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Advanced Springback Compensation Strategy through elimination of avoidable elastic strain energy

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Abstract. The stamping of dimensionally accurate sheet metal body components still represents a huge challenge in the automotive industry. This is partly caused by the multi-stage production process which complicates the design of an appropriate compensation strategy dramatically. A key prerequisite of an appropriate compensation strategy is to eliminate any undesired influence of elastic energy being potentially induced when closing the blankholders in the several operations throughout the production process. Here, a universally applicable compensation strategy is presented which fulfils this requirement thoroughly; by applying this process, the involved strain energy is reduced to a minimum due to proper part position in all operations. Technically this compensation strategy is achieved by, first, simulating all operations of the stamping process individually, second, by individually calculating the springback after each operation and, third, by accumulating the calculated deviation vector fields for each operation appropriately, which are then used for springback compensation. The process is time and cost effective and the required efforts are moderate even for complicated multistage stamping operations.

1. Introduction

During the opening of the tools in the manufacturing process of stamped parts the part geometry is changing due to the release of elastic energy. This phenomenon is called springback and leads to undesired dimensional deviations between the produced part and the target geometry. If the respective parts are out of dimensional tolerance, subsequent quality issues and difficulties in the assembly process of the parts result. To reduce the dimensional deviations caused by springback, a common approach is the so-called *geometrical springback compensation*. Here, the geometries of the stamping dies are modified in the opposite direction of the springback. The geometries modified in this way will be called *compensated tools* in the following.

In order to determine the compensated tools based on the springback result and the dimensional deviations, respectively, there are different approaches referred to as *compensation methods*. Well known compensation methods are, for example, the *Displacement Adjustment Method* [1] or the *Force Descriptor Method* [2], mainly differing in the way how a displacement rule for the compensated tools is generated from the springback results.

Most body parts are manufactured in several consecutive forming operations and, consequently, after each operation different springback results are obtained. The *compensation strategy* defines which operation of a multistage manufacturing process has to be compensated and which springback result is used. The decision for a compensation strategy is quite often based on practical experience and often requires several trial-and-error loops. The main goal of the compensation process is to obtain produced parts within the required dimensional tolerances which can, however, be achieved with very different compensation strategies. In addition, also the part position in each operation should be stable in order to guarantee a robust stamping process; an important condition being neglected in many compensation strategies. Besides the mentioned aims, also the required time and cost efforts have to be considered when assessing a compensation strategy.

In this paper an *Advanced Springback Compensation Strategy* is presented which delivers produced parts within given dimensional tolerances while a stable and reproducible part position is guaranteed. Nevertheless, the effort to apply the new method is small compared to other strategies.

2. Review of currently used compensation strategies

Due to the multistage character of common stamping processes in car body manufacturing and due to the impact of every individual stamping operation on the final springback result, *Roll et al.* [3] recommend the independent compensation of each stamping operation based on their respective springback. Just in cases where this approach fails, a different strategy should be used.

Birkert et al. [4] describe different such compensation strategies and compare their advantages and drawbacks. Subsequently, the most common strategies for practical application are summarized. One popular compensation strategy uses the deviations at the end of the process chain to compensate the drawing operation only. This strategy is very popular because only one operation has to be modified and thus the effort of the overall compensation process is very small in comparison to other strategies. However, it is very unlikely that this strategy works for components with complex manufacturing processes.

Another popular compensation strategy contains the compensation of all stamping and trimming operations, each based on the deviations at the end of the process chain. This means that the amount of compensation is the same for every single operation. The advantage of this strategy is the relatively small compensation effort due to the fact that (more or less) the same compensation vector field can be used for all operations. The third worth mentioning strategy is the *Drawshell-Compensation.* This strategy is mainly used for the compensation of trimming operations and is applied to ensure a proper positioning of the incoming part and to avoid unwanted plastic deformations. To adapt the tools of the trimming operation to the incoming part, the calculated or measured springback before the respective trimming operation is used.

