Advanced Line Die Forming Simulation Technology and Its Impact on Stamping Automotive Body Panels

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Abstract. Line die forming simulation and validation create tremendous business values for automotive die developments and production stamping while they pose a great technological challenge to stamping CAE community. GM Manufacturing Engineering Die Center has developed an integrated line die analysis technology to validate die lines as a productionized business process. In this process, a finished stamping body panel can be streamline analyzed with required time, accuracy, and quality. This paper presents critical issues in line die analysis, discusses technical challenges in production applications and software development, and finally demonstrates the impact of line die forming simulation and validations on automotive body styling and tooling developments.

INTRODUCTION

With the advent of CAD, CAE and CAM in automotive industry during the last decade, formability analysis has transformed the tool and die development of automotive body panels from a traditional trial-and-error process to a math-based engineering process. Forming an automotive body panel requires a die line that consists of draw/form die, trim die, pierce die, and flange die. Only through line die forming analysis of the entire die line can the total manufacturability and quality of stamped panels be thoroughly assessed [1, 2]. As of now, however, the formability analysis is mostly limited to the draw die development alone, rather than to the entire die line necessary to manufacture a part. The reasons are due to the following technological challenges: (1) a robust analysis code with the required accuracy, (2) an innovative computational technology and facility to reduce excessive CPU time, (3) an expert team and analytical tool kits for problem solving to drive product and tool geometry changes, (4) a comprehensive quality buyoff standard to validate virtual manufacturing, and (5) an integrated process across engineering and manufacturing for stamping production.

GM Manufacturing Engineering’s Die Center (previously Metal Fabricating Division’s Die Engineering Services) has successfully developed an integrated process of line die formability analysis to address the challenges listed above. The integrated process is actually a virtual manufacturing process ensuring a die line can stamp quality panels before die design and construction begin. This results in elimination of proof tools and significant reduction of time and cost in die construction and tryout (Figure 1). All failure modes, including splitting, wrinkling, surface quality, and springback issues in draw die, trim die, redraw or restrike die, and flange die, are addressed and resolved during the die engineering stage of vehicle development. A math-based workbook is then created for each die line. The workbook serves not only as a manufacturing guide during die construction and tryout, but also as a trouble shooting tool during day to day stamping production.

FROM DRAW DIE ANALYSIS TO LINE DIE ANALYSIS

In the math-based line die development process, the draw die is first designed and validated through formability analysis. The potential formability and quality problems (Figures 2 and 3) are predicted and resolved in the math development stage before a physical die is built and tried out. As early as 1997, the GM Die Center had utilized formability analysis to
**Digital Validations of Line Die Developments**

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**FIGURE 1.** Line die development process: digital validation versus traditional tryout.

**FIGURE 2.** A typical draw die setup of a fender.
eliminate proof tools and associated tryout. Both the draw die development and the die tryout were purely based on the passed formability analysis on the validated math data [3].

During the past three years, the GM Die Center has moved its focus onto advanced stamping simulation for line die operations. In each die operation, there are particular concerns in formability, quality, and throughput requirements. The total quality and manufacturability of stamping depends on the success of each die operation in the press line. More attention has been paid to resolving line die formability and dimensional quality problems in the secondary forming operations such as re-strike, trim and flange. In the stretch flanging operation, the common failure modes are the fracture at the bend radii of flange break line and splits along the hoop direction of the trim edge. In the shrink flanging operation, the bending fracture along the bend radii of flange break line and excessive wrinkles along the hoop direction of the trim edge are common failure modes. Springback and its induced dimensional and surface quality problems are the increasing concerns in vehicle manufacturing quality control.
users’ setup time and kinetic checking of the setup inquire a higher demand for the analysis software terms of user friendliness and functionalities. The GM Die Center has been working jointly with several simulation software vendors to improve the software’s functionality to meet the line die analysis requirements.

TURN-AROUND TIME IN LINE DIE ANALYSIS

The forming analysis for the line die simulation is now becoming increasingly demanded as an extremely critical business segment to support the fast vehicle development and tooling readiness. Application of the line die forming simulation, however, has been hindered due to its excessive simulation time and its induced unstable solution process. For a large body side panel, for example, each draw die simulation itself usually takes 2 to 3 days to complete. For a line die simulation, it could have taken several weeks to complete a single cycle of draw, trim, and flanging simulations. The excessive simulation time creates a significant technical barrier for the line die analysis to be used as a production tool in die engineering and design.

