

A Springback Compensation Study on Chrysler 300C Stamping Panels Using LS-DYNA®

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ABSTRACT

Springback compensation studies on a few selected auto panels from the hot selling Chrysler 300C are presented with details. LS-DYNA® is used to predict the springback behavior and to perform the iterative compensation optimization. Details of simulation parameters using LS-DYNA® to improve the prediction accuracy are discussed. An iterative compensation algorithm is also discussed with details. Four compensation examples with simulation predictions and actual panel measurement results are included to demonstrate the effectiveness of LS-DYNA® predictions. An aluminum hood inner and a high strength steel roof bow are compensated, constructed and machined based on simulation predictions. The measurements on actual tryout panels are then compared with simulation predictions and good correlations were achieved. Iterative compensation studies are also done on the aluminum hood inner and the aluminum deck lid inner to demonstrate the effectiveness of LS-DYNA® compensation algorithm.

1. INTRODUCTION

Springback compensation has been a challenging problem for auto industry. Although simulation based virtual try out to resolve the formability issues has been adopted by all the major OEMs before the stamping production, the successful story of simulation based springback compensation is still rare. There are a few key issues which are to be addressed before successfully implementing on all the major auto panels. 1. Consistency in accuracy of the springback prediction using various stamping software packages. 2. Need for a simulation based iterative compensation method. 3. Need for methods to speed up the time consuming surface morph activities to compensate the tool in order to meet the manufacturing delivery requirements. 4. Requirement of quality control during die construction and actual tryout to make sure that the manufacturing is based on original design intent with minimum process

deviations. 5. Need to investigate and fully understand the functional try out requirements due to welding, hemming and sub-assembly. In this paper, we only focus on the first two issues.

Much effort has been made to improve the springback simulation accuracy. In NUMISHEET conferences, benchmark problems have been experimented and simulated. Good results have been observed [Ref 1-5]. NIST-SPP project, a US government supported consortium project between big three and major metal suppliers, is another forum to gather industry and academic researchers to work on the springback simulation accuracy. New material models which address key issues such as nonlinear kinematic hardening, anisotropic hardening, and Young's modulus during unloading have been developed and tested. New friction models have been tested. Penalty based and Lagrange multiplier based contact algorithms to improve contact force calculation and friction calculation have been developed and tested. It is observed that correlations can be achieved even based on regular LS-DYNA® simulation without enhancements in material modeling and contact algorithms for the lab test benchmark examples [Ref 1-5].

There are many different ways to do the compensation. Springforward method was introduced by L Wu [Ref 6]. The main concept was to use residual stress from forming and mapping it to the final deformed trim panel with a reverse direction. Then, the deformed trim panel shape under the specified load of the residual stress is used as the compensation intent. In industry applications, the most popular way to achieve compensation is to use the measured displacement from springback and map it in the reverse direction. For example, if a 6 degree open is measured after springback, a 6 degree close from design intent is to be added to the compensation. This method is proved to be effective as long as the springback amount is within a small amount [Ref 9].

In this paper, springback simulation parameters to improve prediction accuracy and iterative compensation algorithm using LS-DYNA® are discussed in detail. Application procedure in Chrysler is also discussed with supporting application examples.

2. SPRINGBACK SIMULATION PARAMETERS

Many studies have been done to identify appropriate simulation parameters for springback predictions using LS-DYNA®. Since LS-DYNA® is a general purpose FEA software, most of the default parameters were chosen from other applications such as crash simulations. The default parameters are not necessarily good for metal stamping springback predictions. Among the simulation parameters, the following are identified as the ones which are sensitive to our final springback results: tool speed, mass scaling factor and time step, mesh refinement, shell element selection, the number of integration points through thickness, the material model selection, adaptive mesh control parameters, penalty factors for contact, the contact stiffness, and the tooling contact offset.

