Springback compensation of symmetrical and quasi-symmetrical sheet metal car body parts

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Abstract. Springback compensation for symmetrical and quasi-symmetrical sheet metal parts presents specific challenges. The common approach involves modifying forming tools in the opposite direction of the springback to achieve dimensional accuracy. However, asymmetrical springback effects, such as twisting, can occur even in symmetrical parts. These effects should not be compensated, as they are typically unstable, whether numerical or physical. Numerical distortions can be avoided using symmetry boundary conditions in simulations, but this is not always advisable for quasi-symmetrical parts or symmetrical parts with low stiffness. In quasi-symmetrical cases, it is often unclear whether asymmetry arises from numerical artefacts or slight geometric differences. For theoretically symmetrical parts, ensuring symmetrical behaviour in reality is crucial before applying compensation. This paper analyses springback behaviour in symmetrical and quasi-symmetrical parts and presents a guideline for handling such cases. Quantitative criteria for applying asymmetric compensation are proposed. Additionally, methods are introduced to systematically induce asymmetrical springback to enhance stability.

Keywords: springback compensation; symmetrical parts; dimensional accuracy; unstable springback

1 Introduction

For springback compensation, the tool surfaces are adjusted in the opposite direction of the springback. The goal is to ensure that the components conform to the desired target geometry within the specified dimensional tolerances after springback. The compensation is carried out virtually based on the simulated manufacturing process. Extensive research has been conducted on virtual tool compensation, leading to the development of various methods [1-4].

However, before tool surface compensation can be performed, it must be ensured that the springback behaviour is stable. This means that the springback characteristics remain consistent even with fluctuating process parameters, and the springback values ideally vary only within the specified dimensional tolerances. Several methods have been developed to stabilize springback, including increasing the stretching or geometrically stiffening the component [5, 6].

A particular challenge in springback compensation arises with symmetrical or quasi-symmetrical components (symmetrical components with small asymmetrical features such as embossments or holes). For these parts, it is advisable to design the manufacturing process symmetrically as well. If both the part geometry and the forming process are symmetrical, the simulated springback must also be symmetrical.

However, asymmetric springback behaviour has been observed in some symmetrical components. In simulation, this can only be attributed to unintended numerical effects — such as mesh refinement or rounding errors. In reality, however, unavoidable asymmetries such as incorrect blank positioning, ram tilting, or tool wear can lead to asymmetric springback. Since this springback behaviour is unstable in both simulation and reality, springback compensation is not feasible.

The aim of this study is to stabilize the springback behaviour of parts exhibiting this issue through various measures. Furthermore, the study addresses the handling of quasi-symmetrical parts, where it is not immediately clear whether the asymmetry is caused by the geometry or results from numerical effects.

An unstable asymmetric springback behaviour was observed in components that have low structural stiffness and exhibit little to no plastic strain in certain regions. This applies, for example, to battery covers, which functionally require large flat surface areas.

With the ongoing transformation of the automotive industry towards electromobility, ensuring dimensionally accurate battery covers — including the described challenges — is becoming increasingly important.

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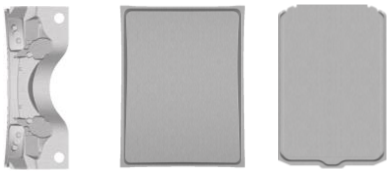
2 Methods and procedures

The forming and springback of the parts discussed here were simulated using the FE software *AutoForm R10*. The variation of process parameters was conducted using the *ProcessRobustness* module [7] in *AutoForm*. The process parameter variations are shown in Table 1.

Table 1. Varied process parameters.

variables	spread width
blank holder pressure	± 10%
friction coefficient	± 10%
r-value	± 10%
yield stress	± 10%
tensile strength	± 10%
sheet thickness	± 10%

In this study, the springback behaviour of three different car body components (firewall, car roof, and battery cover) was analyzed. Further details on the components can be found in Fig. 1.



	firewall	roof	battery cover
Material	aluminium	aluminium	medium strength steel
E-Modul [Mpa]	70000	69000	195000
Yield stress [MPa]	135	118	446
Tensile strength [MPa]	272	215	570
Yield surface model	Barlat 89	Barlat 89	Hill 48
Failure prediction	FLC	FLC	FLC
Sheet thickness [mm]	2.5	1.1	1.0
Size [mm]	1550 x 610	2420 x 1870	2200 x 1400

Fig. 1. Properties of the tested parts.

