Springback Prediction, Compensation and Correlation for Automotive Stamping

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Abstract. To reduce weight and increase fuel efficiency and safety, more and more automotive sheet stamping parts are being made of aluminum and high strength steels. Forming of such materials encounters not just reduced formability but also dimensional quality problems. Springback prediction accuracy and compensation effectiveness have been the major challenge to die development, construction and tryout. In this paper, the factors that affect the accuracy of springback prediction are discussed, which includes the effect of material models, the selection of element size, and the contact algorithms. Springback predictions of several automotive aluminum and high strength panels are compared with measurement data. The examples show that the prediction correlates with measurement data in both springback trend and magnitude. The effect of springback on final product can be reduced or eliminated through process control and die face compensation. The process control method involves finding the root causes of springback and eliminating them through process modification. The geometrical compensation of die surface is a direct way to eliminate the springback effect. The global scaling compensation method is normally limited to parts with relatively small springback. For large springback and twisting, a new approach is discussed, which takes into account of the effect of deformation and springback history. The compensation is achieved iteratively by solving a system of non-linear equations. Production dies were cut to the compensated surface, which shows that the die compensation is an efficient way to reduce springback-induced geometry deviation.

INTRODUCTION

The increasing application of aluminum and high strength steels (HSS) in the automotive industry (to meet increasing demand of vehicle fuel efficiency and safety requirement) has posted a challenging issue for the numerical simulation technology of sheet metal forming. That is the accurate springback prediction and compensation. The relative large springback due to the low Young’s modulus of aluminum and high yield strength of HSS often causes large springback after parts are formed, resulting in dimensional deviation of the formed part from the designed shape. The springback is also a major factor affecting the surface quality of outer skin panels. Improving the springback prediction accuracy has thus been the focus of many researchers [1-5] and software development. The recent advances in this area have made the springback analysis much faster and reliable. The springback analysis has become a routine process of sheet forming analysis for CAE engineers in automotive industry. This article will briefly review some of the factors that affect the springback analysis accuracy. Then methods for the springback reduction and correction will be discussed with examples of springback die face compensation of automotive panels. The examples illustrate that there are many ways to tackle the springback issue to meet part dimensional tolerance requirements and to reduce the die tryout efforts with computer simulation.

SPRINGBACK PREDICTION

Springback is an elastic recovery process which occurs at the end of plastic deformation (which may cause reverse plastic deformation locally). In addition to the influence of part geometrical shape, springback pattern and magnitude are mainly determined by the stress level and distribution in a stamped part. Therefore, forming simulation is one of the most
important factors affecting the quality of springback simulation. However, forming simulation is controlled by many factors. Among them are finite element formulation and modeling, tool and sheet contact, sheet material model, friction model and solution algorithm.

For automotive stampings with complex geometry, the correct contact between sheet and tools is critical to avoid artificial penetrations and incorrect contact forces during numerical simulation [1]. A correct contact requires:

- Connected tool mesh without gap, overlaps and duplicate entities and appropriate tool mesh size at radii (at least 8 element at 90 degree bending radius)
- Appropriate initial sheet element size and adaptive refinements (a minimum of four elements around the radius). If possible, uniformed fine meshes should be used to increase the smoothness of contact and the flexibility of panel.
- Adequate integration points through sheet thickness to fully capture bending stresses (minimum seven points for thin gage and additional points for increasing thickness), and
- Appropriate simulation speed and other numerical parameters

As an example, Fig. 1 and Table 1 show the springback predictions of a HSS part. It is shown that with adaptive meshes the simulation underestimates the springback, while the uniformed mesh can improve the springback by 2 mm, which is significant for this case.

<table>
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<th>TABLE 1. Measurements and Predictions</th>
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<td>Point Location</td>
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**FIGURE 1** HSS Body Structure Reinforcement
The correct contact between sheet and tool provides a fundamental base for correct stress calculation. To improve the smoothness of contact, CAD tool surface could be used directly for the contact calculation instead of tool mesh [6]. However, this requires much longer computing time and much higher quality CAD surfaces than those required for normal die engineering. The creation of such a high quality surface would require much more work and time in the die engineering phase. An alternative approach to create a better contact is to re-construct a surface based on the tool mesh model for the contact calculation only. The effort in converting mesh to a simple surface should be much less than to create a perfect CAD surface.

Material response to plastic deformation is characterized by material models used in the finite element analysis. The yield function determines the shape of the yield locus while the hardening law governs the evolution of the yield surface. Since different materials behave differently during plastic deformation, numerous hardening laws and yield functions have been proposed trying to capture the details of material anisotropy, kinematical hardening effect, and microstructural evolution effect. [7-12]. While the models are supposed to improve the springback predictions, the determination of material parameters involved in most of the models requires extensive tests using specially designed equipment and data processing. Up to now, there are no unified industrial test standards and requirements for steel and aluminum producers to provide these material parameters to the end users. Therefore the traditional Hill’s yield function and a realistic hardening curve directly obtained from tensile tests is still widely used for forming and springback analysis for steel and aluminum. In this case, the CAE engineer’s skill and knowledge are very critical to obtain a reliable forming and springback results.

In order to capture all possible springback modes in simulation, especially the twist, a full model should be considered instead of half model for symmetric parts. The real draw bead shape instead of equivalent drawbead force should be used to reflect the material hardening effect due to bending and unbending, and bead shape stiffening effect. For flexible parts (body closure panels), the gravity force is found to be an important factor in the springback analysis to capture the panel drooping and its induced springback pattern. In the implicit springback analysis, the displacement convergence criterion is usually used. However, the convergence tolerance is normally chosen arbitrarily based on application engineer’s experience. In addition to the displacement convergent test, it is found that the residual stress should be also considered as a convergence test criterion. A low residual stress distribution after springback calculation indicates that unbalanced stresses are released properly and the applied constraint schemes are adequate. Otherwise, the springback calculation results should be re-evaluated.