Assuming the stamping speed at 15 strokes per minutes and the distance of tooling travel at 100mm leads to a tooling travel speed of 50mm per second. If we use this tooling speed in our simulation and do not use any mass scaling, it could be weeks, or even months before we can have the forming simulation completed. In order to reduce CPU time and make stamping simulation achievable using our current computing resources, we have to artificially increase the tooling speed and add some mass scaling. Usually, we use 1 – 2 meter per second as the tooling speed for the springback simulation while zero mass scaling or 1 to 2 times mass scaling is added. Recently, selective mass scaling method was implemented in LS-DYNA®. It is found that the user can use much large time step without affecting the springback prediction.

Sheet metal blank mesh size is also very important. If we do not have a fine mesh to cover the controlling radii of the panel, the springback results can be incorrect. The general guideline is to have 3-4 elements covering the smallest controlling radius. For example, the smallest blank element size is $R \cdot \pi / (2n)$ mm if the minimum controlling radius is R mm, where, R is the radius, and $n=3$ to 4. The shell element 16 with 5 integration points through thickness is selected for enhanced accuracy in springback simulation. Tool gap and tool offset are also very important parameters in simulation and 20% of metal thickness is added for tool contact offset in this study.

Penalty-based contact interfaces are recommended for most of metal forming simulations. The penalty stiffness scale factor (SLSFAC on the *CONTROL_CONTACT keyword) should be set between 0.01 and 0.05. When significant penetrations are found, larger value should be used. Recently, a new feature, smooth contact, was

implemented in LS-DYNA®. With this new feature, smooth surfaces are automatically generated inside LS-DYNA® based on FEA mesh and the contact calculation is performed based on the created surfaces, rather than on the linear elements. By using this smooth contact feature, it is found that the springback prediction is much less dependent on SLSFAC and the results agree better with test measurement data.

Adaptive mesh is usually applied for regular forming simulation. It is very important to capture the desired geometry features with adequate fine mesh while still maintaining reasonable CPU time. To achieve that, adaptive mesh is needed. But it is found that the error introduced by adaptive mesh can introduce some noises in stress calculation and that can introduce slightly different springback results. It is decided that a connected mesh derived from the adaptive mesh should be used for springback simulation.

Hill's 1948 planar isotropic model is used for high strength steel application while Barlet's model is used for aluminum applications. Since we used Alcoa's aluminum product for our application, we obtained the Barlet's model material parameters from Alcoa. We did not use any non-linear kinematic hardening material models due to lack of material parameters associated with these models.

In implicit springback analysis, converged solution must be obtained with a tight enough tolerance. The default tolerance is applicable in most cases.

3. COMPENSATION ALGORITHM

In the 90s, many people focused their research on springback prediction, which resulted in significant improvements in this area. Due to improvements in prediction accuracy, springback compensation becomes a hot topic recently. A dedicated consortium project, Springback Compensation Project (DFE), sponsored and organized by USAMP, was proposed. GM, Ford, Chrysler, US Steel, and Alcoa were the active participants, and LSTC was hired as the major software supplier. During this project, a new module was successfully implemented in LS-DYNA® to automatically compensate for springback.

Nielsen Stander et al [Ref 7] proposed an algorithm by using optimization method. The springback was compensated based on CAD surface. The parametric preprocessor TrueGrid was used. A set of design variables, such as geometric variables in critical locations, were selected for optimization. Tool elevation was modified during the optimization. The NUMISHEET'96 S-Rail was used as an example. It was found that 96 iterations were needed to achieve the convergence. Because the method is extremely CPU time consuming, it is impossible to extend this algorithm to industrial applications. However, from this study, it was found that springback trends are consistent with

changes in the die shape, namely, proportional convergence is observed.

To effectively compensate springback, a new algorithm was proposed and implemented in LS-DYNA®. This algorithm was based on the digitized mesh, rather than on the CAD surface. The capabilities of this feature includes the following: a) Ability to calculate the deviation of the part from its design intent of the stamped part, and automatically compensate the tool to minimize the deviation; b) Ability to modify the trimming curve after the die modification to make sure that the trimming curve follow the modified tool; and c) Ability to automatically detect undercut problem.