Birkert et al. [5] recommend an *Improved Springback Compensation Strategy* (*Improved Strategy*) through optimized part position in the dies. This strategy can be generally applied to all multistage car body component stamping processes. It leads to an improved dimensional accuracy compared to other common strategies, caused by a reduction of the involved elastic energy when the blankholders are closed. This reduction is achieved by ensuring a proper part position in all trimming and forming dies of the stamping process. The disadvantage of the strategy is a very complex and time-consuming work process compared to other compensation strategies.

3. Deficits of today's compensation strategies

As previously discussed in Sec. 2, different compensation strategies have different pros and cons with regard to general applicability, compensation amount, effort and complexity. The *Improved Strategy* described in [5] is the only strategy, which can fulfil the requirement of a general applicability, i.e. a reliable reduction of dimensional deviations of any car body component after compensation. However, the main disadvantage is the very complex and time-consuming application, mainly caused by two reasons. Firstly, the amount of compensation is different for each forming operation in a multistage car body stamping process; this means each operation must be compensated differently in each compensation loop. Secondly, the compensation of the operations must be executed consecutively with each compensation depending on the respective springback of the previous operation. This requires an alternating process of adaption and simulation (Figure 1), which prevents a continuous simulation of the entire process chain and thus causes a high time effort, especially when a large number of operations is involved.

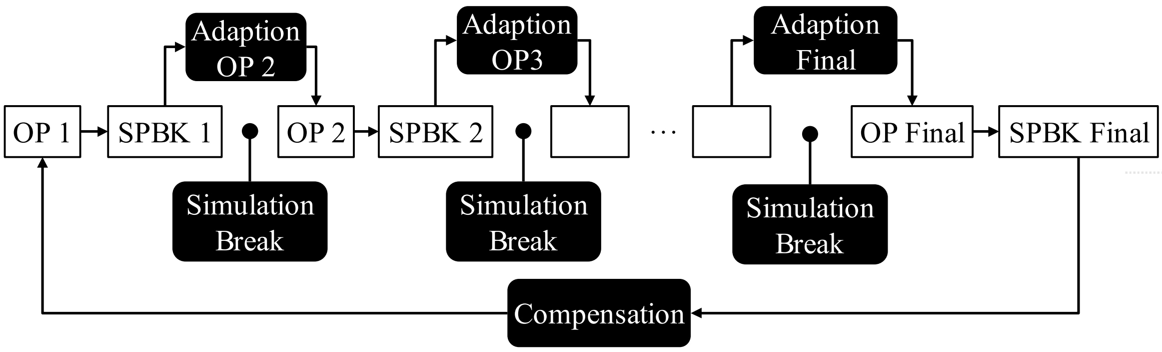

Figure 1. Alternating process of adaption and simulation when applying the *Improved Springback Compensation Strategy*

Figure 2 shows the qualitative representation of the dimensional deviations in the initial and last compensation loop of the compensation process when the *Improved Strategy* is applied. In the initial compensation loop the focus is not the improvement of the dimensional deviation of the respective part at the end of the process chain but rather on a proper part position in all operations to eliminate any negative influence of elastic energy while closing the blankholders. Indeed, the additional effort in the initial loop can lead to even higher dimensional deviations than those observed in an uncompensated process. In the last compensation loop, however, the desired state should be reached; the dimensional deviations are then expected to be within tolerance while, additionally, in every operation a proper part position without any elastic energy is provided when closing the blankholders.

To maintain the advantages of the *Improved Strategy* and, at the same time, to reduce the computational effort, it would be desirable to obtain the initial deviations (free of the negative influence of the elastic energy while closing the blankholders) without the possibly higher dimensional deviations. Also, it would be preferable if the tool-compensation of the respective compensation loop could be completed before starting the simulation of the next compensation loop, so that the simulation can be performed without the breaks indicated in Figure 1.