3 Results and discussion

The following section first examines the springback behaviour of symmetrical parts. Subsequently, methods for stabilizing springback are presented. Finally, a guideline for compensating symmetrical and quasi-symmetrical components is introduced.

3.1 Springback behaviour of symmetric parts

In two of the three analyzed parts, asymmetric springback occurs in the reference simulation, despite symmetrical component and tool geometry as well as symmetrical process parameters (particularly symmetrical blank positioning), as shown in Fig. 2. The comparatively stiff firewall shows symmetrical springback. In contrast, the car roof and the battery cover — both components which exhibit lower geometric stiffness due to their flatter shape — show a clearly asymmetric springback behaviour.

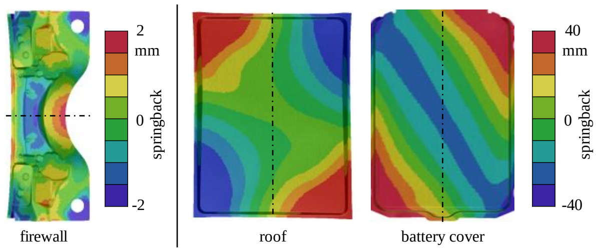


Fig. 2. Nominal springback behaviour of symmetric parts in the reference simulations.

From a physical perspective, these asymmetric springback behaviours make only limited sense, as they — if they were to occur in reality — could just as well appear in the opposite direction. However, this may indicate that these parts could actually twist or bend in one direction or the other due to minor, unavoidable process-related asymmetries. Such deformations would not pose a problem for springback compensation if they occurred consistently in the same direction. However, this is precisely where the problem lies.

Fig. 3 illustrates the variation in springback for the three components. The lower part of the figure presents the variation in springback at a representative point on the respective parts in a histogram. It can be observed that the firewall exhibits a process-stable (unambiguous) springback behaviour under the selected parameter variations. In contrast, the other two components show a "bistable" behaviour. The upper part of the figure shows the springback results for the entire area of the parts. The representative point, which the histogram refers to, is marked with a magnifying glass symbol.

The asymmetric springback of symmetrical parts in the nominal simulation (without considering parameter variations) can therefore already serve as an indication of unstable behaviour. However, this does not replace a simulation-based analysis of process stability, as even parts exhibiting symmetrical springback in the nominal simulation may show unstable springback behaviour when process parameters vary.

The springback results presented in Fig. 3. are used as a reference to compare with the results of the following approaches for stabilizing the springback behaviour. In the reference simulations and all modified simulation setups, the springback was calculated as a free springback, i.e., without the influence of gravity and without fixed points where the part after springback is aligned with the target geometry. The only exception is the results in Section 3.4, where virtual clamps were used to align the part with the target geometry.

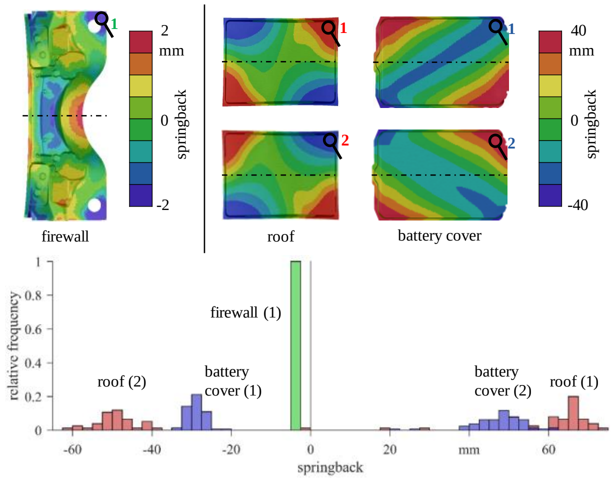


Fig. 3. Scatter in springback results due to variations in process parameters in the reference simulations.

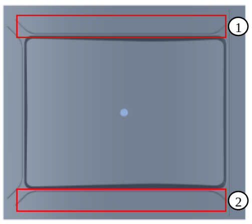
3.2 Stabilization of the springback behaviour by creating intentional asymmetries

One approach for stabilizing the springback behaviour is the deliberate introduction of asymmetries, whether those affecting the component geometry or those that can be implemented purely from a process perspective.

