# A method for modifying the forming tool geometry in order to compensate for springback effects

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## ABSTRACT

There is always a certain amount of springback deformation in a metal forming process. The high strength steel is becoming a more attractive choice for many applications when low weight of the structure is of importance. One major drawback with the high strength steel is that the springback deformation increased compared to low strength steel.

All currently known techniques to reduce the springback deformation are used in tool design today, so it can be really hard to reduce the springback deformation further. The only possibility to obtain the desired geometry for the sheet after springback is to have a shape of the tool that is different than the desired final shape of the sheet.

A method to modify the tool geometry in order to compensate for the springback effect is here presented. It is a heuristic method, based on the difference between the sheet after springback and the desired shape. No parameterisation of the tool geometry is needed. Since no parameters are describing the shape of the tool geometry, it can be modified in an arbitrary way without the restriction of the design space spanned by design parameter.

The method is demonstrated on a doubly curved sheet and it is shown that the method gives a very fast convergence for the desired shape of the sheet. It is most likely that the method will work on a variety of different shapes. The method is applicable regardless of the yield strength of the sheet material, but most interesting are probably those materials which gives a large springback deformation, such as high strength steel and aluminium.

## INTRODUCTION – The Springback Problem

In metal forming, there is always a certain amount of springback deformation when the forming tools are removed. A controlled stretch on the blank can reduce the amount of springback but some springback will always remain. The industry is considering using high strength steel and the springback effect gets larger when forming with high yield strength materials. So it is of great importance to be able to control this effect, in particular when introducing these new materials. One can expect it being hard to reduce the springback effect more than what is done today since all available techniques are currently used and the springback problem is still considerable for many forming applications, even with low strength materials.

The springback effect must be considered when designing the forming tools. Thus, the desired shape is not obtained if the tools are created using this geometry of the formed part. Designing the formed parts so that the shape is not of any major importance for the tolerance in the assembly stage often circumvents the problem. Attachment holes of a formed part are usually drilled after that the formed part has sprung back. There are however parts where the deviation from the desired shape is particularly important, such as outer car panels and attachment brackets with small tolerances.

The common way to deal with the problem is to add special techniques to reduce the effect of springback, such as extra features in radii, using smaller radii or adding or modifying the draw beads to get an increased stretch of the blank. These techniques only reduce the effect of springback but the formed part will always spring back a certain amount. The only way to get the formed part to be "exactly" as the desired shape is to have a tool geometry that have a different geometry than the desired shape. Changing the tool geometry from the desired shape, in order to get the correct final shape of the part is here called tool compensation.

## Previous Work

Little work related to tool compensation from a simulation point of view has been found in literature. The most complex problem in this context is how to change an arbitrary part of the geometry in an arbitrary way. There has been work made on tool compensation for springback, where the geometry is parameterised with TrueGrid[1], see Stander et al. [2]. LS-OPT [3] was used for obtaining the values on the parameters that were input to TrueGrid. A response surface was built up between every change of the tool geometry by performing a number of simulations. The tool geometry was modified according to the design parameters at the optimized values from the response surface. This method seems to work on simple geometries but examples can easily be found when the parameterisation of the geometry with TrueGrid becomes extremely difficult.
Moshfegh [4] and Jansson [5] have proposed parameterisation of the IGES tool surfaces when modifying the forming tools. This is probably an unmotivated approach, because even if the IGES geometry could be parameterised, the IGES geometry will be meshed and a new finite element description of the tool geometries is created within the iteration loop. In fact, it should be considered as an advantage to eliminate the geometry parameterisation since it only adds more sources of errors to the iteration in finding the new tool geometry. Another problem is to find suitable design parameters for controlling the geometry, such that it becomes possible to create a large range of different geometries. Furthermore, parameterisation of arbitrary free-form IGES surfaces is indeed far from a trivial task.

## The Heuristic Method

An iterative method for the tool compensation is presented in this report. There are several advantages using this method:

- It does not require a parameterised model.
- No optimization, at least in a classical sense, has to be carried out for finding the geometry used for the next iteration.