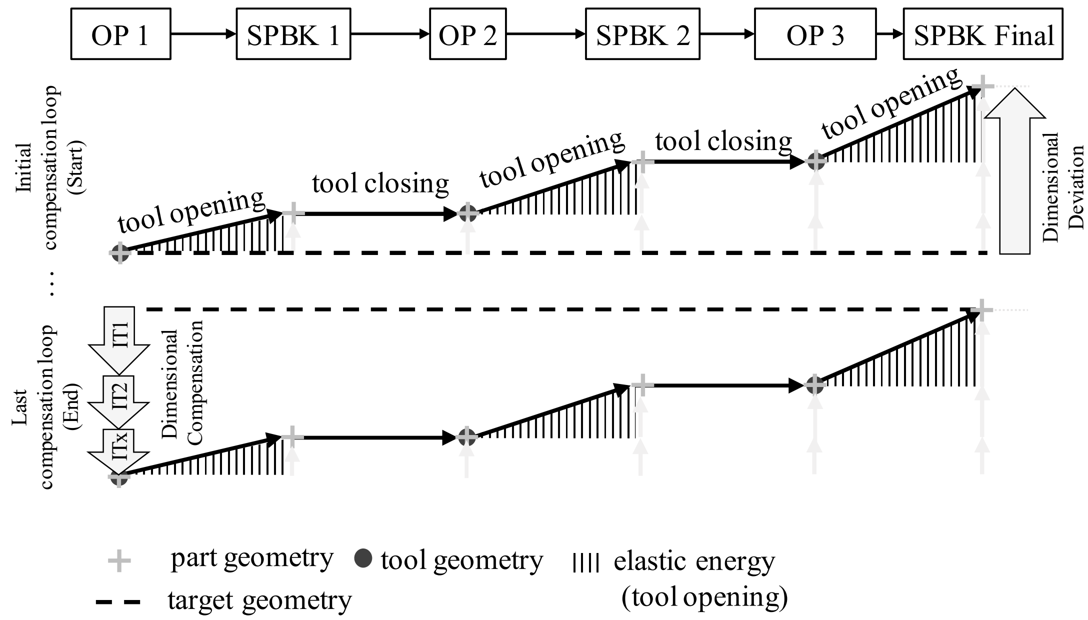

Figure 2. Qualitative representation of the dimensional deviations when applying the *Improved Springback Compensation Strategy*

4. New advanced springback compensation strategy

The *Advanced Springback Compensation Strategy* (*Advanced Strategy*) differs from the *Improved Springback Compensation Strategy* insofar as it does not need an adaption of the forming tools to calculate the initial dimensional deviations (without any influence of elastic energy while closing the blankholders) caused by springback. As can be seen in Figure 3, the entire process chain will be split up. For each operation (OP) a separate forming simulation with a subsequent springback calculation step (SPBK) is being performed. Thereby the process in the first simulation (Simulation 1) is identical to an uncompensated process. After the forming simulation and subsequent springback calculation the part is in its first springback-state (P1) and the dimensional deviations (D1) to the target geometry can be measured.

In the second simulation (Simulation 2) a part is needed exhibiting all geometric characteristics resulting from OP 1 but without the dimensional deviations caused by springback (P1*). To achieve this, the part from Simulation 1 is taken *after* the forming operation but *before* opening the tools (i.e. before calculation of the springback), and in this state all stresses are deleted. The same geometry could be obtained by other methods, e.g. a CAD geometry of the part state could be meshed and mechanical parameters – for instance the sheet thickness – mapped on this mesh. The most important thing is to have the same geometry for the part and the receiving tool surface so that no stresses are induced into the part when closing the blankholders. After closing the blankholders and forming the part in OP 2, the subsequent springback (SPBK 2) and the resulting dimensional deviations (D2) to the target geometry can be calculated. It is important that this deviation is only caused by the desired forming in this operation, without any other (negative) influences.

The procedure in Simulation 3 is the same as in Simulation 2 but taking the part without any dimensional deviations after OP 2 (P2*). Subsequently, the corresponding springback (SPBK Final) and the resulting dimensional deviation (D3) are calculated. Now, all the isolated dimensional deviations have been calculated and can be used to compensate the forming tool surfaces.