3.2.1 Implement asymmetric process parameters

Asymmetric draw-in behaviour

To create a process asymmetry, for example, the draw-in can be designed asymmetrically. For the car roof, the drawbead height was adjusted asymmetrically for this purpose (Fig. 4).



bead	symmetric (reference)	asymmetric (modified)
1	t = 5 mm	t = 2 mm
2	t = 5 mm	t = 6 mm

Fig. 4. Asymmetric drawbead height.

Fig. 5 shows the springback behaviour of the symmetrical (left) and asymmetrical process (right). It is evident that the nominal springback characteristic (Fig. 5, top) has shifted from a global twisting to an asymmetric springback. The deliberately introduced asymmetry has transformed the bistable reference state into a stable one, which is clearly reflected in the histogram (Fig. 5, bottom) of a representative point on the part.

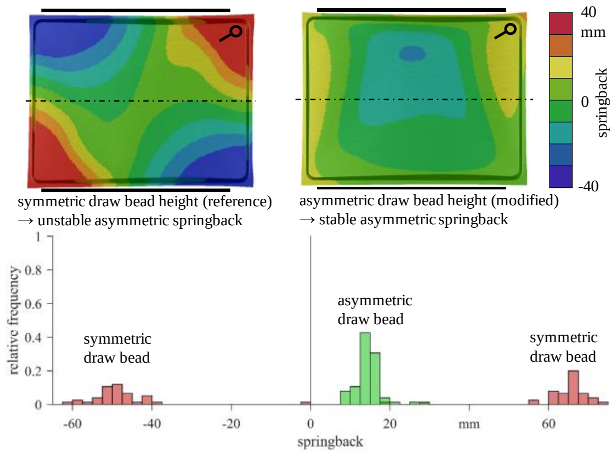


Fig. 5. Stabilization of springback characteristic due to asymmetric draw beads.

Asymmetric blank position

A process-related asymmetry can also be created by an asymmetric blank position. Fig. 6 shows the blank rotated by 4° from its reference (symmetrical) position.

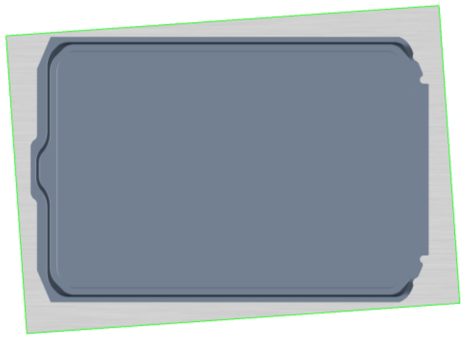


Fig. 6. Asymmetric blank position.

Fig. 7 shows the springback behaviour for the symmetrical (left) and asymmetrical blank position. The springback characteristic in the nominal simulation remains largely unchanged. However, the asymmetric blank position was able to transform the springback characteristic from a bistable state into a stable one.

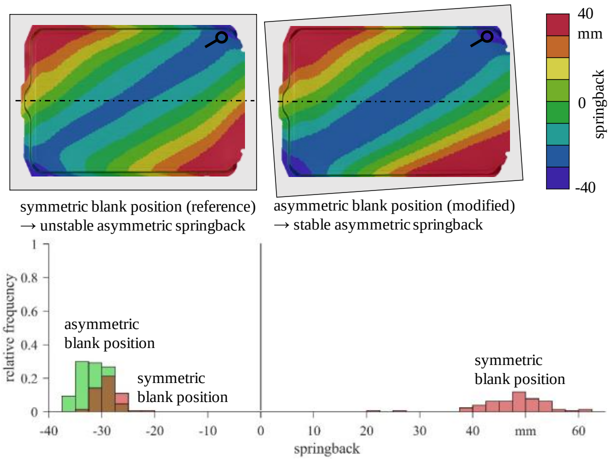


Fig. 7. Stabilization of springback characteristic due to asymmetric blank position.

3.2.2 Implement asymmetric geometric part features

Asymmetric part radii

An asymmetric springback behaviour can also be generated by introducing asymmetric geometric features in the part. However, the question arises whether the part designer would allow this. For the battery cover, a part radius was increased by 3 mm along the entire part length (Fig. 8). This leads, on the one hand, to an asymmetric structural stiffness of the part. On the other hand, it also asymmetrically influences the strain distribution.