The proposed method is based on heuristics. Thus, the results from one forming simulation and one springback simulation give input on how to proceed in the next iteration. This is probably much like what is used in metal workshops practice today for springback compensation, in the few companies that actually do compensate the tool for springback effects.

By making the geometry changes on the finite element description of the tool surface, a new tool geometry is directly obtained for the next forming simulation.

The method is basically straightforward, but it requires some programming since the functions needed are not directly available in any commercial program. A forming simulation and springback simulation are performed. A measure of the difference between the desired shape and the shape after springback is calculated. The tool geometry is modified according to this geometry measure by moving it in the opposite direction to the springback displacement. The iteration scheme is:

1. Forming simulation using LS-DYNA [6][7].
2. Optionally coarsen the blank mesh using LS-DYNA.
3. Prescribe suitable nodes and perform the springback simulation using LS-DYNA.
4. Calculate the distance from each node on the blank to the desired geometry.
5. Map the deviation in distance of the blank onto the nodes on the die. Only nodes on the die, which lies on the same area as the trimmed final part gets a deviation value.
6. By adding the current deviation to the previously calculated modifications, the new geometry of the finite element tool surface is obtained. A static analysis is performed where the nodes with a deviation from the desired shape gets a prescribed displacement. The outer boundary of the tool geometry is fixed. In this way, a smooth modification of the addendum is obtained (the area between the primary modified tool and the outer edges of the die).
7. The modified die tool is offsetted to obtain both the binder and the punch.
8. The tools are positioned and new prescribed motions of the binder and punch are calculated.

Even though the method may seem simple, it is shown to work well on the demonstration model.

## Calculation of Deviation Distance

The distance from the current surface to the desired surface, for each node on the blank after springback, has to be calculated. At the first iteration, the desired shape is given by the sheet after a forming with tools which have the desired shape, i.e. the resulting geometry after the forming simulation but before springback analysis is performed.

A difficulty with the deviation distance calculation is that the nodes on the blank after springback should not necessarily be located at their closest point on the desired surface geometry. Figure 1 illustrates this issue. The problem becomes less critical the closer the surfaces are to each other.

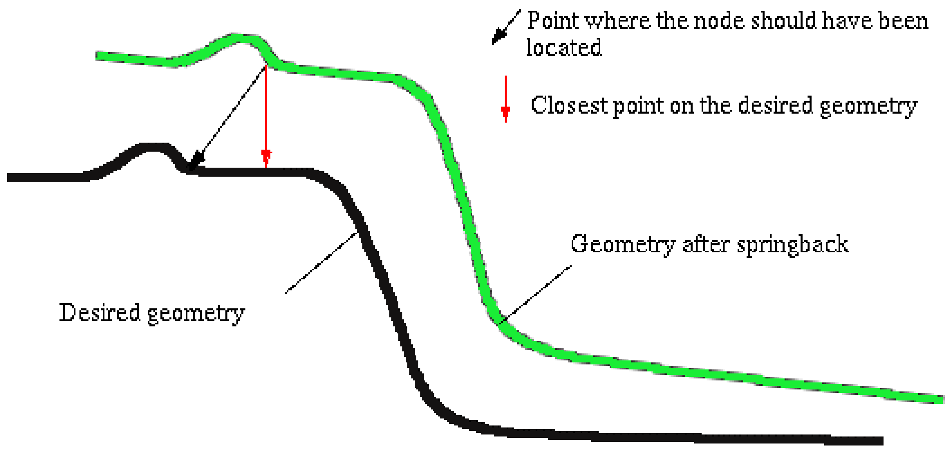


**Figure 1** Problem with measuring deviation between different geometries

A good solution would be some kind of feature-mapping algorithm to get a better estimate where each node on the sprung backed part should be located on the desired geometry.

The calculation of the distance between the blank nodes and the desired geometry is here done by measuring the distance to the closest element face on the desired geometry. This is used for all iterations except for the first iteration. In the first iteration, the desired location of each node is exactly known, i.e., it is the location before springback.

