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Reduction of Spring-Back of Sunroof Panel and Avoid Springback Compensation Operation

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Abstract— Springback is the most known complex defect that faces all sheet metal stamping plants. In automotive sheet metal parts application, it is very critical to accurately predict and control the springback. Hence spring-back is a great challenge for today's press shops about the dimensional accuracy of cold-formed sheet metal parts. Springback in Sheetmetal parts are mainly dependent on the stress state introduced by the forming process and part geometry. This paper aims to determine the influence of the various parameters on springback and bring the springback value under control. In this case study, sheet metal forming simulation in Autoform for a large sunroof with two openings has been used. The product remains untouched while modifying various process parameters such as binder force, draw bead type, draw bead force, die radius, wall angle, etc. to control the springback. Different methodologies and concepts have been used to reduce the springback at the desired level. The process has been finalized in such a way that as the product gets mature, springback value will further reduce. This method can be utilized in all upcoming sunroof panels without or minimum product change.

Keywords— Cold-form, Press shop, Sheet Metal Stamping, Springback, Sunroof, Stess.

I. INTRODUCTION

It is very critical to maintain part quality till the entire life cycle of sheet metal formed part. Die stamping sheet metal components have complex and aggressive shapes which gives problems, such as splits, wrinkles, thinning, thickening, springback, etc. Spring-back is the most known complex defect that is difficult to control and hence springback reduction is a great challenge in sheet metal stamping operation.

Springback is a manufacturing defect in the sheet metal forming process. When the tools are released after the forming operation, the product will deviate from the target shape due to its internal stresses [1]. This distortion of the drawn panel is caused by elastic recovery within the material and is inherent in the die-stamping process. Spring-back has an adverse effect on the dimensional accuracy and precision of the formed part. The appearance and extent of springback are determined by the stress state, stress distribution, and magnitude of elastic deformations in the direction of the sheet thickness [2].

In recent years, in automobile industries, to improve the performance of vehicles, lightweight automotive parts have been widely used by automakers due to demand in fuel consumption and carbon dioxide emissions. These steels have high yield strength and tensile strength and this manifests themselves in large hardening transients following a stress reversal, large changes in the elastic modulus following plastic deformation, and high temperatures attained by the plastic work in areas of large strain. For these reasons, springback has become a focus of research in the industry.

Springback in sheet metal forming is influenced by several factors that impact the elastic recovery of the material after the forming process. Larger amounts of springback are affected by many parameters such as sheet metal thickness, blank shape, level of ultimate tensile strength, hardening rate, Young’s modulus, method plan, tool radii, tool clearance, and forming conditions as well [3].

II. PRESENT METHODS TO CONTROL SPRINGBACK

To control springback, there are two different methods used in practice.

1. By modifying the forming process i.e., process control parameters like binder shape, addendum shape, draw bead force, die radius, addendum wall angle, providing strengthening features, etc. Due to high yield and tensile strength, there are limitations to modifying these parameters which give other forming issues such as splits and wrinkles. Though these methods are effective in reducing springback, they cannot eliminate springback completely.
2. A formability analysis study carried out as per the defined process and standards having calculated springback value. A common countermeasure against springback is to design forming dies that anticipate springback compensation, but the compensation amount is a difficult question even for experienced die designers, and field practice is largely based on trial and error [4]. To reduce the springback value at the targeted range, springback compensation software named OMNICAD is used. This software reduces the springback value by inverse springback calculations to achieve the target shape. Though die compensation by modifying the die-face is an effective way to overcome this issue, this method requires the high cost

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of purchasing a software license, additional manpower, skill, and time. Further, after compensation, it is necessary to simulate once again in Autoform to verify the springback value.

The final goal of this study is to achieve the dimensional accuracy of the sunroof panel, without major modifications in the part and surface compensation by controlling springback. This study starts with completing the formability analysis having optimized results and free from any formability defects like splits, wrinkles, etc. The focus remains in this paper is to identify the parameters that cause the springback, to find the ideal method that counters the springback effect during the stamping operation, and to reduce the springback value of the selected part. At the end of this paper, a new approach is presented for the reduction of springback.