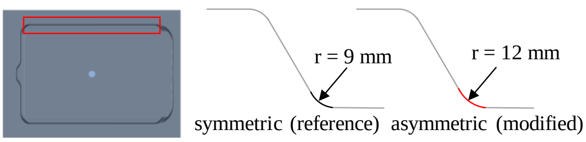


Fig. 8. Asymmetric part radii.

Fig. 9 shows that the springback characteristic does not change significantly in the nominal simulation due to the one-sided modification of the part radii. However, this characteristic could be fully stabilized by introducing the asymmetry.

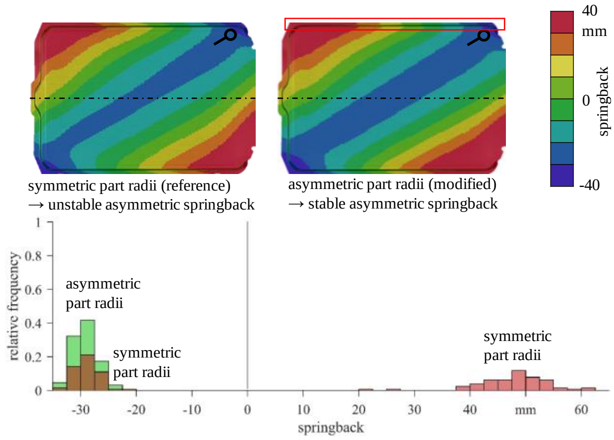


Fig. 9. Stabilization of springback characteristic due to asymmetric part radii.

Asymmetric displacement of part features

In this setup, instead of modifying the part radii, a symmetrical reference part feature (protrusion) was shifted 40 mm from the centre (Fig. 10).

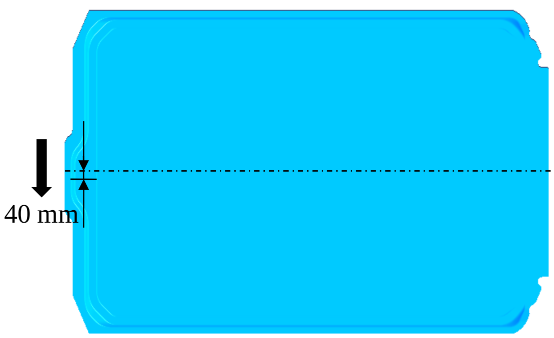


Fig. 10. Asymmetric part feature.

This modification changes the springback characteristic in the nominal simulation (Fig. 11, top). The geometry now springs back into one of the two previously bistable states. However, in contrast to the symmetrical reference configuration, this state is stable, as can be seen in the scatter of the springback results (Fig. 11, bottom).

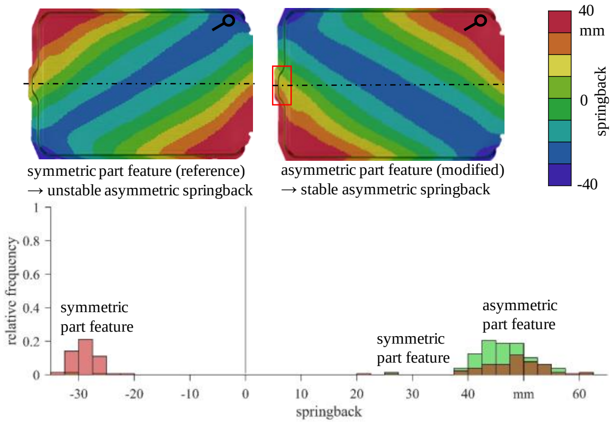


Fig. 11. Stabilization of springback characteristic due to asymmetric part feature.

3.3 Stabilization of the springback behaviour by higher strain rates

The evaluation of plastic strain shows that the two parts with unstable springback behaviour (car roof & battery cover) have a large area that is only elastically deformed in the reference simulation. Assuming that these purely elastic regions contribute to the unstable springback characteristic, the blank holder force was increased for the car roof to ensure a minimum amount of plastic stretching in these areas. Fig. 12 shows the plastified areas before and after modifying the blank holder force for the car roof. It can be seen that all areas of the part are now plastically stretched.

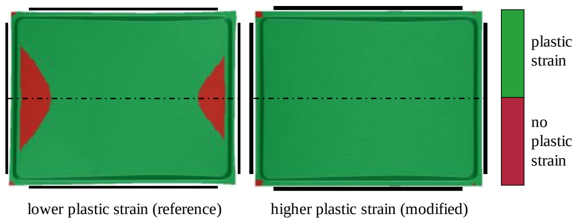


Fig. 12. Higher plastic strain.