**SPRINGBACK REDUCTION AND COMPENSATION**

Springback occurs after draw, trim and flanging due to unbalanced residual stresses in the panel. The effect of springback causes the panel geometry to deviate from the designed shape. Therefore, the sprung drawn panel may not fit into trim post, the sprung trim panel may not fit into flanging post, and the final finished panel may not meet the product nominal shape. In the past, springback compensation was done manually based on trial and errors due to the lack of accurate springback prediction and the process has taken a long time. This may jeopardize vehicle program timing. The recent improvement in the springback prediction makes the springback compensation possible in die engineering phase of vehicle development.

There are two ways to solve the springback problem. One is the mechanics-based springback reduction (MBSR) and the other the geometry-based springback compensation (GBSC) [1]. For each particular part, the MBSR method is different based on the product geometry, addendum development, and die process. The commonly-used methods include engineering proper product features (adding darts, stiffening beads, offset, etc.) to stabilize the part shape, changing die process to balance stresses and deformation modes, and engineering certain level plastic strain at dimensional critical areas to reduce bending and twisting springback (by adding draw beads and varying bending radii).

Fig. 2 shows the effect of drawbead on the springback for a HSS automotive part. This part has no split and wrinkles without using drawbeads along the sides of the panel. However, severe twisting occurs and the trimmed panel deviates from the nominal shape by 20 mm. After drawbeads are added, especially along the sides at the twisting location, the twisting springback disappears and the maximum deviation of the trimmed panel is within 1 mm.
For some aluminum, the annealing process during forming can not only enhance formability but also reduce springback significantly. Fig. 3 shows springback distributions with and without annealing for a hood inner which was initially designed for steel. With the annealing process, the same steel hood can be made with aluminum and the springback is reduced to a magnitude similar to that of steel hood.

The GBSC is the modification of the nominal die geometry so that the sprung shape of a panel matches the designed shape of the part after forming operations. The geometry compensation can be done on the entire die face or locally at certain concern areas. The local compensation involves less die face variation and less risk. For most parts, the sprung panel can be rotated with respect to the nominal part to transfer most of the springback variation into a local area where the compensation will not cause a significant change to the original forming process (no under-cut, addendum and binder change).

The common practice of GBSC usually involves: 1) forming and springback calculation based on the nominal die face, 2) modification of the die face with a selected global scaling factor which scales the die face compensation linearly based on the springback displacement vectors, 3) forming and springback calculation based on the compensated die face, 4) comparison of the sprung shape from step 3 with the nominal part shape. If the dimension tolerance is not met, iterations from step 1 to step 4 would be required. For a part with relatively small springback amount, the global scaling compensation method can compensate the die face after several iterations. The compensated die face normally can produce a part which meets dimensional tolerance requirements.
Figures 4a and 4b show the application of the global scaling method to the aluminum deck lid inner of Benchmark Problem #1. After five iterations of adjusting global scale factor, the compensation still does not meet the tolerance requirement in some local areas. Additional manual compensation was carried out at those areas at the rear corners. Fig. 4b shows CMM checking results of the part before and after the compensation. It is shown that most of springback is compensated at the cowl area (points 1-7) while more than 4 mm deviation near the water fall area (points 10-18) is reduced to 1.7 mm.

The springback pattern and magnitude vary nonlinearly with the die face variation. For a problem with large springback or twisting, the above-mentioned linear scaling method may not be able to compensate the die face satisfactorily even after many iterations. In order to compensate the die face more effectively, the following function can be defined:

$$\Psi (T, F, M) = ABS (P - T - S)$$

Where \(P\) is the nominal part shape, \(T\) represents the tool surface and \(S\) the springback vector, \(F\) is forming condition vector (lube, binder force, bead force, binder travel, etc.) while \(M\) is the vector of material property parameters. The compensation of the die face is therefore equivalent to find a solution of the following problem:

$$\min \{\Psi (T, F, M)\}$$

If it is assumed that material properties and forming conditions will not change during forming process, the above minimization problem becomes to find a solution for the following system of nonlinear equations.

$$\partial \Psi/ \partial T = 0$$

Finding a solution for such a highly nonlinear system of equation is not trivial. It involves developing a method for proper die face variation, automatic simulation process setup, and automatic multi-iteration forming and springback result processing. Recently, it seems that Livermore Software Technology Corporation (LSTC) has adopted a similar approach (although no technical details were released by them yet) and developed a die face compensation capability within LS-DYNA. The applications of this LS-DYNA function to several die compensations has demonstrated that this approach is more effective compared with the linear compensation method and spring-forward method.

Fig. 5 shows the compensation result on the HSS part shown in Fig. 1. Only one section is shown in the Figure. After 3 iterations of compensation using LS-DYNA, the maximum deviation of the drawn panel (after trim) from the nominal shape is less than 0.2 mm.
CONCLUSIONS

The accuracy of springback prediction is critical to the die face compensation. To obtain a reliable springback prediction, attention should be paid to the factors discussed. Although the current springback prediction can only reach 70-80% accuracy for most of automotive parts, the die compensation technology based on the FEA prediction can significantly reduce the geometrical deviation induced by springback and help increase the application of aluminum and HSS in automotive industry.

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REFERENCES