The Evolution of Sheet Metal Forming Simulation in Stamping Industry

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Abstract

The field of sheet metal forming has experienced numerous innovative changes over the past few decades, such as new forming techniques and application of computer technologies. New forming techniques include application of tailor-welded blank, high strength steel forming, hydroforming, press automation and so on. One of the computer technologies is the implementation of Computer Aided Engineering (CAE), such as sheet metal forming simulation. The application of sheet metal forming simulation has been commonly utilized in the stamping industry to predict the forming feasibility of a wide variety of complex components, ranging from aerospace and automotive components to household products.

Since the early 1990s, engineers have adopted LS-DYNA, because of its "incremental solution" capabilities, as their solver of choice for sheet metal forming simulations. Through continuous improvement and implementation, the incremental solution has proven to be accurate, reliable and effective. eta/DYNAFORM with its engine driven by the powerful LS-DYNA solver, has over the years been developed and changed from a FEA oriented approach to a process oriented environment that is most suitable for the tool & die industry. It is widely utilized by the tool and die industry to troubleshooting stamping defects, improving tooling design and product quality. Combining the strengths of the solver accuracy, enhanced computer processing speed, and user-friendly graphic user interface (GUI), eta/DYNAFORM has greatly assisted the tool and die industry in shortening tool making lead time and reducing it's associated cost.

As the demand for sheet metal forming simulation technology accelerates, the need for new technology and requirements have also grown rapidly. In this paper, the evolution of LS-DYNA based sheet metal forming simulation technology from a FEA based environment has been changed to a tooling process based application. The key features include Blank Size Engineering (BSE), Die Face Engineering (DFE), Die Structure Analysis (DSA), Springback Compensation Process (SCP) and Tubular Hydroforming (THF).

Introduction to Stamping Simulation

During the past few decades, the implementation of computer technologies such as computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) has created tremendous impact in the area of military, aerospace, automotive and stamping industries. Today, one of the innovative changes in stamping industry is the implementation finite element simulation to improve design and manufacturing of stamped components.

The finite element simulation for sheet metal forming applications created strong interest by researchers beginning in the mid-twentieth century. Throughout the 1970s and 1980s, numerous sheet metal forming simulations were conducted based on axi-symmetric or plane strain conditions [1]. However, these studies only provided general information on a variety of important issues on sheet metal forming and provided little use to the complicated 3D sheet metal forming problems. In the 1990s, more vigorous research and development had been carried out to improve the reliability and accuracy of sheet metal forming simulations. The most noticeable are the NUMISHEET and NUMIFORM series of international conferences [1-12], though there are similar conferences in this field. These conferences were organized to study 3D industrial problems through computer simulations and experiments.

In recent years, stamping simulation applications have grown enormously, as the benefits of troubleshooting and optimizing processes through the computer rather than through extensive shop trials, have been realized [13]. The rapid development of software technology, together with faster and lower cost computer hardware, have enabled many metal forming operations to be modeled cost-effectively.

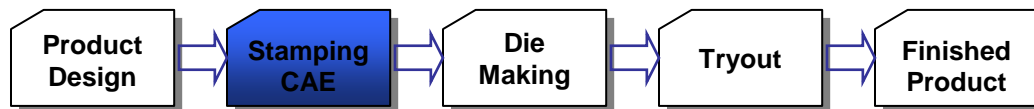Product Design → Stamping CAE → Die Making → Tryout → Finished Product

Figure 1: The Stamping CAE Application in Modern Stamping

The maturity of stamping simulation has made Stamping CAE one of the key components in modern stamping industry. As highlighted in Figure 1, Stamping CAE can be broken down to include formability analysis, blank size engineering (BSE), die face engineering (DFE), die structure analysis (DSA), and springback compensation (SCP). In this paper, Stamping CAE technology will be described along with emerging tubular hydroforming (THF) modeling technology.

Evolution of DYNAFORM

The sheer power of sheet metal forming simulation in providing an effective stamping solution prompted the development of eta/DYNAFORM in mid 1990. With numerous automated features and incorporating the power of explicit non-linear FEA code LS-DYNA [14,15], the innovative eta/DYNAFORM software has proven to be an efficient FEA tool for stamping simulation. It has been widely used by the sheet metal forming industry for solving complex forming problems such as wrinkling, skidmarks, tearing, excessive thinning and springback.

In the later 1990s, the Personal Computer (PC) version of eta/DYNAFORM was first developed to suit the tool and die industry users who were predominately using the Microsoft Operating System (OS) based PC. With additional modules and capabilities to be added to the revolutionary eta/DYNAFORM, the development team decided to unify the graphic user interface (GUI) and database for both the PC and Unix/Linux platforms in order to avoid double development effort. As result of this unification, eta/DYNAFORM 5.0 now provides capabilities with a quantum leap from the released version 2.0 level.

eta/DYNAFORM has continuously gained popularity and demand in the tool and die industry. One of the major demands is a robust and process based simulation technology. In order to meet such demand, a Quick Setup (QS) scheme was organized using a process guidance approach. It offers the user a simulation environment based on the actual stamping process.

The Die Face Engineering (DFE) module was developed to enable the user to quickly derive a suite of binder and addendum surfaces as a baseline tooling design for subsequent formability studies. With the powerful and versatile toolbox, DFE serves as a bridge to enable early assessment of the part and tooling design.

The capabilities of eta/DYNAFORM have been continuously improved in recent years to meet the demand of the stamping industry. Several new capabilities have been developed in eta/DYNAFORM Version 5.5 to facilitate stamping engineering solutions for its customers to get their job done more efficiently. Some of these capabilities are briefly described in the following section.

