

Guideline to optimize the convergence behaviour of the geometrical springback compensation

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Abstract. The need for car body structures of higher strength and at the same time lower weight results in serious challenges for the stamping process. To produce accurate parts at the end the stamping dies must be adjusted more or less by the amount of the springback in the opposite direction. Which stamping dies out of a multistage die set need to be adjusted, and how great the respective adjustment needs to be, is still quite often defined by practical experience and trial-and-error. Normally a certain number of compensation iterations based on the same compensation strategy must be realized and in addition to that, even the compensation strategy itself must be modified in some iterations in order to achieve accurate parts within tolerance. In contrast to the today still convenient trial-and-error optimization approach, a compensation guideline has been developed. Key content is the influence of the relevant compensation parameters, such as the measuring reference system (measurement system) including clamping of the parts (orientation of the springback part relative to the target part) and the amount of the compensation in the different stages (compensation factor and compensation strategy).

1. Introduction

Springback is the change of geometry, which occurs in stamped parts during the opening of the tools, due to the release of elastic energy. The respective parts are mostly out of dimensional tolerance, which causes quality problems and difficulties in the assembly process. To handle the springback the common approach is to modify the die face geometry of the stamping dies more or less by the amount of the springback in the opposite direction (=springback compensation). Assuming that the springback should remain the same after compensation the final product shape shall closely approximate that of the desired product. To enable this approach, the first step is to measure the deviations of the respective part. To do so, a measurement system, in which the springback with regard to the target geometry is being displayed, must be defined. Which measurement system should be used in order to modify the die face geometry of the stamping dies is discussed by Birkert in [1]. By the example of a *door outer panel* Birkert presents different measurement systems and suggests a measurement system, in which the respective deviations show a simple and homogenous characteristic. This approach enables a simple compensation on the basis of various compensation methods (manual CAD-modelling, *Displacement-Adjustment-method* [3], *Physical-Compensation-Method* [4] etc.). The second step to realize a geometrical springback compensation is to decide which die face geometry of the stamping dies out of a multistage die set needs to be adjusted. In [2] Roll *et al.* recommended to compensate the springback in the operation, in which the respective springback occurs. Just in case that this approach does not bring the desired result also different strategies should be applied. In [1] Birkert *et al.* described different compensation strategies

and their field of application. Still, which principles are decisive for the outcome of the deviations after the compensation depending on the chosen compensation strategy, and which requirements the compensation strategy has to fulfil, is still not sufficiently explored. In the last step it must be defined how large the respective modifications for the selected die faces need to be. The so-called *compensation factor* is defined as the ratio of the amount of compensation and the amount of the springback. In [5] *Gösling et al.* investigated the influence of the chosen compensation factor on the convergence behaviour of the springback compensation using the example of a *top hat profile*. The investigation showed that there is a dependency of the optimal compensation factor, which enables the best convergence behaviour, on the respective part area. In [4] *Lingbeek et al.* showed on the basis of a theoretical view of a stretch-bending forming process that the optimal compensation factor varies in dependency of the effective tensile stresses of the sheet. Still, the selection of the compensation factor for the compensation of complex body parts in practical application, is quite often defined by practical experience and trial-and error. In this paper the results of a practice-oriented, simulation based investigation of the described influencing variables of the geometrical compensation are being presented: namely the measurement system, the compensation strategy and the compensation factor. Objects of the investigation were an *A-pillar*, a *bulkhead*, a *longitudinal beam* and a *wheel housing*. The results are only presented for the *A-pillar* due to the lack of space, but are validated based on the results of the other parts also.

2. Influence of the definition of the measurement system

The first step for the development of the guideline was to investigate the influence of the definition of the measurement system. The investigated measurement systems have been chosen in that way, that the following influence factors could be investigated: influence of the static stability of the springback part within the chosen clamping concept, influence of the amount of the deviations of the springback part from the target geometry, influence of positioning of the used clamping points with regard to geometric leverage. Figure 1 shows four of the investigated measurement systems. *Measurement system 1* has been chosen in such a way that the deviations of the springback part to the target geometry are minimal (best fit system). *Measurement system 2* has been chosen in such a way that the static stability has been optimized versus *measurement system 1* (to the disadvantage of the maximum local deviation). *Measurement system 3* has been chosen in such a way that the maximum deviations are equal to *measurement system 1* but with a larger average deviation to the disadvantage of the static stability. Last but not least *measurement system 4* has been chosen in such a way that the maximum distance of any topological point of the part geometry to the next clamping point is minimal in order to minimize the influence of geometrical leverage on the dimensional deviations.