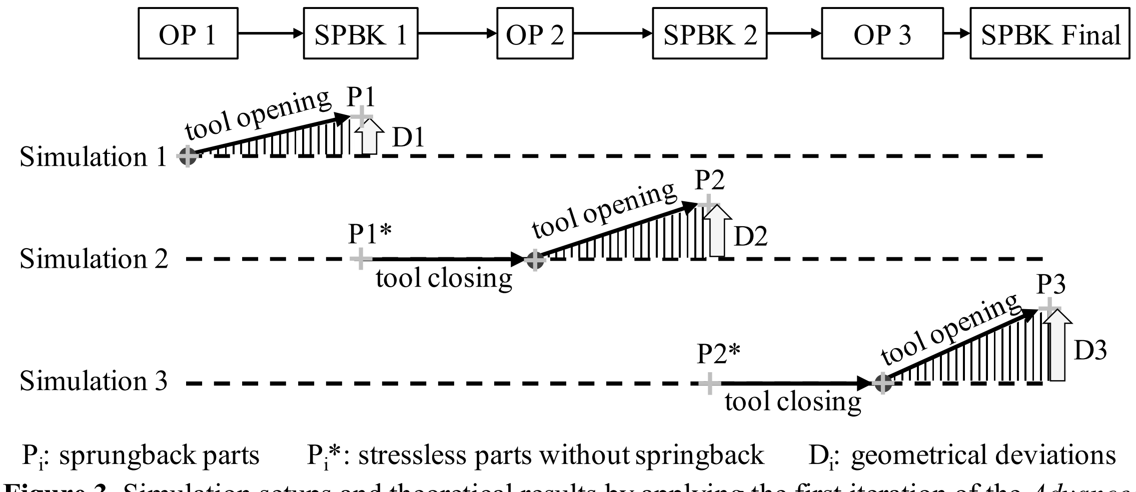

Figure 3. Simulation setups and theoretical results by applying the first iteration of the *Advanced Springback Compensation Strategy*

In order to achieve a comparable situation as with the *Improved Strategy* (Figure 2, bottom), the following steps have to be carried out. For the first operation (OP 1) all deviations (D1+D2+D3) have to be accumulated whereas for the second operation (OP 2) only D2 and D3 have to be used, as demonstrated in Figure 4. Finally, the last operation (OP 3) is compensated based only on the last deviation (D3). The general rule is, that for a distinct operation the deviations of the corresponding operation and those of all subsequent operations have to be accumulated to get the basis for the compensation.

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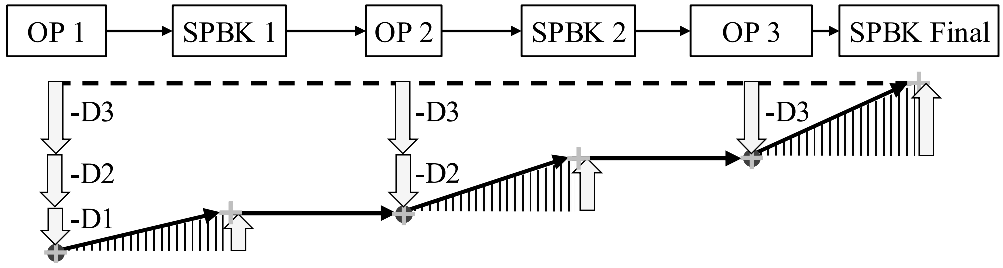

Figure 4. Theoretical situation after the first compensation loop by applying the *Advanced Springback Compensation Strategy* (if springback is not affected by compensation)

Assuming that the amount of springback is not affected by the compensation, the part will now be in tolerance and the compensation process will be finished. Normally, however, the springback is affected when modifying the tool surfaces with the effect that the part will still be out of tolerance, as shown in Figure 5. On the one hand, there are dimensional deviations between the part and the target geometry at the end of the process chain (D3-1); on the other hand, the incoming part does not properly fit to the respective receiving tool surface geometry in the other operations (D1*-1, D2*-1) causing elastic energy in the part and thus further dimensional deviations after the last operation. Only in case that the dimensional deviations between the incoming part and the respective tool geometries (D1*-1, D2*-1) are negligible, the resulting dimensional deviations between the part and the target geometry at the end of the process chain (D3-1) can be used to compensate the tools again. In case that the deviations are not negligible, the tools have to be adapted to the respective incoming part with the consequence that the advantage in computational effort with respect to the *Improved Strategy* is lost.

