This means that the amount of springback is not reduced by the compensation but increased.

2.2. The smooth displacement adjustment method

The geometry of the part after releasing the tools is either determined by numerical simulation or by (photo-optical) measurements. In both cases the displacement field is defined at discrete points of the part only. In the standard DA-method this leads to problems when applying this field to the tool geometry, since the tool description usually strongly differs from the part description. The solution for this problem in the SDA method is the introduction of a smooth displacement field $\mathbf{u}(\mathbf{x})$. Now the displacement field is defined at all points of the tool geometry. It is not important whether the tool geometry is described by a tessellated surface of triangles or quadrangles or by CAD-patches which are defined between control points.

Starting point of a single iteration of the SDA-method is the calculation of the compensated material point $\mathbf{c}(\mathbf{x})$ by:

$$\mathbf{c}(\mathbf{x}) := \mathbf{x} + a\mathbf{u}(\mathbf{x}), \tag{2}$$

where a is again the compensation factor. Here $\mathbf{x}$ is a point on the tool geometry and $\mathbf{u}(\mathbf{x})$ is the smooth displacement field defined in 3D space. It approximates and replaces the discrete field $(\mathbf{s} - \mathbf{t})$ of the DA-method. The task is to find the displacement field $\mathbf{u}(\mathbf{x})$ that minimizes

$$\| (\mathbf{s} - \mathbf{t}) - \mathbf{u} \|_{\mathbf{L}_2} \ . \tag{3}$$

The deformation caused by springback is mostly an elastic deformation and therefore a relatively smooth deformation with long modes. Therefore it can be assumed that its description is simpler than the description of the part geometry itself. This justifies the approximation of springback with polynomials $p_i, i = 1,...,n$ of low order. Thus, the displacement field can described by:

$$\mathbf{u}(x, y, z) = \sum_i \mathbf{a}_i p_i(x, y, z) \tag{4}$$

with $\mathbf{a}_i$ the 3D vector containing the weights of the polynomials. Inserting (4) into equation (3) gives with a variation the linear system of equations

$$\sum_i m_{ij}\mathbf{a}_i = \mathbf{r}_j \tag{5}$$

with the matrix entries

$$m_{ij} = \int_G p_i p_j \ dx \tag{6}$$

where the domain of integration G is the target geometry. Equation (6) is solved numerically by summarizing over all facets of the target geometry with appropriate mass lumping. The right hand side $\mathbf{r}$ is given by the components of the discrete displacement field $(\mathbf{s}-\mathbf{t})$. Each component $\mathbf{r}_j$ is defined by:

$$\mathbf{r}_j = \int_G (\mathbf{s}\text{-}\mathbf{t}) \ p_j \ dx. \tag{7}$$

The approximation error (3) is calculated and has to be small with respect to $\| \mathbf{u} \|_{\mathbf{L}_2}$. Another possibility is to calculate the maximum deviation between the discrete and the continuous displacement field. Experiences with displacement fields from industrial parts showed that the error is in the range of 10% and can be considered to be small. In order to improve the results the function space can be extended further if necessary.

2.3. Discussion
The advantage of the new SDA-method is that the calculated smooth displacement field can be directly applied to the tool geometry, independent whether this is tessellated or defined by CAD patches. Another advantage is its use when the discrete displacement field is not known. For instance when the optically measured part geometry after springback is given and has to be compared to the target geometry. In this case a discrete distance field between the two tessellated objects has to be calculated. High curvatures can make this field very rough. The SDA-method is able to smooth the roughness.

In this paper the displacement field was represented by polynomials. Bezier splines, for instance, may also be suitable to represent the displacement field. Furthermore, the functions can be confined to have local support in order to restrict the compensation of local areas where springback is dominant. Another possible extension is the definition a non constant compensation factor, for instance as a function of the local displacement norm. Symmetry conditions can be regarded by restricting the space of the polynomials. The smooth displacement function is only well defined in the vicinity of the part. Since polynomial functions tend asymptotically to infinity the smooth displacement function obtains large values outside the part. In some cases this will lead to unwanted tool distortion in regions of the blankholder. This problem can be avoided by multiplying the polynomials with a cut-off function vanishing in critical regions. Generally, displacement adjustment methods are restricted to parts with no undercutting tools, i.e. parts where the normal vector is not oriented towards the drawing direction.

