Improved Spring-Back Compensation Strategy through Location Optimized Part Position in the Dies

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Abstract. Further increasing requirements to the quality of car body components represent a huge challenge for the process planner. As the elastic energy is changing in each stamping operation, it is quite challenging to decide how to compensate which stamping operation. The belonging process definition is known as the compensation strategy. A key prerequisite of an appropriate compensation strategy is a proper location of the part in all stamping operations along the process chain. Proper means that the distance of the part to the die must be minimal to prevent any undefined shift of the part in the die and thus unwanted deformations when closing the dies. Both shifting and deformations would cause dimensional deviations and surface defects. Today different strategies are applied to meet these requirements at least approximately. Strategies, which are published in different papers yet, can only provide suboptimal results. Here a new compensation strategy is being presented, which fulfils the requirement to a proper part location not only in the trimming dies, which corresponds to the so-called Drawshell Strategy, but also in the restriking dies. An important advantage of the respective strategy is that it generally can be applied on all multistage car body stamping operations.

1. Introduction

Springback is the change of geometry which occurs in stamped parts during the opening of the dies; it is caused by the release of elastic energy. The results are deviations of the part from the target geometry. The respective parts are mostly out of dimensional tolerance, which causes quality problems and difficulties in the assembly process. To handle springback the common approach is to modify the die geometries of the stamping dies more or less by the amount of springback in the opposite direction. This doing is called geometrical springback compensation.

The procedure for geometrical springback compensation is to define a so-called compensation strategy and to compensate the chosen tools based on a compensation method. The compensation strategy defines which concrete operation out of a multistage tool set needs to be modified by what amount. The compensation method means a straightforward procedure to develop the compensated tool geometry based on the available deviations of the part.

Regarding to the compensation method a lot of research has been conducted in the past. Two well-known compensation methods are the Displacement Adjustment Method developed by Gan and Wagoner [1] and the Force Descriptor Method developed by Karafillis and Boyce [2]. The definition of a proper compensation strategy is at least as important as that of a proper compensation method but has not drawn the attention of researchers for an adequate degree yet. The definition of the compensation...
strategy for the compensation of complex body parts is quite often done based on practical experience and trial- and error loops. The problem of today known and used compensations strategies is that they cannot ensure a proper location of the part in all stamping dies along the process chain, what can cause dimensional deviations and surface defects.

At the end of the compensation process the modified dies of course should supply a part within required tolerances. In addition to that the part location in each stamping die must be stable in order to obtain a robust stamping process [3]. In this paper a New Improved Strategy is being presented to improve the dimensional tolerances and to guarantee a stable and repeatable position of the part in the respective subsequent die after the compensation of a certain die.

2. Review of some compensation strategies

In [4] Roll et al. recommend to compensate springback (SPBK) in the one operation (OP), in which the respective springback occurs. Just in case that this approach does not bring the desired result also previous or following operations shall be modified. The proceeding of Roll is shown in Figure 1.

![Figure 1. Compensation Strategy of Roll [4]](image1)

In [5] Birkert et al. describe different compensation strategies and their field of application. Figure 2 shows one possible option to compensate springback. In this case the deviations at the end of the process chain are used to compensate the drawing operation only. All other operations are not compensated.

![Figure 2. Compensation Strategy 1 - Compensation of the drawing operation with the springback after the last operation [5]](image2)

Another strategy which is described in [5] is shown in Figure 3. By using this strategy the deviations at the end of the process chain are used to compensate all operations.

![Figure 3. Compensation Strategy 2 - Compensation of all operations with the springback of the last operation [5]](image3)

In [6] Birkert et al. stated that the location of the part in the die can have a big impact on the dimensional accuracy. Insofar the part location in the die must be considered when defining the
compensation strategy. In Figure 4 it is shown that a proper part location in the die can help to improve the dimensional part accuracy – sometimes even significantly.

**Figure 4.** Influence of the compensation strategy on the part location and dimensional accuracy [6]

Till today the impact of the chosen compensation strategy and the belonging fundamental relationships are not sufficiently explored, so that no reliable and universal compensation guideline is available.

3. **Deficits of today’s compensation strategies**

The present studies have been carried out on the example of an aluminium (modified AC120) fender (Figure 5). The springback analysis process starts with a drawing operation (D20). Then the part is being separated from the addendum by a laser cut (T30). Finally different flange areas are formed in two restricking operations (F40, F50).