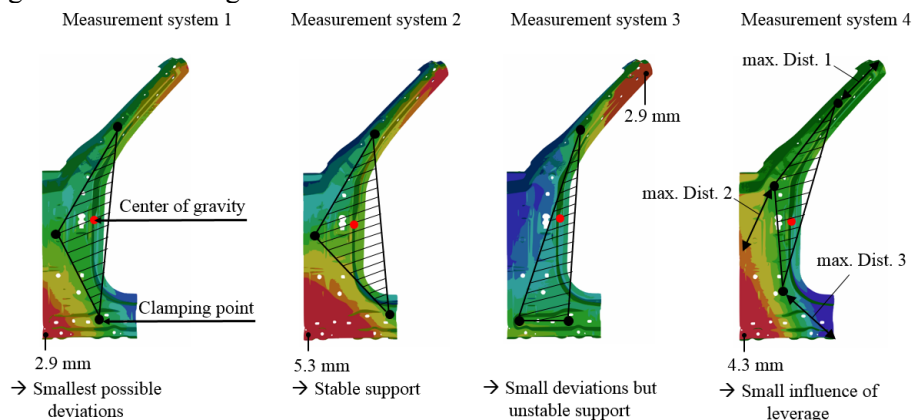


Figure 1: Investigated measurement systems of the *A-pillar*

Based on the four different measurement systems a geometrical springback compensation has been done in four compensation iterations each, based on the *Displacement-Adjustment-Method* [3] with a well-known software tool. Figure 2 shows the average deviations, dependent on the respective measurement

system and compensation iterations. Figure 2 and Figure 3 show that the best convergence rate and dimensional accuracy can be achieved when using measurement system 1, which allows the best compromise of the named influence factors.

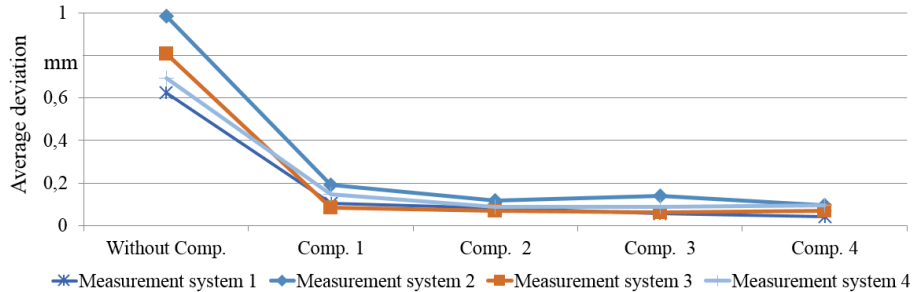


Figure 2: Convergence rate in dependency of the defined measurement system

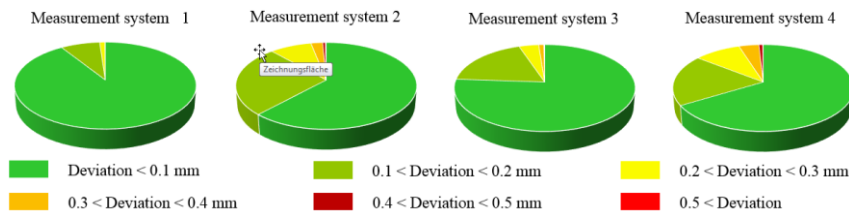


Figure 3: Evaluation of the deviations after the fourth compensation iteration

The highest dimensional precision and convergence rate can be achieved by a measurement system, which is based on a so-called best-fit positioning of the springback and target geometries. Thereby a minimal distance of the springback geometry to the target geometry is maintained. This orientation has to be maintained at distinct positions over the different compensation loops by defining clamping points. The position of the clamping points must be selected in such a way, that the clamping points are located in areas, in which the target and the springback geometry are identical. In addition to that the influence of any geometric leverage has to be reduced to a minimum for all part areas by realizing the most stable support. By doing so a high convergence rate can be achieved and it can be guaranteed that the springback itself is being compensated and not any effect which results from clamping.