III. FORMABILITY ANALYSIS OF THE SUNROOF PANEL

In this research paper, a Sunroof panel of the Sports Utility Vehicle program was selected which has a very high springback defect. This part has two large sunroof openings, a negative gutter area, and a negative front flange wall. Figure 1 shows the sunroof panel studied for the research paper. The material of the sunroof panel is CR180 grade, 0.7mm thickness.

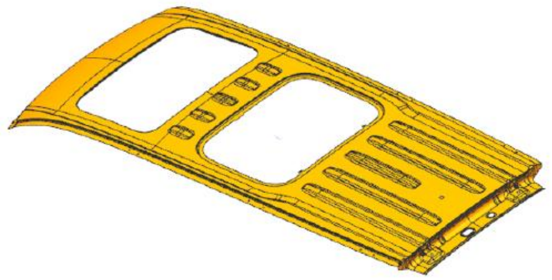

Figure 1: Panel Sunroof

A. Material Properties

The material used for the selected sunroof panel is CR180B2 with 0.7mm thickness. Material properties for steel grade CR180B2 are shown in Table 1.

Table 1. Material properties for steel grade CR180B2

Material	CR180B2
Thickness [mm]	0.65
Yield strength [MPa]	200.00
Tensile strength [MPa]	320.00
Strain Hardening Coefficient, n-value	0.21
Strength Coefficient, K-value (MPa)	543.00
Normal Anisotropy, R-Bar	1.60
Poisson's ratio	0.33

B. Feasibility Study for panel Sunroof

In order to analyze the springback behavior of the selected sunroof panel, the simulation was performed using the software Autoform. All tool surfaces required for simulation were prepared in Autoform software itself. Figure 2 shows the dieface generated for the sunroof panel formability analysis study.

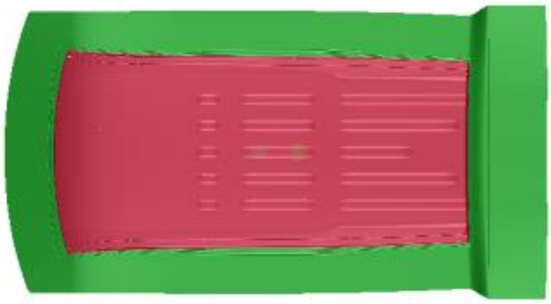

Figure 2: Panel Sunroof

This panel is manufactured through four different stamping operations. The operation's names are draw die, form die, trim die, and flange die. Evaluation of formability analysis is based on different modes of failure/quality. The quality of the entire forming process is checked with various criteria like formability, thinning, thickening, minor stress, draw-in, wrinkles, splits, springback, etc. The formability results are optimized through multiple iterations by error and trial and all formability defects removed which appeared during simulation such as splits, wrinkles, etc.

C. Springback

In the Evaluation stage, the most important and the main focus of the study is Springback calculation. In Autoform, to analyze the springback, 'Displacement in Normal Dir' is used. 'Displacement in Normal Dir' shows the translation of the elements of the sprung back part compared to the part before springback. The absolute value results from the normal proportion of the translation vector with respect to the sprung back. There are two algebraic signs used to express the springback value as shown in figure 3 and 4.

a. Negative algebraic sign (-): The springback occurs in the direction of the Thickness Direction of the Part/ Reference Geometry.

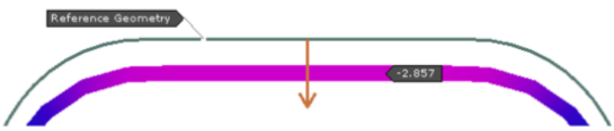

Figure 3: Negative algebraic sign

b. Positive algebraic sign (+): The springback occurs against the direction of the Thickness Direction of the Part/ Reference Geometry.