**Figure 5.** Manufacturing process chain of the fender

Figure 6 shows the development of the deviations of the part without compensation of the tools along the entire process chain at an imaginary point on the part in a schematic way. By doing so, it is possible to visualize the deviations of the part and the location of the part in the subsequent dies in one single
The dashed line represents the target geometry of the part (zero geometry) and the non-compensated tool geometries (zero tools). Because Figure 6 represents the part behaviour in a non-compensated process the tool geometries (dark grey circles) lie on the dashed line. As long as the tools are closed the part geometry (light grey crosses) lies on the dashed line also (D20, T30, F40, F50). After the opening of the tools the part changes its geometry because of the release of elastic energy (M35, M45, M55). The elastic energy is represented by the vertically hatched triangles in Figure 6. Because of the springback of the part, the part geometry deviates from the tool geometry in the respective subsequent operation (light grey cross in M35 – dark grey circle in F40, light grey cross in M45 – dark grey circle in F50). The deviation between the part and the tool geometry again causes elastic energy in the part during the closing of the tools in the respective subsequent operation (horizontally hatched triangle). At the end of the process chain the elastic energy results in a simulated deviation between the part and the target geometry (thick grey arrow). According to the current state of technology the presented process with zero tools (basic simulation) represents the basis for the subsequent springback compensation.

![Diagram](image)

**Figure 6.** Development of the deviations of the part without compensation of the tools along the entire process chain at an imaginary point on the part

The schematic development of deviations will now be shown for the two existent compensation strategies, which were presented in chapter 2. Following Strategy 1 (Figure 7) the deviations at the end of the process chain of the basic simulation with zero tools are used to compensate the drawing operation only. Under the assumption that the restriking operations in the basic simulation have an influence on the deviations, it is most unlikely that the arriving part will fit sufficiently well to the receiving die surfaces of the first restriking operation. So by closing the blankholder an elastic energy will be induced in the part which is different from that in the basic simulation. In this case it is also unlikely that the part will fit to the receiving die surfaces of the second restriking tool and finally that the dimensions will be in tolerance at the end of the process chain.

![Diagram](image)

**Figure 7.** Development of the deviations of the part with compensation of the tools based on compensation Strategy 1 along the entire process chain at an imaginary point on the part

For the second compensation strategy (Figure 8) the same deviations are used as in the first one. In contrast to the first strategy here all operations are being compensated. This results in the same course of deviations as in the basic simulation, but with an offset by the amount of the deviations in the opposite direction. As a result of that it is possible to virtually produce a part which is within required dimensional tolerances. However the part location in the tools is still suboptimal as in the basic simulation, which can be derived from the existence of the horizontally hatched triangles.
4. New improved springback compensation strategy

The New Improved Strategy differs from the previous ones insofar that it does not use the deviations from the basic simulation to compensate the dies. In this procedure the process initially consists only of the drawing operation (D20), the laser cutting operation (T30) and the subsequent springback calculation (M35) (Figure 9). Now the calculated springback is used to match the first restriking operation to the arriving part. If this adaption is applied on the trimming operations it is known as Drawshell-Compensation. Now the springback (M45) after the first restriking operation (F40) is being calculated. In the next step the second restriking operation (F50) is also being adapted to the arriving part. Finally the springback (M55) after the second restriking operation (F50) is being calculated. In contrast to the other strategies this result does not underlie the influence of any induced elastic energies when closing the blank holders.

The deviations at the end of this modified process are now used to compensate all operations (Figure 10). In case that the trimming operations are done in trim dies and not by laser, as assumed here, then also the trimming operations are adapted to the arriving part – which is not new at all. This results in a similar situation as in the basic simulation. The difference is that the dies no longer correspond to the target geometry.

With the compensated dies the process will be repeated as in the previous loop. The dies of the restriking operations will be adapted to the respective arriving parts as before. At the end of the compensation process the dimensions should be within tolerance. The key advantage of this strategy is that an optimal part location is being achieved in each operation.
5. Comparison of the results of the new strategy with those of existent strategies

In this chapter the results of the two known strategies and those of the new improved one are compared to each other. The production process of the fender was simulated with the FE-Software Autoform R7. To compensate the die geometries the Physical Compensation Method [7] has been used.

At first the part location in the first restriking operation is considered (Figure 12). The evaluation is done by visualizing the distance between the arriving part and the receiving tool after three compensation loops. By using Strategy 1 nearly the complete part surface has a distance higher than 1.0 mm to the receiving die surface. If Strategy 2 is used there is a better part location, but still larger part areas deviate by more than 1 mm from the die surface. The best part location is clearly achieved with the New Improved Strategy. Nearly the complete surface is below 0.5 mm distance to the receiving die, which can be seen as nearly perfect. The rest of it is significantly below 1.0 mm, which is still very good.