## Deviation Mapping

The calculated deviation distance between the desired surface and the actual surface for each node on the blank has to be mapped back to the die tool surface in order to modify the tool nodes in the opposite direction. To improve the convergence of the process, the modification vector of the tool node coordinates should be scaled by a factor *a*. It is however difficult to recommend a suitable value of *a*, but 1.0 for the initial modification, 0.5 for the two following iterations and 0.2 for the subsequent iterations gave a reasonable convergence for the demonstration model.

It would be possible to take the value for the closest node on the blank and use this for modifying the tool. This would however not be very robust. It could easily result in inverted elements on the tool, which would invalidate the tool model for simulation. A smoothing function is therefore applied.

The mapping of the deviation is done in the following way. For each node on the die, find the nodes, *i*, on the sheet, which lies within a radius *R*, and calculate the deviation in position, $e_i$, for every tool node by:

$$\frac{\sum e_i f_i(r)}{\sum f_i}$$

The function $f$ is made as a linear decreasing function, where $f(r=R) = 0$ and $f(r=0) = 1$.

This will give a relatively smooth modification to the tool. The radius $R$ will depend on the size of the elements on the blank and should be chosen to be about this size.

## Demonstration Model

A demonstration model has been set up to show the applicability of the method. It is deliberately made as a double curved U-profile, which is quite simple, but would be complicated to parameterize. The chosen geometry can be considered as a reasonable representative structure for the type of formed beams that are used in the automotive industry, but it does not contain any detailed features, see Figure 2. The size of the model is about 220x420x55 mm. The initial thickness is 1.0 mm and the yield strength is set to 700 MPa, which is a relatively high value for steel materials in forming applications.

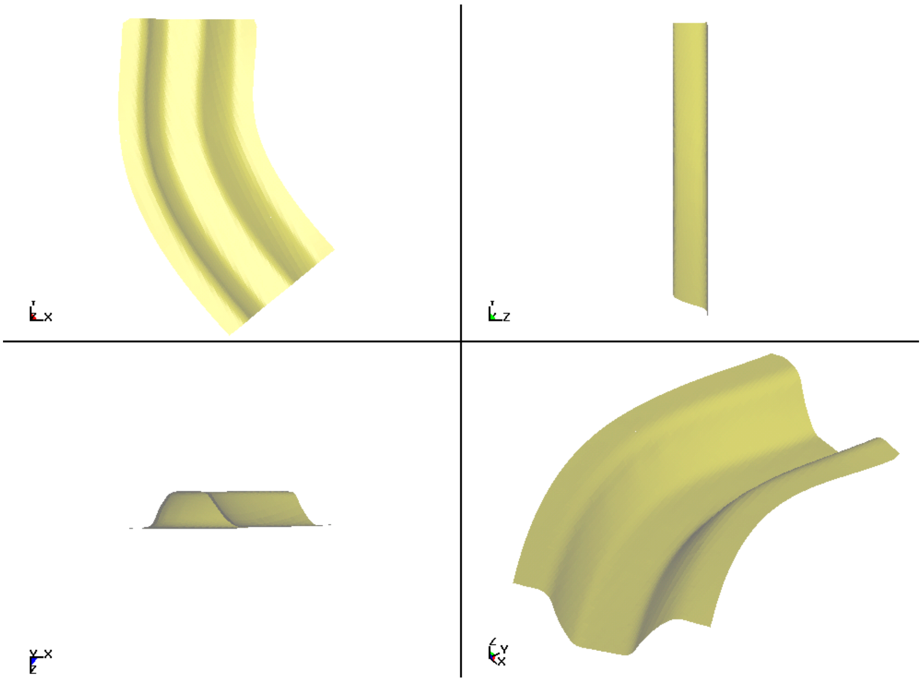

**Figure 2** The example model

It is difficult to set a number on how close the formed part is to the desired geometry. A possible measure could be to calculate a mass weighted (≈area weighted) root mean square value.

$$\sqrt{\frac{\sum_i e_i^2 m_i}{m_{total}}}$$

$m_i$ is the mass of node $i$ and $e_i$ is the node deviation distance for node $i$ from the desired geometry. This measure could however give a low value even if the two geometries differ a lot at a very small area. Another measure would be the maximum deviation at any place on the blank. This is probably a better measure but the largest deviation may be in an area that is unimportant so an ocular inspection may be the most appropriate measure in many cases. This method has been used here.