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Figure 4: Positive algebraic sign

D. Free Springback

In stamping operations, 'free springback' refers to the amount of elastic recovery or dimensional change that occurs in a formed sheet metal part after it is released from the forming tool or die, without any external constraints or fixtures holding it in place. Free springback occurs when the formed part is allowed to spring back naturally without any external constraints. It represents the inherent elasticity of the material and can lead to dimensional deviations from the intended final shape of the part. Additional springback occurs when the part is constrained or held in place, such as when it is clamped or fastened. Controlling springback, both free and constrained, is crucial for achieving dimensional accuracy and producing parts that meet the required specifications.

E. Free Springback Evaluation

In free springback calculation, there are no external constraints or fixtures holding the panel. After a successful simulation run, the springback result is available for evaluation. Figure 5 shows the free spring of the Panel Sunroof. It shows that the maximum and minimum values of springback are +7.64mm at the side and -22.08mm at the front area, respectively. The expected maximum and minimum springback is +/- 5mm. This is a major defect in the feasibility study of the panel sunroof. In this study, the focus is to control springback or reduce springback at the desired level.

These springback results indicate that it is not possible to use this panel directly and it is necessary to reduce the springback by either springback compensation software or a newly developed method.

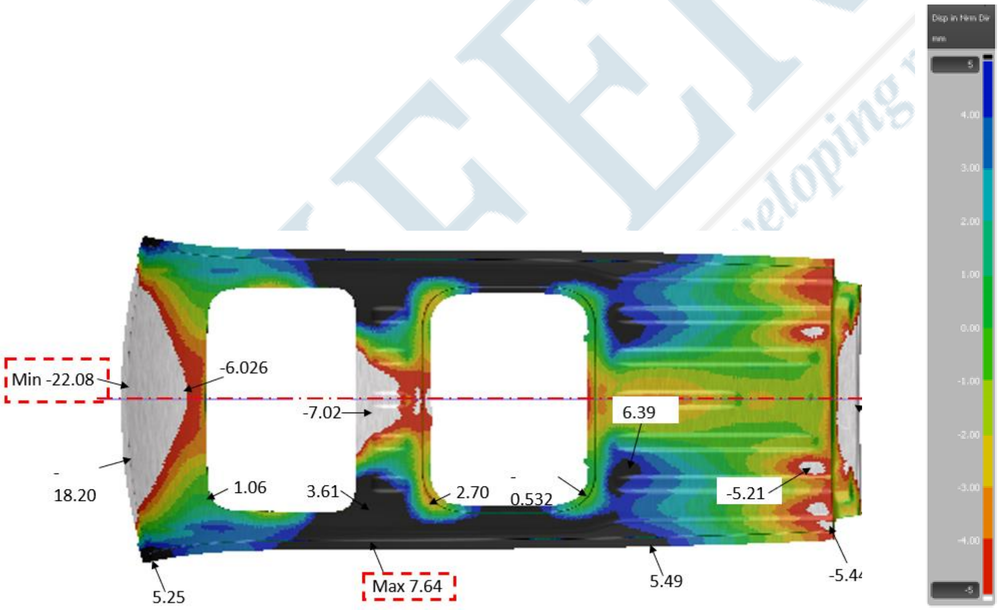

Figure 5: Free Springback of Panel Sunroof

IV. REDUCTION OF SPRINGBACK BY A NEW METHOD

As there is high springback observed in part, it is essential to conduct a comprehensive study to reduce springback effectively. Such a study should consider various factors influencing springback and implement targeted strategies to minimize it. To work out this problem, the following steps are decided to be conducted to reduce the springback.

1. Identify the cause of high springback.
2. Run the simulation with springback after each operation to identify which operation impacts on springback effect.
3. Finding the best method to counteract on springback effect.
4. Reduce springback at desired tolerance by using the newly identified method.

1. Identify the cause of high springback

This is the primary stage to analyze the part by studying its shape, features, counterpart, Material Requirement criteria, etc. The basic reason for excessive springback is a part geometry. This part has two large openings, a high blank weight-to-part weight ratio, no adequate strengthening feature, and a short distance between these two roof openings. Springback can be improved by modifying part. A major change in part means modification in the original product, and it affects all other surrounding part. Hence major part change is constrained. We can raise the minimum product change request which helps to reduce springback value.