3. Influence of the compensation factor

In the next step the influence of the compensation factor on the convergence behaviour of the geometrical springback compensation has been investigated. In order to do so, operation *OP20 – Drawing* and operation *OP50 – Forming* have been compensated by the amount of the springback after the last operation. First of all a constant compensation factor of 1.0 has been used. Figure 4 shows the belonging average deviations of the springback geometry to the target geometry, dependent on the compensation iteration (*blue curve*). Figure 4 shows that after the second compensation iteration no further improvement of the dimensional accuracy can be achieved. As a result of that after the fourth compensation loop there are still deviations beyond the given tolerance of ± 0.5 mm, Figure 5 *left*. In the second step the four compensation iterations have been realized using a compensation factor of 0.75. The evaluation of the average deviations after the individual compensation iterations shows that after the first two compensations loops the remaining deviations are large than using a compensation factor of 1.0 (Figure 5 *orange curve*). This result seems likely, using a disproportionate compensation factor. What is remarkable here, is that the deviations after the third and fourth compensation iteration are lower than when using a compensation factor of 1.0. By doing so a reduction of the dimensional deviations appears after all compensation iterations. In conclusion after the fourth compensation iteration there are no deviations beyond the given tolerance of ± 0.5 mm, Figure 5 *middle*. The conclusion is that for small deviations a disproportionate compensation factor seems to be the better choice for geometrical compensation of complex body parts. It is important to note that the result can be confirmed by the

investigation of the other parts also. Last but not least different compensation factors have been used in dependency on the compensation iterations to combine the named advantages of a proportional and disproportional compensation factor. Hereby, in the first two compensation iterations a compensation factor of 1.0 was used. The third and fourth compensation loop have been realized using a compensation factor of 0.75. The result is shown in Figure 4 (*green curve*). The change of the compensation factor in dependency on the compensation iteration or rather the given deviations enables the best convergence rate for the geometrical compensation. In conclusion the investigation showed a clear dependency of the optimal compensation factor on the amount of the dimensional deviations. This means that an adjustment of the compensation factor between the various compensation iterations is necessary in order to achieve the best convergence behaviour. In case of large dimensional deviations (larger than 2.0 mm) a compensation factor of even 1.2 should be used (usually for the first compensation iteration). For medium size dimensional deviations (1.0 mm – 2.0 mm) a compensation factor of 1.0 should be used. For small dimensional deviations (0.5 mm – 1.0 mm) a compensation factor of 0.75 should be used. And for very small deviations (smaller than 0.5 mm) a compensation factor of 0.5 should be used.

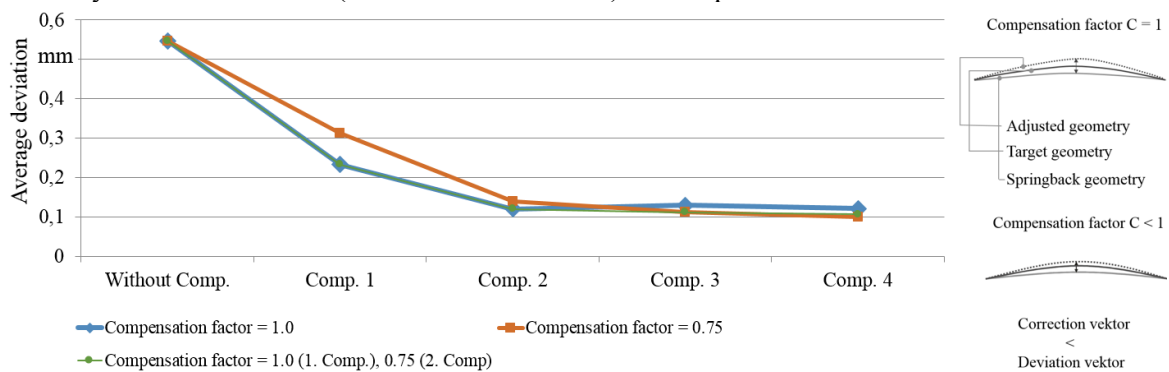


Figure 4: Influence of the compensation factor on the convergence behaviour (Figure right [1])