## Comparing Geometries

The following images show the congruence between the desired geometry and the geometry after springback using the initial tool geometry and the tool geometry after five subsequent modifications. The initial tool geometry is the same geometry as the desired shape of the sheet.

Three sections are used for visualizing the congruence. The displacement magnification factor is 1:1 in all images. The three sections are located as shown in Figure 3.

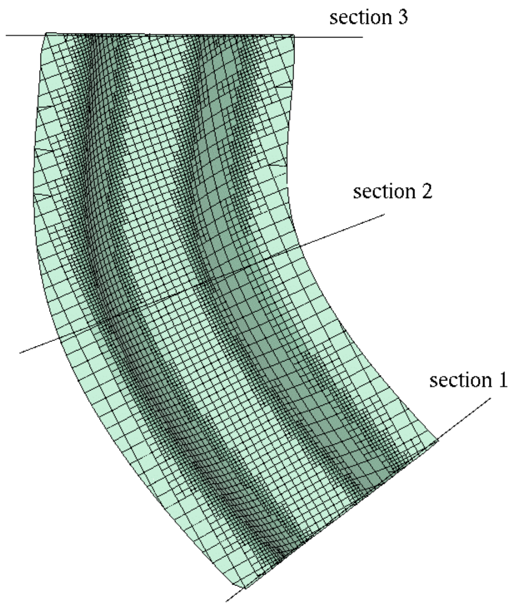


**Figure 3** The sections used for visualize congruence

The deviation between the springback geometry and the desired geometry for section 1 is shown in Figure 4 and Figure 5.

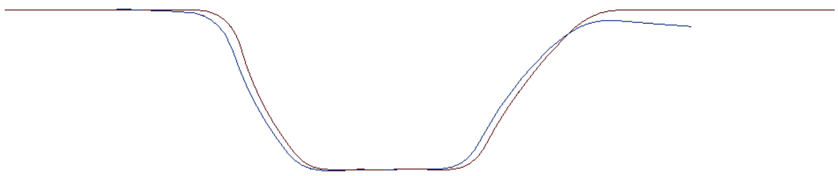

**Figure 4** Section 1, desired shape of the sheet and shape after first springback iteration

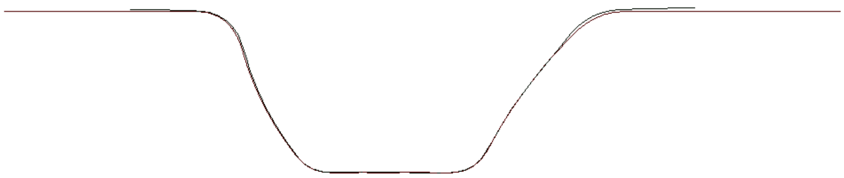

**Figure 5** Section 1, desired shape of the sheet and shape after five iterations

The deviation between the springback geometry and the desired geometry for section 2 is shown in Figure 6 and Figure 7.