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2. Calculate springback for each operation

Calculating the springback for each operation helps to find where the springback value increased. After finding the most impacted operation, it is easy to focus on that particular stage. Figure 6 shows the maximum/minimum springback value of each operation.

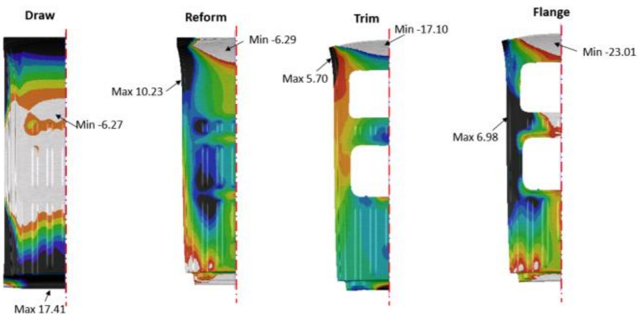

Figure 6: Springback for each operation

In general, when the part separates from the tools, elastic recovery happens, and the part tends to its original shape which causes distortion. After the cutting operation, internal stresses are relieved and higher elastic recovery is observed. It means higher springback. Table 2 specified the springback value of each operation and it can be concluded that after the Op30 operation, the springback value drastically increased and further increased after the final operation.

Table 2. Maximum/Minimum Springback value

Operation No. & Name	Springback value(mm)	
	Minimum	Maximum
OP10 - Draw Die	-6.27	17.41
OP20 - Trim, Form, Cam Form Die	-6.294	10.23
OP30 - Trim, Cam Trim & Pierce Die	-17.1	5.697
OP40 - Flange Up and Flange Down Die	-23.01	6.981

After studying the springback of all operations, the below observations are available for further steps.

1. After the draw die, the springback is within 5mm at the show surface.
2. After reform operation, -6.3mm springback at the front area.
3. After the Trim operation, the springback increased 3 times at the front area i.e., -17.1mm.
4. After the last operation i.e., flanging, springback increased further and ended up with -23mm and 7mm.

3. Finding the best method to counteract springback

In springback defect resolution, Process parameters play a major role in controlling springback. It will take various combinations, iterations, and experiments to find the ideal method. It includes a change in operations, draw bead segmentation,

variation in draw bead force, use of different draw bead models, change in blank shape, use of different strengthening features at scrap area, change in a binder, addendum shape, and many more.

Among these parameters, draw bead is crucial which controls the material flow. Hence it is important to study the impact of draw beads on springback.

4. Reducing Springback

After studying significant factors affecting springback, it is necessary to implement these to reduce springback. Different variations of these factors are to be used to get the desired value.

a) Draw Operation - Profile 3D Draw Bead

It is the first operation of the process which initiates and affects all the formability results. Though round beads combined with trapezoidal beads give sufficient stretch and good formability results, the panel resulted in the highest springback. When the springback was checked for draw die, it was -6.2mm at the front side, leading to a higher springback. Using profile 3D draw bead, there was a positive change in springback value. Draw force variation brought by changing draw bead force and segment.

b) Draw Operation – Step bead

Though there was a reduction in springback, the value was not at the desired level. The step bead was tried along with the round bead to get higher stretching. In order to control the springback, a round bead was used as the primary bead, and a step bead was used as the secondary bead at the front area where the highest springback was observed.

The use of the Step bead changed the springback value significantly. Springback reduced from 17.4mm to 3.8mm which is a scrap area and this change remains the same till the last operation. Figure 7 shows the springback after the draw die when the round bead is used with the step bead.