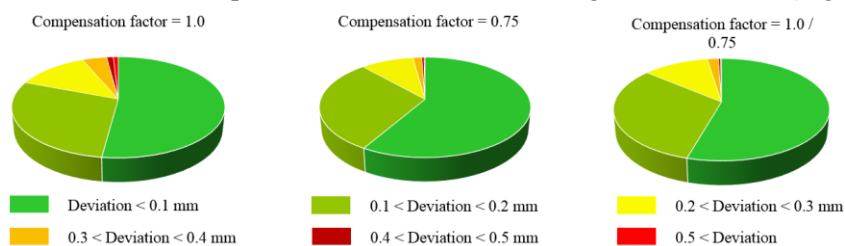


Figure 5: Evaluation of the deviations after the fourth compensation loop

4. Influence of the compensation strategy

Finally the influence of the compensation strategy has been investigated. The investigation showed that it is from key importance for the efficiency of any compensation strategy that the incoming part can be placed in such a way in the respective follow-up stage that any unintended deformation is being avoided. By doing so the convergence behaviour of the geometrical springback compensation can be improved significantly. Figure 6 shows the average deviation of the investigated *A-pillar*, dependent on the compensation iteration. For the investigation operation *OP20 – Drawing* and operation *OP50 – Forming* have been compensated by the amount of springback after the last operation with a compensation factor of 1.0. The *blue curve* represents the average deviations without any actions in order to avoid any unintended deformation; this means the simulation model has been built based on the basic tool geometries. The *green curve* represents the average deviations for a simulation with distinct actions in order to avoid any unintended deformation in *OP50*. To achieve this, the negative radii of the tool geometries in the follow-up operations have been enlarged. Figure 6 shows that the convergence behaviour is improved significantly when any unintended deformations are avoided. In consequence after four compensation iterations there are no deviations out of tolerance. Otherwise there are still deviations larger than 0.5 mm. The improved convergence behaviour of the compensation is founded in

the fact that by the enlarged negative radii in the follow-up operations any unintended deformation is avoided. The change of the unintended deformation from one compensation iteration to another is caused by a changing support of the part in the follow-up operations due to the adjustment of the tool geometries. If the influence of the unintended deformations is not considered, the springback after each compensation iteration can be affected considerably. Thus, the basic requirement for a successful geometrical springback compensation is not be fulfilled, namely that the springback remains the same from one compensation loop to another. In summary this means that any unintended deformations in follow-up operations must be avoided at all costs to achieve a high convergence behaviour and dimensional accurate parts after compensation.

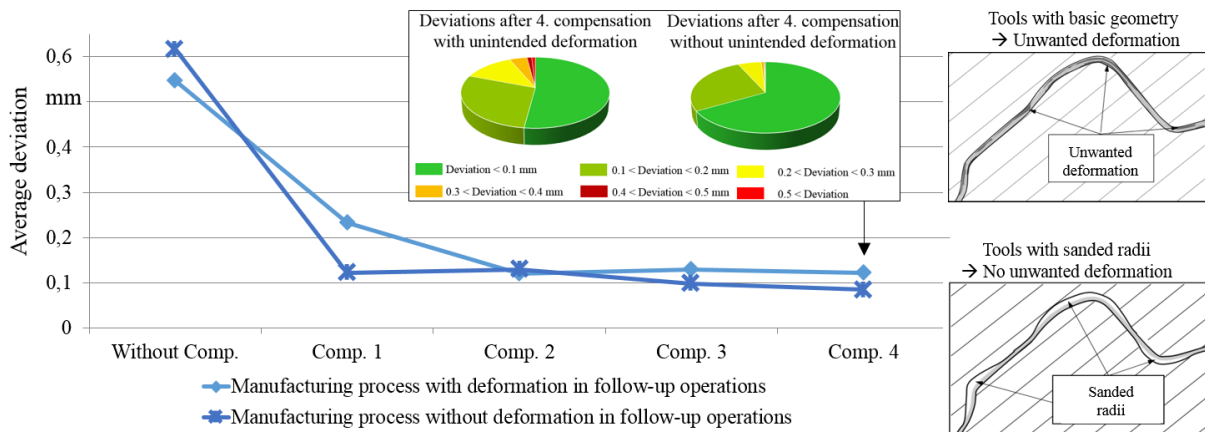


Figure 6: Influence of unintended deformation in follow-up operations on the convergence behaviour

As we have already seen, a change of the amount of unintended deformation from one compensation iteration to another can have a large influence on the convergence behaviour of the geometrical springback compensation. This is also one reason why a certain compensation strategy is efficient for the compensation of a specific part and another is not. In Figure 7 the convergence behaviour of two different compensation strategies are compared. The *blue curve* represents the average deviations for the compensation of operation *OP20 – Drawing* and *OP50 – Forming* and the *yellow curve* represents the average deviations for the compensation of each operation by the amount of springback after the last operation. It is shown that the compensation strategy, which intends a modification of the tools of all operations, shows a significantly better convergence behaviour than just the compensation of *OP20* and *OP50*. The reason for that is that if just *OP20 – Drawing* and *OP50 – Forming* are compensated the location of the part in the follow-up operations differs significantly from the process with not compensated tool geometries, Figure 7.