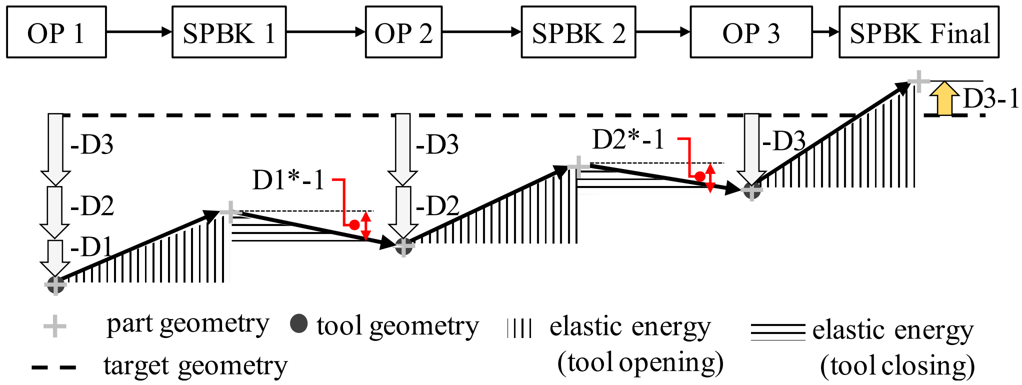

Figure 5. Theoretical situation after the first compensation loop by applying the *Advanced Springback Compensation Strategy* (if springback is affected by compensation)

In the second compensation loop the deviations (D3-1) are used to compensate all tools by the same amount (-D3-1), as displayed in Figure 6. Thus, the deviations at the end of the process are being reduced while the part position in the distinct operations stays more or less the same (D1*-1≈D1*-2, D2*-1≈D2*-2). This process is being repeated until the part is in tolerance.

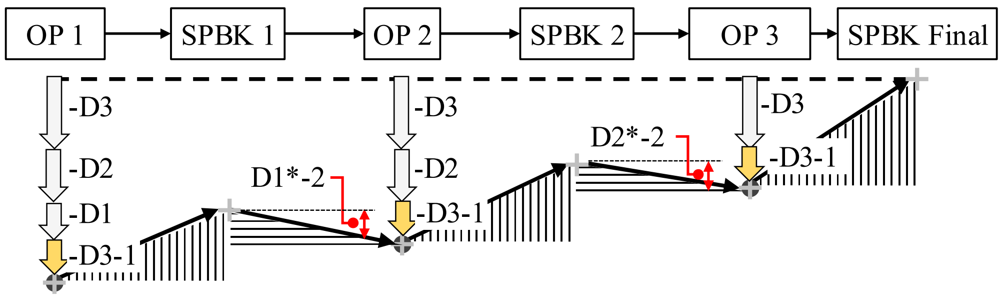

Figure 6. Theoretical situation after the second compensation loop by applying the *Advanced Springback Compensation Strategy* (dimensional deviations after OP 3 in tolerance)

5. Results of the new *Advanced Strategy* and comparison with those of the older *Improved Strategy*

In this chapter the results of the *Improved Springback Compensation Strategy* and those of the *Advanced Springback Compensation Strategy* are compared to each other. The present studies have been carried out using the example of an aluminium fender (modified *AC120*) (Figure 7). The manufacturing process starts with a drawing operation (*D20*); then the part is being separated from the addendum by a virtual laser cut (*T30*); finally, different flange areas are formed in two flanging operations (*F40*, *F50*). The production process of the fender has been simulated with the FE-Software *AutoForm R8*. To compensate the tool geometries, the *Physical Compensation Method* [6] has been used.