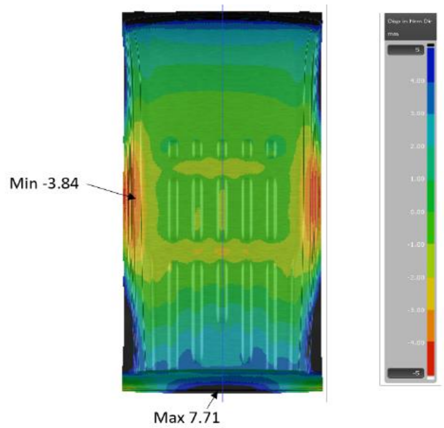

Figure 7: New Spring back after Draw operation

c) Reform and Trim Operation–Stage Trimming

After the reform operation, springback dramatically increased from -6.3mm to - 17.1mm. It happened due to the internal stress relieved after trimming. In the draw and reform operation, stress is introduced during the forming process. To overcome this issue, the sunroof opening was trimmed into

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the stage. While doing so, care was taken about the material available and the panel moved to the next station having good strength. Also, the upper pad is used in cutting operations as in the actual die. This step helped to reduce springback from -6.3mm to 5.5mm and also gave strength to the part while transporting part from one station to another station.

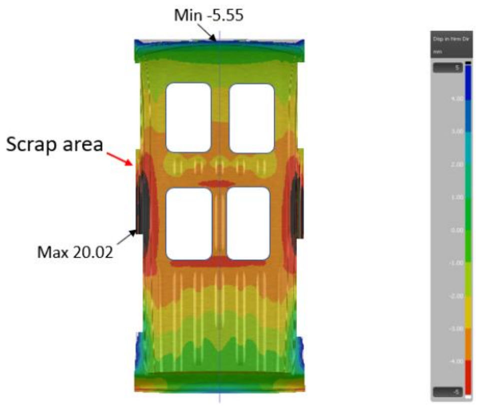

Figure 8: New Spring back after Reform and trim operation

Figure 8 shows the springback value after the reform and trim operation. In this operation, trim stages at specific areas are decided by using different combinations and iterations.

d) Trim Operation

In this panel, a very high springback was observed in the front area. For that reason, overall trim was avoided, and kept scrap area at the front area. Also, this scrap material in the front area helped to give stability to the panel. This stage trim helped to reduce springback from -17mm to -12.8mm which is at the front scrap area and gave strength to the part while transporting part from one station to another station.

Figure 9 shows the springback value after the trim operation.

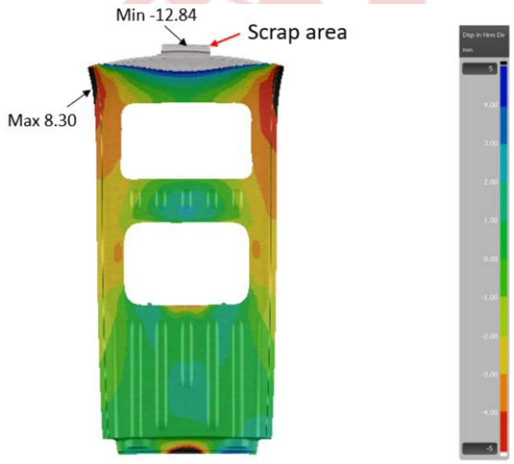

Figure 9: New Spring back after Trim operation

e) Trim and Flange down Operation

It is the last operation in this setup. In this operation, there is a flange-down operation at the sunroof opening and a flange-up operation at the rear. Due to flanging down, springback further increased from -17.1mm to -23mm. To improve the springback value, stage trimming helped by keeping scrap in the front area. This scrap area is with bead formed, having both beads i.e., round bead and step bead. This scrap area located at the front gave strength to the part as well as counter impact to flange down.

Figure 10 shows the free springback of the final part. Free springback reduced from -23mm to -11mm. This value is in control and can be further improved by minimum product change.