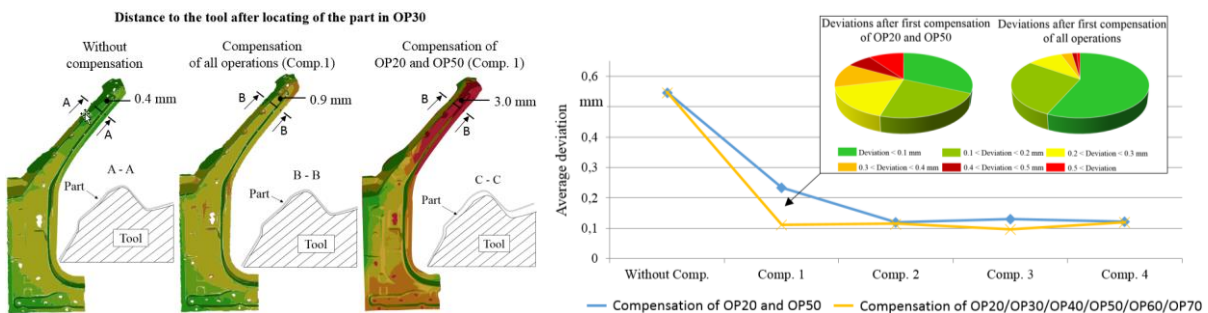


Figure 7: Comparison of different compensation strategies on the convergence behaviour

In consequence the influence of unintended deformation changes significantly and therefore also the springback, if just *OP20 – Drawing* and *OP50 – Forming* are compensated. In contrast, if all tools are compensated, the support of the part in the follow-up operation shows just a small difference from the

support of the part in the follow-up operations without compensated tool geometries. In consequence the neither any unintended deformations nor the springback change noticeably. Thus, the basic requirement for a successful geometrical springback compensation is just been fulfilled when all operations are compensated, so that the springback remains the same from one compensation loop to another.

5. Conclusion

The need for car body structures of higher strength and at the same time lower weight results in serious challenges for the stamping process. To produce accurate parts at the end, the stamping dies must be adjusted more or less by the amount of the springback in the opposite direction. Which stamping dies out of a multistage die set need to be adjusted, and how great the respective adjustment needs to be, is still quite often defined by practical experience and trial-and-error. In contrast to the today still convenient trial-and-error optimization approach, a guideline to optimize the convergence behaviour of the geometrical springback compensation has been developed.

In the first step the influence of the definition of the measurement system has been investigated. The results showed that the highest dimensional precision can be achieved by a so-called best-fit positioning of the namely geometries. This orientation has to be maintained at distinct positions over the different compensation iterations by defining clamping points in order to achieve the best convergence rate. The position of the clamping points must be selected in such a way, that the clamping points are located in areas in which the target and the springback geometry are identical and in such a way that the influence of any geometric leverage is being reduced to a minimum for all part areas.

In the next step the influence of the compensation factor has been investigated. The investigation showed a clear dependency of the appropriate compensation factor on the amount of the dimensional deviations. In case of large dimensional deviations (larger than 2.0 mm) a compensation factor of even 1.2 should be used (usually for the first compensation iteration). For medium size dimensional deviations (1.0 mm - 2.0 mm) a compensation factor of 1.0 should be used. For small dimensional deviations (0.5 mm - 1.0 mm) a compensation factor of 0.75 should be used. And for very small deviations (smaller than 0.5 mm) a compensation factor of 0.5 should be used.

Finally the compensation strategy has been investigated. The results showed that a key requirement for any compensation strategy is that any unintended deformations in follow-up operations are avoided to achieve a high convergence behaviour and dimensional accurate parts after compensation. This can be achieved by enlarging the negative radii tool geometries in the follow-up operations. In addition to that the tools of the follow-up operations should be compensated in such a way, that no significant change of the location of the part in the respective operation does occur.

The validation of the new guideline with its single procedures has been done by applying it on four practical body parts. Compared to other compensation approaches several compensation iterations could be avoided at each of the four parts. Insofar it seems that an important contribution for the future adjustment of stamping tools has been made with regard to the production of design con-form first-off-tool stampings.

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