Since springback compensation is a non-linear problem, it is difficult to compensate for springback within one iteration. An iterative approach was incorporated into this algorithm. If a single iteration is not enough to bring down the deviation to be less than the acceptable tolerance, it is always advised to use more iterations. Usually, it is found that 2 to 4 iterations are needed for most of the applications.

In addition to iterative approach, a scale factor was also available. It is found that it is not effective to fully compensate the springback deviation by changing the tools just in the opposite direction. An effective scale factor allows the user to decide the ratio of the shape deviation the part is compensated. The preferred scale factor is case dependent. The experienced user can always use the proper one to reduce iteration times. For in-experienced ones, it is suggested that a scale factor of 0.75 be used.

One of the challenging issues in springback compensation is the modification of the binder and addendum. After trimming, only a limited part of the tool has direct relationship with springback of the blank part. The modification of the rigid tool outside the trimming curve has to rely on extrapolation, which is an unstable process and can easily result in an un-smooth surface. To resolve this problem, eight approaches were implemented to meet the requirement for each application. The frequently used methods are 6 and 7, which tend to provide smoother surfaces.

Method 6: the smoothness and the transition region of the modified surface will depend on the springback magnitude and the smoothing factor. If the springback is large, the transition region will be increased automatically. A larger smoothing factor will result in a smaller transition region. This method is used in places when the binder can be changed.

Method 7: in many cases, it is expected that binder remains unchanged, and method 7 is designed to meet this requirement. Under this option, the smoothing factor has little effect. The smoothness of the modified tool depends on the magnitude of the springback and the size of the addendum region. If the springback is large

and the transition region is small, the resulting compensated tool might not be smooth.

To obtain a homogeneous gap between the rigid tools, an option to define the master side was also available. If both sides of the rigid bodies are treated equally, the numerical error can result in a non-homogeneous gap between the die and punch. Usually, only one side (master side) of the tool will be chosen as the master side, and the modification of the other side (slave side) depends solely on the change, which happens in the master side. In this way, the two sides are coupled and a constant gap between the two sides is maintained. If both sides are chosen as master side, the gap between the two sides might change and the gap might become inhomogeneous. In method 7, the choice of master side will have effect on the final result for three piece draw. At this time, when the punch and binder are chosen as the master side, the binder region will not be changed. Otherwise, when the die is chosen as master side the binder will be changed because the changes extend to the edges of the master tool.

Sometimes it is found that compensation becomes saturated. When it happens, it is important to check the mesh quality for the rigid bodies. Reasonable fine mesh is needed, even for the rigid bodies, for an effective compensation.

4. APPLICATION PROCEDURE

Formability simulation and virtual try out are performed from clay/styling design stage prior to NC machining. It is expected that the product geometry and associated process are free from formability issues prior to NC machining. Namely, all the over thinning issues, wrinkle issues and surface quality issues are expected to be resolved before NC machining starts. A few weeks before NC programming, a plan is proposed to prepare for springback compensation.

Springback simulation and compensation is still a relatively new application in Chrysler group. A few different approaches of compensation have been tested in Chrysler. The first one is the approach of mixed method between historical data and simulation, which means that the compensation proposal is based on both historical data and simulation prediction. This approach is employed whenever a similar part history is available from the past. The springback simulation prediction is presented and compared with the historical data. If the springback trend is consistent between prediction and historical data, the compensation will be based on simulation prediction. The second approach is the mixed method between soft tool panel measurement and simulation. Before hard tool NC programming, a pilot build vehicle is usually built to do many different tests such as structural, fatigue, safety, etc. To build the pilot test vehicles, soft tool die is constructed and stamping panels are made. As long as the soft tool die is built using the similar process, the springback measurement from the soft tool panels can be used for reference.