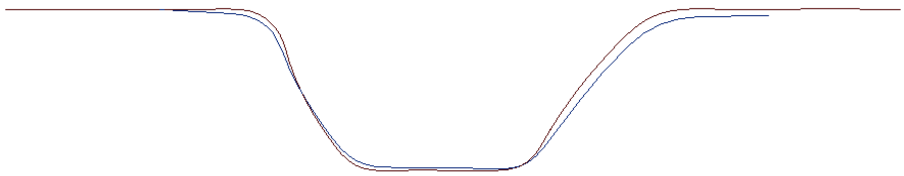

**Figure 6** Section 2, desired shape of the sheet and shape after first springback iteration

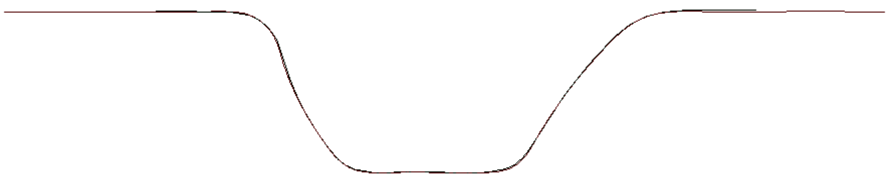

**Figure 7** Section 2, desired shape of the sheet and shape after five iterations

The deviation between the springback geometry and the desired geometry for section 3 is shown in Figure 8 and Figure 9.

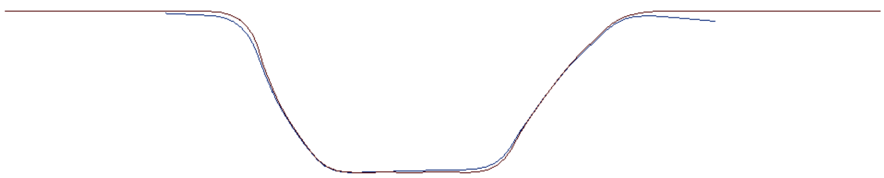

**Figure 8** Section 3, desired shape of the sheet and shape after first springback iteration

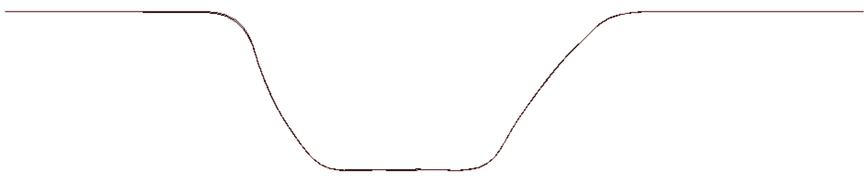

**Figure 9** Section 3, desired shape of the sheet and shape after five iterations

The tool geometry was changed by the described method in eight iterations. It was noted that the sheet after springback was quite close to the desired shape after only three iterations and the result was not noticeably improving after five iterations. A probable cause is that the magnitude of the deviation is in the same order as the accuracy of the implicit springback solution.

The maximum deviation distance between the sheet after springback and the desired shape was initially more than 6 mm. After tool compensation, the maximum deviation distance is less than 1 mm.

## Comments and Limitations of the Method

A possible limitation of the method exists if only certain areas of the tool are allowed to be changed. It would be tricky but definitely manageable. It could be made by a decreasing weight function from one to zero in the transition area between the area, which is allowed to be changed, and the one that is not. This restriction does not to seem be likely in the general case.

Suppose that a tool shape can be shown to give a desired shape of the formed part when using simulation. It is not certain that the tool shape would give the desired shape when the tool is manufactured. This depends on the correctness of the simulation. Material parameters, mesh convergence and accuracy of the numerical methods for both the forming and the springback simulation are potential sources of errors. It is important to be aware of these factors when trying to compensate the tool for springback using simulations. A nice characteristic of the described method is that it could easily be verified to work by just comparing the geometry after the springback simulation to the desired geometry.

It is difficult, but not impossible, to automatically run a sequence of iterations in order to get the final tool shape. The different stages in the iteration, i.e., deviation calculation and result mapping are solved by programs written solely for these purposes. A number of additional scripts have also been made which make the different stages in the iteration loop automatic.

## Conclusions

The described method for tool compensation has shown to produce a tool shape which gives a final shape of the formed part, which is much closer to the desired shape than what would be obtained without tool compensation. The method need just a few forming and springback simulations. The method presented here is considerably faster than the response surface technique (RSM) where, in addition, only a limited number of design variables can be used.

For the demonstration model, the deviation calculation by measuring the distance to the closest point on the desired surface seems to work very well. A feature-mapping algorithm may be necessary for more complicated geometries.

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