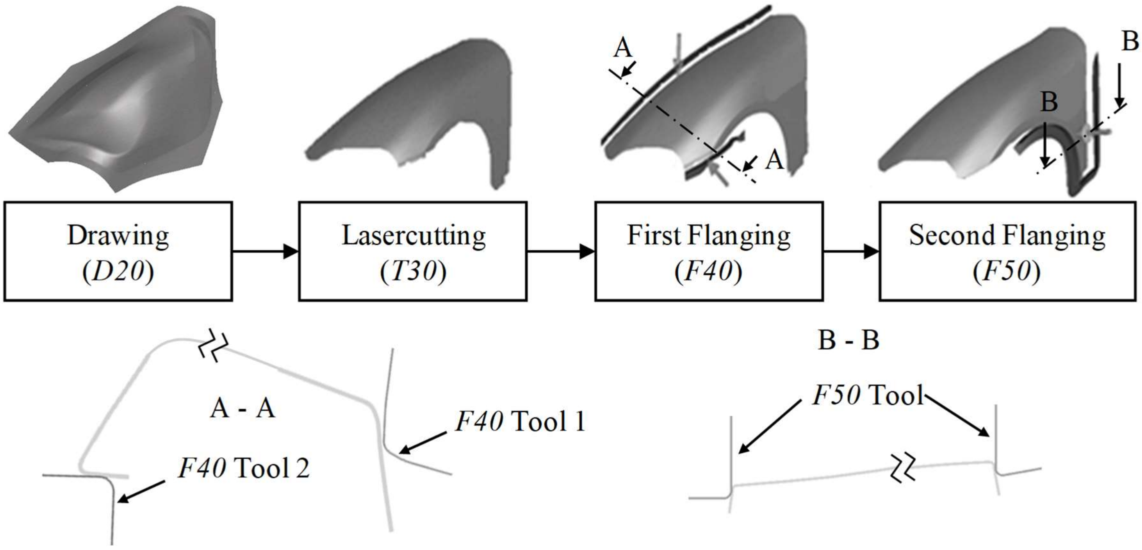

Figure 7. Manufacturing process of the aluminium fender

At first the part position in the first flanging operation (*F40*) is considered, see Figure 8. The distance between the incoming part and the receiving die surface is evaluated after three compensation loops and is split up into three distance classes, marked with different colours. When the *Improved Strategy* is applied, this distance is lower than 0.5 mm nearly on the whole surface; only two small areas exhibit higher distances but still below 1.0 mm. The maximum distance is 0.7 mm. If the *Advanced Strategy* is used, there are two larger areas with distances of more than 1.5 mm being again surrounded by areas with distances of more than 0.5 mm. The maximum distance amounts to 2.0 mm.

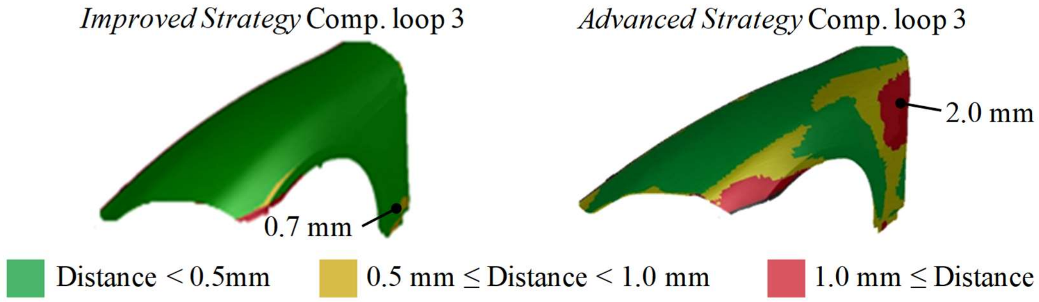

Figure 8. Part position in the first flanging operation (*F40*) after three compensation loops

In the second flanging operation (*F50*) the results are similar to those of the first flanging operation (*F40*), see Figure 9. With the *Improved Strategy* nearly the complete surface exhibits distances below 0.5 mm and a maximum distance of only 0.6 mm. By using the *Advanced Strategy,* more than 50% of the part has got distances larger than 0.5 mm with a maximum of 2.3 mm.

With the *Improved Strategy* the part position is nearly perfect; this being a result of the continuous adaption of the receiving tools to the respective incoming parts in every compensation loop. The

Advanced Strategy leads to higher distances between the part and the receiving tools, but not so much that it would necessarily cause a so-called instable part position. Thus it needs to be assessed, whether the additional time for the *Improved Strategy* is worth spending or whether the slightly worse part position caused by the *Advanced Strategy* is acceptable.