Due to the increased stretching, the springback characteristic already changes in the nominal simulation. Instead of the reference twisting, the part now has a quasi-symmetrical bending springback characteristic (Fig. 13, top). The evaluation of the springback results from the robustness analysis (Fig. 13, bottom) shows that this springback characteristic is now stable.

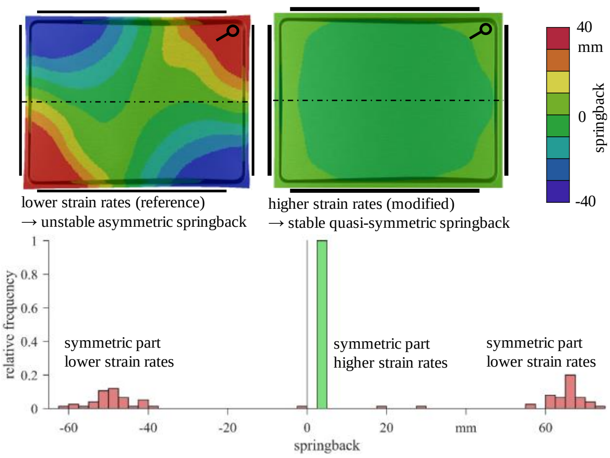


Fig. 13. Stabilization of springback characteristic due to higher strain rates.

This approach was also tested on the battery cover in the FE simulation. However, the simulation predicted cracks in the drawshell when increasing the blank holder force before sufficient plasticization of all part areas was achieved. This cracking was identified based on the Forming Limit Curve (FLC) used for failure prediction.

3.4 Reducing springback amount using external constraints

Despite the previously discussed methods for stabilizing springback behaviour, compensation can become problematic when springback values are excessively high. One challenge is that the compensation amount may be limited — for example, if the machining allowance is too small for already existing tool castings. Additionally, an excessively high compensation amount can significantly alter the springback characteristics, potentially causing convergence issues in iterative adjustments toward the target geometry.

To mitigate this issue, external constraints (virtual clamps) can be applied to suppress part twisting, a common practice in industrial applications. As shown in Fig. 14, the springback amount is significantly reduced due to these constraints (Fig 14, top right section, black dots), leading to a quasi-symmetrical springback behaviour, while maintaining process stability.

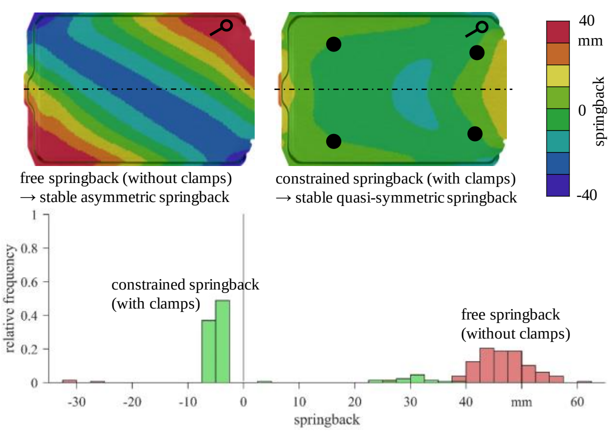


Fig. 14. Reducing the springback amount using external constraints (virtual clamps).

3.5 Symmetric compensation of quasi-symmetric parts

Quasi-symmetrical parts can, under certain conditions, also be compensated symmetrically. This is useful when the asymmetry is minimal, as it cannot be guaranteed that it will occur exactly in the same way in reality.

In the present example, a quasi-symmetrical firewall is considered. The only deviation from full symmetry is caused by the cut-out for the steering column (Fig. 15, red circle). The highest asymmetry in springback occurs at the lower part edge. While the springback on the left side is 3.6 mm, it is 3.9 mm on the right side.

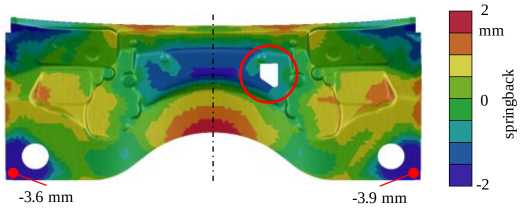


Fig. 15. Quasi-symmetric springback characteristic due to slight asymmetric part geometry.