3. Example

The SDA-method is demonstrated on a wall for a spare wheel well, see figure 1. The dimensions of the blank are 1000x30mm of HSS ZStE340. Here a single deep drawing operation followed by a flanging operation is considered. Especially after the flanging operation large shape deviations existed. This is caused by the non developable flanges being drawn. The shape deviation was up to 7mm and the compensation required a compensation factor of -2.5. Both the deep drawing as well as the flanging operation were simulated with the implicit FE-code INDEED. The numerically computed springback was in good agreement with the observed one. Springback mainly occurred at the ends of the flange.
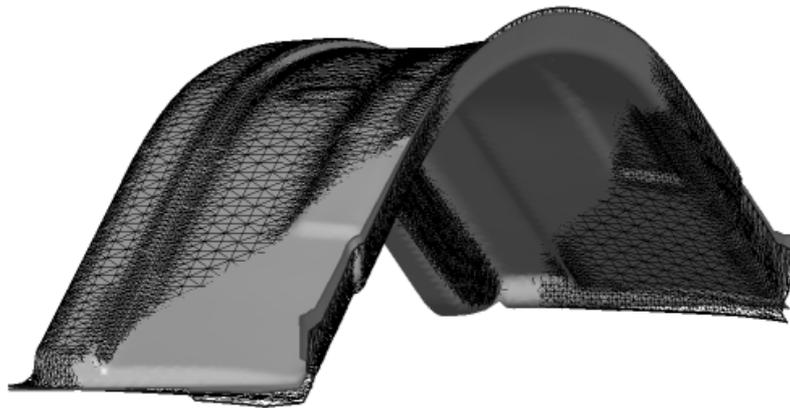

Figure 1.: Shape deviations of up to 7mm with the original tool geometry.

The first step was to test the SDA algorithm. Its approximation based on the calculated continuous displacement field $\mathbf{u}(\mathbf{x})$ was verified against the discrete displacement field, compare equation (3). To do so $\mathbf{u}(\mathbf{x})$ was applied to the part geometry before springback and compared to the geometry after springback. Figure 2 shows that both geometries are in good accordance.

Figure 2.: Part geometry after springback (light grey) and after application of the smooth displacement field (dark grey) (exaggeration factor 5)

Since only minor deviations were observed the displacement field was subsequently applied to the punch, blankholder and die (figure 3). The compensation factor was -2.5. This resulted in a smooth deformation of the original tool geometry.
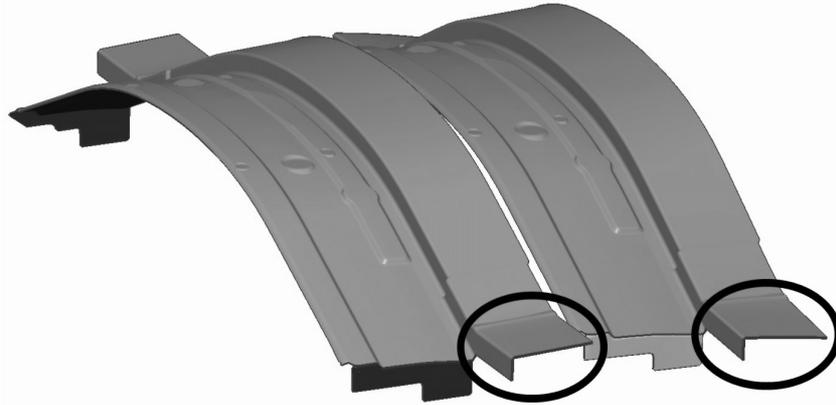
Figure 3.: Tool geometries: left original, right compensated, note the smoothly compensated flanges.

To verify the compensated tools the forming and flanging simulation were repeated with the new compensated tools. This resulted in a significant decrease of the shape deviation after releasing the tools. Instead of the previous 7mm the maximum deviation now was 1.5mm (figure 4).
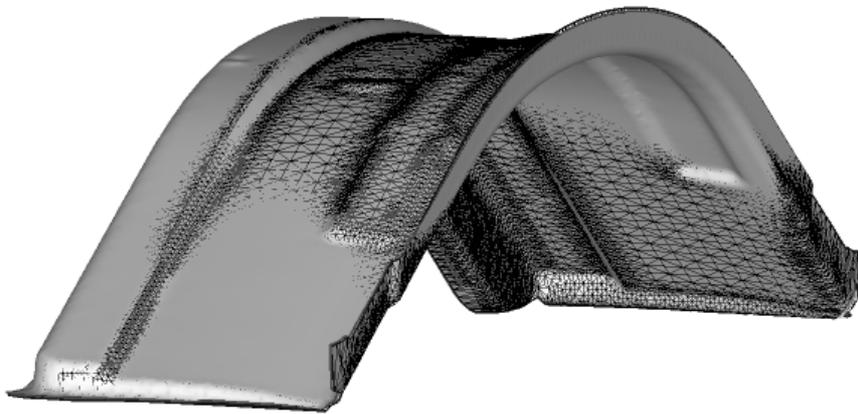

Figure 4. Maximum shape deviation of 1.5mm with the compensated tool geometry.

4. Conclusions

In this paper the smooth displacement adjustment (SDA) method is presented as an extension of the standard displacement adjustment (DA) method. Its main advantage is the easy handling of the method and the direct application on different tool descriptions. The smooth description of the displacement field paves the way for direct compensation of CAD data. The application of DA-methods is restricted to tools that show no undercutting regions. Some possible improvements of the method were given. The SDA-method was successfully demonstrated on an industrial part.

Important towards an industrial application of the presented compensation methods based on simulation is the improvement of the springback prediction itself. The main reason is the insufficient approximation of the residual stresses. Very promising is the development of higher order elements and new contact algorithms.

5. References

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