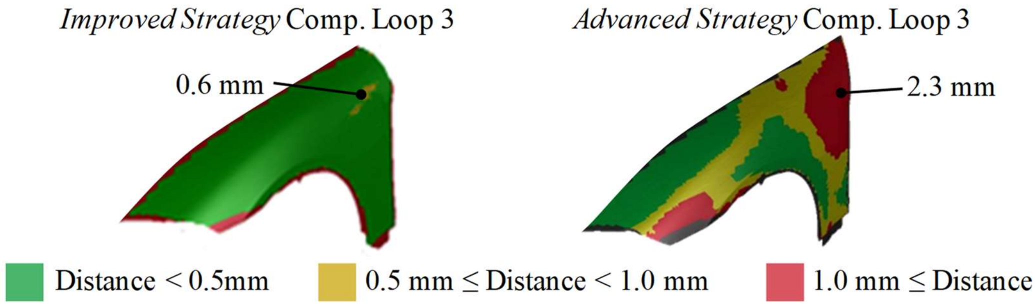

Figure 9. Part position in the second flanging operation (*F50*) after three compensation loops

In Figure 10 the average dimensional deviations are plotted for consecutive compensation loops and for both strategies. Due to the adaption of the flanging operations without compensating the springback, the average deviation with the *Improved Strategy* (A) is even higher than in the simulation without compensation (B). The areas that exceed a deviation of 1.0 mm increase from 34.1% to 51.3%. After the first compensation loop with the *Advanced Strategy* the average deviation is lower (0.44 mm) than with the *Improved Strategy* (0.53 mm). Through all following compensation loops this advantage remains preserved. Both strategies show a good convergence behaviour, which can be seen by the continuously decreasing average deviation from one compensation loop to the next. At the end, after three compensation loops, the *Advanced Strategy* benefits from its initial lower deviations so that 99.5% (!) of the part area show a dimensional deviation below 0.5 mm.

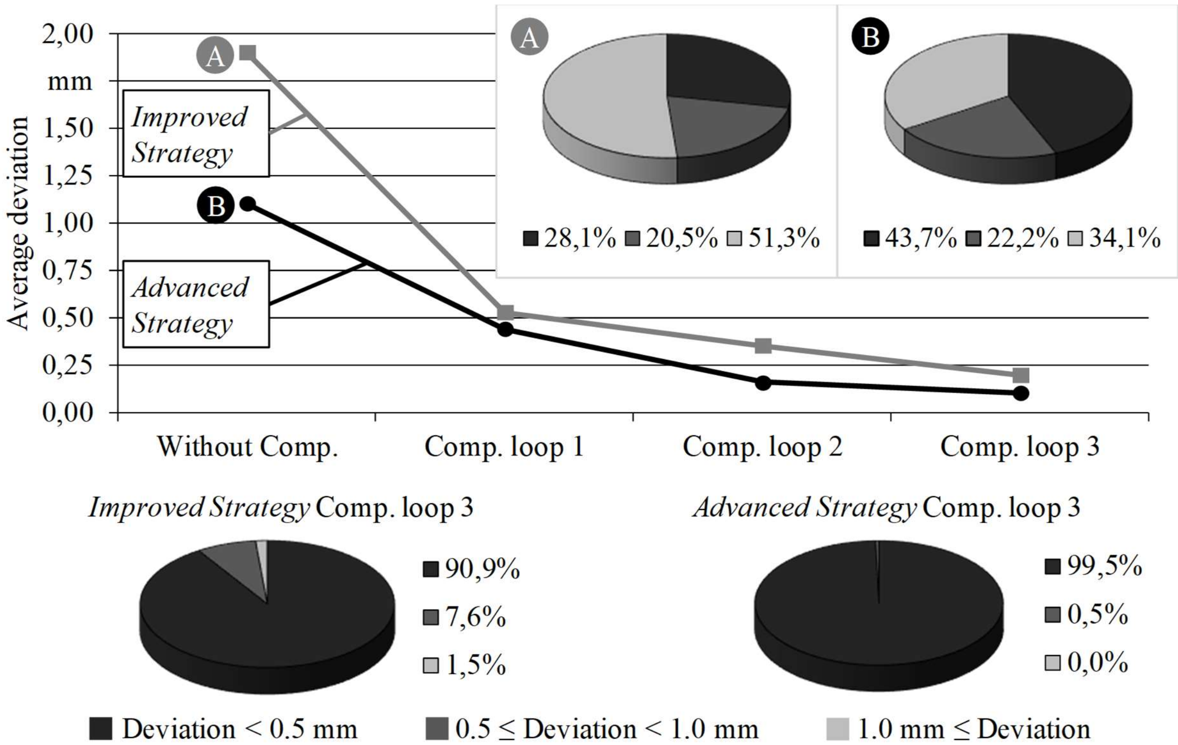

Figure 10. Dimensional deviations in the compensation process by using the two different strategies

