Shape Optimization in Metal Forming Applications Based on the Shape-Manifold Approach

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Abstract. The concept of shape-manifold is applied here to the optimization of a deep drawn blank considering parameterized tool geometries. By adopting this concept, a realistic post-springback shape of the blank closest to a given ideal target shape is obtained. The global approach is fully automated, from the generation of the tool geometries, to the identification of the optimized design parameters. This approach was successfully applied to both simple 2D and complex 3D industrial test cases.

1 Introduction

Due to elastic springback, the shape of a formed blank differs from the shape of the tools: i.e. the die and the punch. Various optimization approaches (often based on Finite Element simulation loops) are used to find the best shape of the tools for obtaining a desired shape, referred to as the target shape in the remainder of this paper.

Geometries are usually described with a set of primitives (i.e. lengths, radii and angles). Although it can be very easy to describe simple geometries with primitives, it often becomes very difficult in the case of more complex shapes, as those obtained in deep drawing, after springback.

Another problem with complex shapes is the number of parameters involved. When these parameters are chosen at random, they may not fully describe the geometry. Some parameters can also be highly correlated together. Finally, the number of parameters is usually greater than the intrinsic dimensionality of the assessed shape. It is common knowledge that the fewer the number of parameters is, the more efficient the optimization approach will be.

In the present work, we propose to use a Level Set approach to fully describe springback shapes. The dimensionality reduction is achieved by Proper Orthogonal Decomposition. After detecting the intrinsic dimensionality, interpolation between shapes is performed by Diffuse Approximation [1]. The obtained response surface is called a Shape-Manifold [2] which represents any admissible shape of the shape-space. Finally, a Walking Algorithm [3] is used to efficiently approach the target shape by constructing the shape manifold only locally, step by step, until convergence.

2 Shape-manifold approach

2.1 Level set approach

The level set approach is used to fully describe springback shapes (Fig. 1), regardless of their complexity.

This Eulerian approach allows us to represent not only the target shape (usually designed with a CAD software) but also the springback shapes (either meshes coming from Finite Element simulations or even actual 3D scanned parts).

However, Level Sets imply a very high dimensionality, due to the resolution of the grid, which still needs to be decreased.

Figure 1. Example of a 2D level set function whose zero level set represents half of the profile of a U-shaped sheet after springback.

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2.2 Proper Orthogonal Decomposition

After the level sets are generated from a set of springback shapes, they can be stored in a matrix whose rows are the distances and columns the snapshots.

Performing Proper Orthogonal Decomposition (POD) on this snapshot matrix allows us to significantly reduce the dimensionality. Each shape may then be described by a vector of coordinates (POD coefficients) in the shape-space (i.e. POD coefficient-space) as shown in Fig. 2.

![Figure 2](image_url)

**Figure 2.** Example of a set of shapes in the shape-space (only 3 coordinates are represented).

2.3 Diffuse approximation and shape-manifold

A fundamental hypothesis that was verified in [4] is that the point-set in the shape-space can be replaced by a smooth shape-manifold.

The next step consists of interpolating between this set of points to get the smooth shape-manifold. Among the various methods of interpolation, the diffuse approximation [1] has been used here. The previous example in Fig. 2 is modified after performing this interpolation in Fig. 3.

![Figure 3](image_url)

**Figure 3.** Example of shape-manifold obtained using diffuse approximation (only 3 coordinates are represented).

2.3 Walking algorithm

Constructing the shape-manifold in the complete range of variation of the input parameters (i.e. the parameters of the tools and any other parameter of the forming process) can be time-consuming.

An iterative walking algorithm is proposed to decrease the computational cost. This approach consists of iteratively constructing the shape-manifold only locally, step by step, around a set of points. At each step, the target shape is projected in the shape-space, onto the local shape-manifold. The direction for the next step is chosen so as to decrease the distance from the target shape. At convergence, the distance between the target shape and the local shape-manifold reaches a minimum. The projection of the target shape corresponds to the optimal shape for the blank. The corresponding input parameters give the optimal shape for the forming tools and the optimal value of any other forming parameters that are allowed to vary.

3 Example of application

The approach was applied on a complex 3D test-case corresponding to the deep drawing of an automotive strut tower. The approach was fully automated, right from the generation of the meshes by driving the parameterized CAD model (Fig. 4), to the computation of the optimal shape (Fig. 5) and its corresponding set of parameters.

![Figure 4](image_url)

**Figure 4.** Example of CAD geometries of the tools for the deep drawing of an automotive strut tower.

![Figure 5](image_url)

**Figure 5.** Example of optimal shape corresponding to an automotive strut tower. The field gives the distance with the target shape.
4 Conclusions

In this work, the authors have proposed an efficient approach for optimizing tool shapes in deep drawing applications.

This approach is based on the fundamental hypothesis of the continuous shape manifold. The transition from a set of shapes to a shape manifold is achieved by using Level Set representations followed by the interpolation of their POD coefficients using Diffuse Approximation. The walking algorithm allows us to reach the optimal shape efficiently.

The global algorithm is fully automated and could easily be adapted to several other fields, not only for optimization but for characterization as well.

References