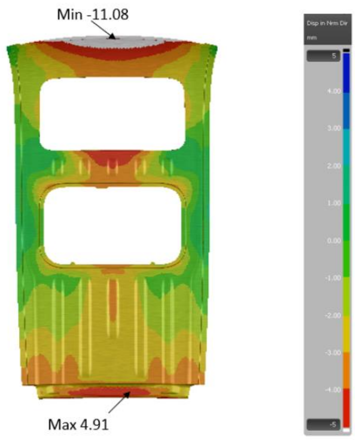

Figure 10: New Spring back after Final operation

f) Blank shape

The blank shape also played a vital role in achieving the expected result. Initially, the simulation started with a rectangular blank. When the rectangular blank shape changed to a trapezoidal springback, it showed improvement in formability results as well as springback results. Along with that, blank also saved and reduced the blank weight from 29.6kg to 28.5kg which helped increase blank utilization from 48.2% to 50.1%.

Figure 11 shows the rectangle and Trapezoidal blank size used in formability analysis. Draw-in value maintained as per GM standard.

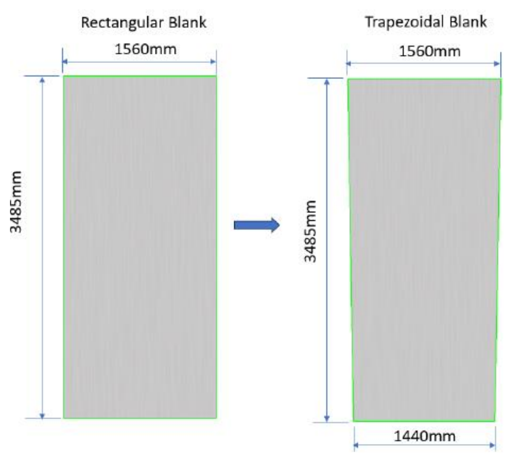

Figure 11: Rectangle and Trapezoidal blank size

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Figure 12 shows the springback result using a rectangle blank and a trapezoidal blank. It shows that the springback value is reduced from a rectangle blank to a trapezoidal blank.

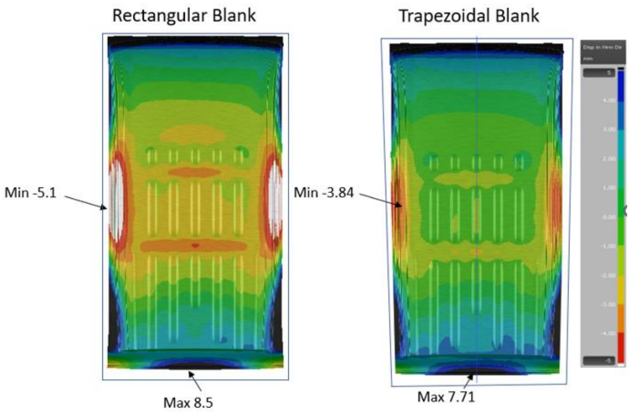

Figure 12: Springback result with new blank shape

g) Real Springback

Springback after clamping is an important consideration in sheet metal forming operations. Real Springback refers to the elastic recovery that occurs in a formed sheet metal part after it has been released from the forming tool and is held in place using clamps or fixtures. Part assembled with the help of welding and hence real springback calculation is helpful to find the state of a part after assembly. Controlling springback after clamping is essential for achieving dimensional accuracy in the final part.

Figure 13: Clamping position as per GD&T drawing

Real springback is measured with the help of clamping, by supporting from the bottom. Clamping points are identified in the GD&T drawing and the part is clamped accordingly. Then springback value is calculated in clamped condition. Figure 13 indicates the number of datums and their positions as per GD&T Drawing.

5. Result

Figure 14 shows the real springback value using clamping pins and these datums are selected as per GD&T drawing. The final value is max 4.53mm and min -4.83mm which are as per requirement.