6. Conclusion

A good springback compensation process is characterised by continuously decreasing dimensional deviations over several compensation loops until the part is within tolerance. Furthermore, it is very important that in every additional operation after drawing a proper part position is guaranteed. A proper part position means, that in the respective die the incoming part lies in a stable and reproducible position and that any deformations by the blankholders are reduced to a minimum. This can be achieved by minimizing the distance between the incoming part and the receiving tool surface.

The so called *Improved Springback Compensation Strategy* [5] fulfils these requirements in a nearly perfect way. However, by applying this strategy, the time effort is huge, especially if the manufacturing process contains more than one additional operation after drawing.

In the present paper a compensation strategy has been described which can be conducted much faster. In a first step all the operations of a multistage manufacturing process and the subsequent springback calculations are simulated separately from each other. Here, it is essential that the respective incoming parts do perfectly fit to the tool surfaces of the receiving operations, which is achieved by eliminating the springback of the previous operation through deletion of the corresponding stresses. By doing this, only those deviations are used for compensation which are caused by the generic manufacturing process itself (drawing, trimming, flanging…) and not by any elastic energy resulting from elastic deformations when the blankholders are closed. Subsequently, for the compensation of any distinct operation the deviations of the corresponding operation and those of all subsequent operations have to be accumulated. If the dimensions are still out of tolerance after the first loop, a second compensation loop has to be performed. In this loop all tools are compensated with the (same) final deviation obtained after the first loop. This process is being repeated until the part is in tolerance.

Based on the example of an aluminium fender, the *Advanced Strategy* has been tested and the results have been compared to those of the *Improved Strategy.* The part position in the flanging operations is slightly worse when using the new *Advanced Strategy* but with a maximum distance of 2.3 mm between the part and the receiving tool surface this is valued as still acceptable. With regard to the dimensional accuracy the *Advanced Strategy* delivers better results than the *Improved Strategy*. After three compensation loops the average dimensional deviation has been reduced to 0.1 mm (*Improved Strategy*: 0.2 mm) and 99.5% of the part surface shows dimensional deviations below 0.5 mm. This advantage results from the lower initial deviations. The main benefit of the new *Advanced Strategy* is the significantly lower time effort which, in the present study, amounts to less than 50% of the *Improved Strategy*.

In future work, the described strategy will be tested on different body components, particularly on structural components of high-strength steel. Here, the impact of a slightly worse part position in the tools in connection with a significantly higher part stiffness needs to be investigated.

References

[1] Gan W and Wagoner RH 2004 Die design method for sheet springback *International Journal of Mechanical Sciences* 46(7) 1097-113
[2] Karafillis A and Boyce M 1992 Tooling design in sheet metal forming using springback calculations *Int. J.Mach. Tools. Manuf.* 34113
[3] Roll K, Lemke T and Wiegand K 2004 Simulationsgestützte Kompensation der Rückfederung, LS-Dyna Anwenderforum, Bamberg
[4] Birkert A, Straub M and Haage S 2013 Umformtechnische Herstellung komplexer Karosserieteile, Springer-Verlag Berlin Heidelberg pp 304-307
[5] Birkert A, Hartmann B, Lepple F, Straub M and Zimmermann P 2019 Improved Spring-Back Compensation Strategy through Location Optimized Part Position in the Dies *IOP Conf. Ser.: Mater. Sci. Eng. 651 012036*
[6] Birkert A, Hartmann B, and Straub M 2017 New method for springback compensation for the stamping of sheet metal components *IOP Conf. Series: Journal of Physics: Conf. Series 896 012067*