In the second restriking operation the results are similar to those of the first restriking operation. Only two small areas have a distance below 0.5 mm to the die surface if Strategy 1 is used. By using Strategy 2 the part location is slightly better, but still more than half of the surface has got a distance with more than 1.0 mm to the die surface. With the New Improved Strategy nearly the complete surface has got a distance below 0.5 mm.
In Figure 14 the geometric deviations after the compensation process of all strategies are shown. As expected in the first loop the average deviation obtained from the New Improved Strategy is higher as in the simulation without compensation (a, b). This is a result of the optimized part location. The proportion of areas that exceed a deviation of 0.5 mm increases from 47% to 72%. After three compensation loops however the average deviation obtained to the New Improved Strategy could be reduced to 0.2 mm (!). The average deviations which have been achieved with the two other strategies are significantly higher with 0.56 mm respectively 0.33 mm. Furthermore the lowest proportion of deviations higher than 0.5 mm has been achieved with the new approach.

**Figure 14.** Dimensional deviations by using the different strategies

In addition to the mentioned advantages there is also a better convergence behaviour when using the New Strategy. This is shown by the continuously decreasing average deviation from one compensation loop to the next.

6. Conclusion

Only such springback-compensation strategies which guarantee a proper part location in all stamping operations can meet the increasing dimensional and surface requirements to complex sheet metal car body components. In this context a proper part location in the die means that the in the respective die arriving part lies in a stable and repeatable position on the receiving die surfaces of the respective stamping operation. This requirement is equivalent to that, that the part shall not be elastically deformed by the blankholder when closing the die. In other words the distance between the arriving part and the receiving die surfaces must be reduced to a minimum.

Here a compensation strategy has been described, which meets these requirements in a nearly perfect way. In contradiction to currently known strategies in a first step the focus is not lie on the dimensional accuracy of the part at all but only on the location of the part in the respective subsequent stamping operation – no matter of any potentially negative influence on the amount of the resulting elastic
springback. In some cases the springback might even be larger than before the modification of the die surfaces in the first loop. Only in the second loop the resulting springback after the last operation is being used to compensate the drawing operation at first. The compensated die geometry of the subsequent restriking operation after drawing is being achieved simply by applying a so-called Drawshell Compensation approach based on the geometry of the arriving part. Drawshell Compensation is known for many years with regard to trimming dies and means that the receiving die is being fitted more or less to the arriving part. New is the consequent application of this approach also on forming dies, which is only possible by applying the here described strategy.

Because of non-linear springback behaviour – the compensation itself will have an impact on the springback of the part – the new compensation strategy is not being expected to deliver parts within the required tolerances after the first compensation loop. Taking this into account an acceptable result will normally be achieved after some iterations. Due to the fact that any disturbance in form of arising elastic energy when closing the blankholder can be prevented the dimensional convergence behaviour of this strategy is significantly better than in any other currently known compensation strategy. On the example of an aluminium fender the maximum contact distance of the part to the receiving die surface amounted to 0.6 mm in the first and 0.7 mm in the second restriking operation. On the other hand by applying currently known compensation strategies the distance amounted to more than 20 mm (!) in the first and 18 mm (!) in the second restriking operation with Strategy 1 and 5.9 mm in the first and 3.4 mm in second operation when applying Strategy 2. With regard to dimensional accuracy the average deviation from zero could be reduced from 0.56 mm (Strategy 1) or 0.33 mm (Strategy 2) to 0.2 mm (!) with the New Compensation Strategy which corresponds to a dimensional improvement of 64% respectively 39%! Taking the maximal dimensional deviations into account, these could be reduced from 2.7 mm (Strategy 1) or 1.4 mm (Strategy 2) to 1.3 mm with the New Strategy. In addition to that by using the new approach a continuous dimensional convergence behaviour could be obtained whereas by using traditional strategies after two or three loops any further improvement could not be achieved.

Finally, a compensation strategy has been developed which meets the requirements with regard to dimensional accuracy and proper part location in a nearly perfect way. The described strategy will be tested on different body components in the future to confirm the benefits of the New Improved Strategy for other parts also. In addition to that the influence of the New Improved Strategy on the process robustness will 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] Birkert A Hartmann B Scholle M and Straub M 2018 Optimization of the process robustness of the stamping of complex body parts with regard to dimensional accuracy IOP Conf. Series: Mater. Sci. Eng. 418 012107
[4] Roll K Lemke T and Wiegand K 2004 Simulationsgestützte Kompensation der Rückfederung, LS-Dyna Anwenderforum, Bamberg
[5] Birkert A Straub M and Haage S 2013 Umformtechnische Herstellung komplexer Karosserieteile, Springer-Verlag Berlin Heidelberg pp 304-307
[6] Birkert A Hartmann B Nowack M Scholle M and Straub M 2018 Guideline to optimize the convergence behaviour of the geometrical springback compensation IOP Conf. Series: Journal of Physics: Conf. Series 1063 012128
[7] 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