As a first step to reduce the simulation time, the GM Die Center pioneered in adopting LSF (Load Sharing Facility) and MPP (Massively Parallel Processing) into stamping simulations. The GM Die Center has been working jointly with its simulation software and hardware vendors to develop, test, and implement this technology in either a heterogeneously distributed computing network or a centralized computing environment. In MPP technology, a single simulation task is performed by a cluster of computers simultaneously by: (1) breaking the master simulation into a number of subtasks by dividing the die set to several pieces using the Domain Decomposition, (2) performing each subtask by an individual computer simultaneously, and the information pieces are processed by Message Passing Interface. A range of six to ten folds reduction in simulation time has been achieved through this technology [4]. The computing technology was successfully implemented for draw die simulations in 2002 and fully productionized for line die forming simulations on a high performance computer platform in 2004. This enables formability analysis to meet the demands for quick response and solutions to product design and die development.
FORMABILITY CRITERIA FOR LINE DIE ANALYSIS

The reliable failure criteria and quality standards for line die forming are critical for stamping CAE engineers to accurately predict formability problems and quality defects with the predicted strains and stresses. A set of comprehensive buyoff criteria have been developed at the GM Die Center by incorporating multiple formability indices and quality measures, in addition to the traditional forming limit curve that has been used in the stamping industry for many years [5-7]. All failure modes, including splitting due to fracture limit of strains or allowable total elongation, wrinkling, and surface quality issues will be assessed by using the comprehensive criteria. A supplementary checking procedure has also been created to evaluate surface distortion, skid lines, wrinkling and waviness.

SPRINGBACK ANALYSIS IN LINE DIE ANALYSIS

With implementation of line die forming analysis in die engineering process, it has become possible to evaluate springback on a finished part thus it is able to correct the springback on the finished part during the die engineering stage. Springback may occur in a significant amount after each die operation of the line die forming. Because of the springback, the shape and dimensions of the panel are out of tolerance due to shrinkage, twisting, and unbending. This dimensional quality problem causes difficulties in the panel subassembly and vehicle assembly (gaps, flushes, and interferences among vehicle body components and subsystems).

The GM Die Center has put remarkable efforts in developing, benchmarking, and productionizing the advanced line die analysis technology to predict and resolve springback [8]. Two major methods in predicting and solving springback are the interactive process and the integrated process. In interactive process, forming simulation, springback analysis and resolutions are sequentially launched for draw, trim, and flanging operations. After the springback predictions, mechanics-based springback reduction methodology is first applied by changing the forming process parameters (bead force, binder forces). If the springback is still significant afterwards, the geometry-based springback compensation for changing the die geometry has to be used. The springback compensation

![Figure 5. Springback contour in a fender panel.](image)
solution is further validated through additional cycles of forming simulations and springback predictions in an iterative manner. It is robust, but requires multiple software and demands higher engineering skills and more human interventions. In the integrated process, the forming simulation, springback predictions and compensations are performed automatically or interactively within the same computation run (Figure 5). This process reduces the dependency of results on human expertise and reduces human intervention and labor hours.

For outer panels like fenders as shown in Figure 5, springback analysis is conducted to identify the dimensioning and tolerancing problems in the finished part. Instead of compensation methodology, the reduction or suppression method is used to correct the dimensioning problems by optimizing flange design. For this kind of outer panels, springback analysis is also used as an analytical tool to help identify surface quality issues in the finished part. Currently at the GM Die Center, large scale parts like sedan body side outers can be streamline-analyzed from draw die, trim dies, and flange dies to springback and compensations with required time, accuracy and quality.

CONCLUSIONS

Productionizing line die forming simulations brings forth tremendous technical challenges but great business values to automotive stamping business, stamping CAE community, and simulation software vendors. An integrated stamping CAE process needs to be developed and fully productionized for line die engineering and validations. With this integrated process, draw, trim, and flange die forming operations can be analytically validated prior to die construction. This will lead to a substantial reduction in die tryout time and significant improvement of panel quality; in turn, it saves cost and supports faster vehicle development. It is stamping CAE that enables to handle such a large volume of dies within ever-decreasing lead time and put got-to-have products in market in time. The business practice at the GM Die Center proves that the integrated process has generated a significant business impact and values onto the die and stamping operations.

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