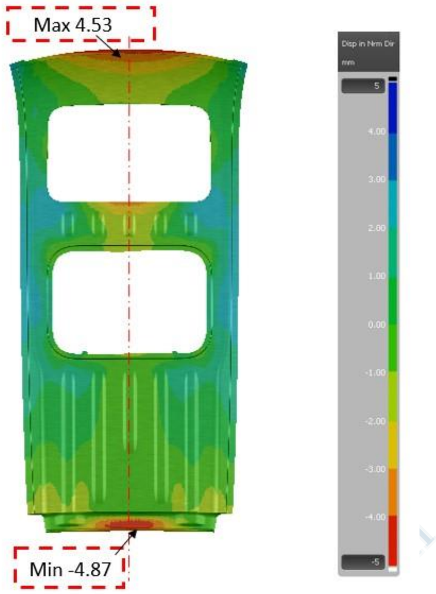

Figure 14: Real Springback

As the product matures through upcoming revisions, the springback value will be further reduced. The final aim of this study is to avoid the need for springback compensation which can be achieved before the start of regular production.

Table 3 specifies the springback value of each operation for the newly developed process. It is observed that the springback value maintained the entire operation and it is within ± 5 mm for the finished part when the real springback is calculated.

Table 3. Maximum/Minimum Springback value

Operation No. & Name	Springback value(mm)	
	Minimum	Maximum
OP10 - Draw Die	-3.84	+7.71
OP20 - Trim, Cam Form Die	-5.55	+20.02
OP30 - Trim, Cam Trim Die	-12.84	+8.3
OP40 – Trim, Flange Up and Flange Down Die	-11.08	+4.91
OP40 – Real Springback	-4.87	+4.53

V. CONCLUSION

As the reduction of springback is a major aspect of sheet metal stamping operation, it must be controlled within a given tolerance. Minimizing springback helps to achieve dimensional accuracy and produce high-quality parts that meet the required specifications. There are many events planned before the start of production to prove the part. Before the production stage, it is expected to control the springback within ±5 mm; during production, it must be within ±1 mm. If it is not achieved, it is necessary to use springback compensation using another software that impacts cost, time, and quality. The newly developed method performs extremely well for the springback reduction. In this research, the springback value is controlled within ±5mm before the production stage which was the target value. This result is obtained for the first release product, and many revisions are coming to mature the product.

This new method presents the following remarkable characteristics:

1. Real springback achieved within ± 5mm before the production stage.
2. Optimized multiple process parameters like physical draw bead, step bead, variation in trim stages, blank shape, smooth and high-quality die face generation.
3. High-quality sunroof pillow and flange steel designed in NX to achieve expected stretching and implement direct trimming.
4. Measured springback after each operation to know the trend of low springback to high springback and the area of focus.
5. For the real springback calculation, datums are used as per the GD&T drawing.
6. Control parameters, settings, and criteria used as per GM Standards.
7. Proper die face design helped to manage the material flow and reduce springback tendencies.
8. 0.5mm plussing used at reform operation as per GM standard requirement.
9. The use of advanced simulation software (Autoform Plus) enabled to prediction and analysis of springback behavior accurately.
10. Trial and error methods are used to refine the forming process and reduce springback.

VI. RECOMMENDATIONS

While doing this study, a product change request has been submitted to the Product Engineering team to improve springback as per the material requirement criteria. These required changes are providing strengthening features, increasing the distance between 2 openings, passing the drop test before the new release, etc.

Based on observations, there are a few recommendations for the product.

1. The product is flimsy, with no strengthening features. This is one of the largest products and is difficult to handle. Need to provide strength to the product by providing beading features.
2. Validate the developed process by applying it to upcoming revisions and similar products to check the robustness of the process and validate it.
3. A study for materials having different mechanical properties can be done to check the springback effect.
4. Utilize physical prototyping to predict and analyze springback behavior accurately.
5. Thoroughly characterizing the material properties, including elastic modulus, yield strength, strain hardening behavior, and anisotropy. This data will serve as a foundation for understanding the material's springback tendencies.
6. Use of different tooling and process parameters to observe their effects on springback behavior.
7. Investigate the impact of process parameters (e.g., forming speed, lubrication, temperature, rolling direction, and dynamic friction model) on springback. Optimize these parameters to find the best combination for reduced springback.
8. Investigate the microstructure and texture of the materials to understand their influence on springback behavior.

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