For the compensation of the part, the averaged springback of both halves is used. The remaining asymmetric dimensional deviation is then to be compensated based on real springback results on the physical tool, provided the dimensional deviations are outside the specified tolerances.

3.6 Guideline for compensation of symmetric and quasi symmetric parts

The results presented allow for the derivation of a guideline for springback compensation of symmetrical and quasi-symmetrical parts.

Fig. 16 illustrates the approach for symmetrical parts. With sufficient part stiffness, a symmetrical springback characteristic typically emerges — also observed with many other parts treated in the past — which remains stable despite fluctuating process parameters and can thus be compensated symmetrically.

For parts with low structural stiffness, both symmetrical and asymmetrical springback characteristics can occur in the nominal simulation. In the case of a symmetrical characteristic and stable behaviour, compensation can be applied symmetrically, just as with stiffer parts.

In the case of an asymmetrical springback characteristic, it may only be numerically induced and therefore be minor, which is why unstable results are to be expected in the robustness analysis. An unstable behaviour must be stabilized before compensation, using one of the methods for stabilization outlined above.

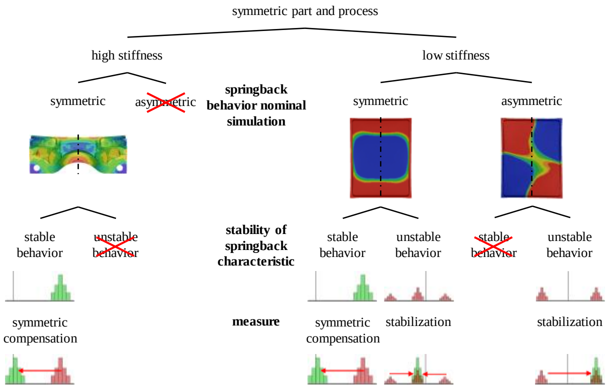


Fig. 16. Guideline for springback compensation of symmetric parts.

Fig. 17 illustrates the procedure for quasi-symmetrical parts. With sufficient part stiffness, both a quasi-symmetrical and an asymmetrical springback characteristic exhibit stable behaviour. This can then be compensated symmetrically or asymmetrically, with quasi-symmetrical springback also being compensable symmetrically in cases of low asymmetry (see section 3.5).

For parts with lower stiffness, a quasi-symmetrical or asymmetrical springback behaviour can occur in the nominal simulation, just like with stiffer parts. Regardless of the characteristic, the springback must first be stabilized in case of unstable behaviour. If stable behaviour is observed, compensation can be performed asymmetrically or, in some cases (see section 3.5), symmetrically.

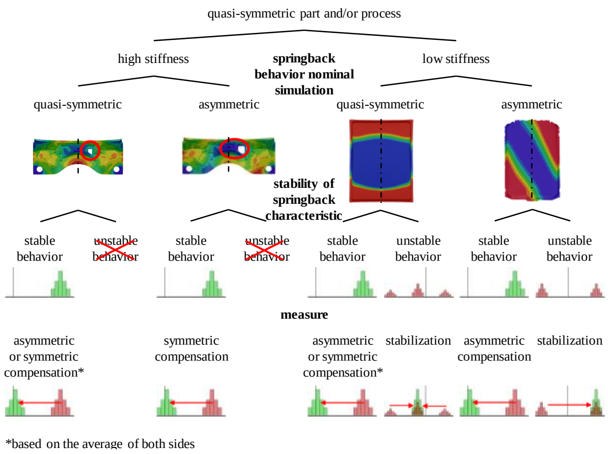


Fig. 17. Guideline for springback compensation of quasi-symmetric parts.

4 Conclusions

There are some specific challenges when compensating symmetrical and quasi-symmetrical parts. For both quasi-symmetry and full symmetry, it must first be ensured that the springback behaviour is stable. The investigations have shown that, particularly for parts with lower stiffness, an unstable springback characteristic can occur. The following methods have been successfully tested for stabilizing the springback behaviour:

- Introduction of process asymmetries
- Introduction of part asymmetries
- Increased stretching (plastic deformation across the entire part)

Furthermore, methods for reducing the springback amount (clamps) and for the symmetrical compensation of quasi-symmetrical parts (averaging both halves) were presented. Finally, a guideline for compensating symmetrical and quasi-symmetrical parts was developed.

Since the issue presented primarily occurred on parts of low stiffness, this topic could also be explored on unstable parts without symmetrical properties, and the stabilization methods could be tested.

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