New Technology in Stamping Simulation

Die Face Engineering (DFE)

The DFE module is a CAE based die face engineering module developed for incremental stamping FEA users to engineer the draw die, including binder and addendum, from the part geometry. As a supplemental tool to CAD based DFE, CAE based DFE enables the user to quickly derive a suite of binder and addendum surfaces as a baseline tooling design for further formability feasibility studies, as shown in Figure 2. As a result, it reduces iteration time for tooling design and the development cycle. In the end, this module helps to lower the associated costs.
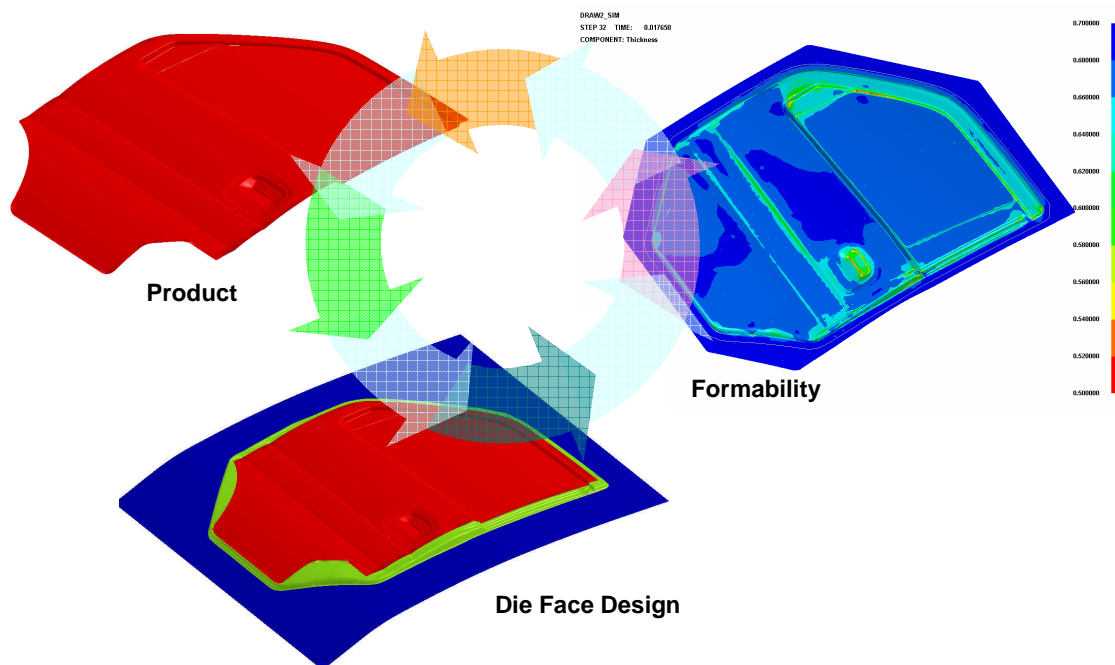

Figure 2: An illustration showing the quick tooling evaluation of a door outer panel using CAE based DFE.

The architecture of DFE in eta/DYNAFORM Version 5.5 provides a "single code" environment for stamping simulation. It allows the user to easily design and re-engineer the die tooling using the numerous automated functions available throughout the software. Built on the powerful parametric *Non Uniform Rational B-spline (NURBS)* surface engine, DFE contains both semi- and fully-automated functions from tipping, element fillet, reverse trimming, outer smooth, binder design and addendum design, draw bar, sausage, etc. [16]. These powerful and robust tools allow the tool design professional to quickly get the job done.
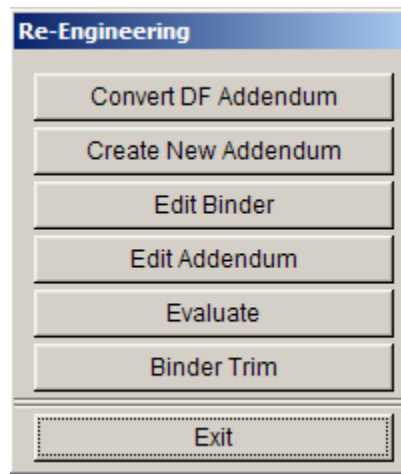
Figure 3: An illustration of the newly developed Re-Engineering dialogue window.

One of the latest developments in DFE is the Re-Engineering tool as shown in Figure 3. The re-engineering tools allow the designers to quickly replace the product design on existing die face development with the same product that has minor product changes. The information is stored as a knowledge-based database and can be efficiently applied to the die design of a new product design of a similar part in the future. The effectiveness of such capability helps to reduce the time spent on the development of a new die design.

Blank Size Engineering (BSE)
Driven by the demand from the tool and die industry to have a tool that can quickly provide blank size estimation for stamping quotation, the BSE module was first introduced in eta/DYNAFORM 5.0 two years ago. Since then, it has been widely utilized by the tool and die users to estimate the blank size of stamped parts.

The demand of tool and die users has further pushed development and improvement of the BSE module. The latest improvements of BSE in eta/DYNAFORM 5.5 include the blank nesting, the blank development and MSTEP (Modified One Step) solution. As shown in Figure 4, the blank nesting function allows the users to obtain an optimized blank nesting layout and estimate the material utilization. Furthermore, the nesting result can be output in an Internet ready format, along with the calculation of cost. Currently, five different types of nesting layouts are made available in BSE.

Another improvement is the blank development function, which allows the user to easily modify the blank outline from blank size estimation. The developed blank outline can then be selected to obtain the mesh needed for subsequent incremental stamping simulations. Finally, the user-friendly MSTEP solution, as shown in Figure 5, is provided to enable the user to evaluate the tooling design in a time effective manner.
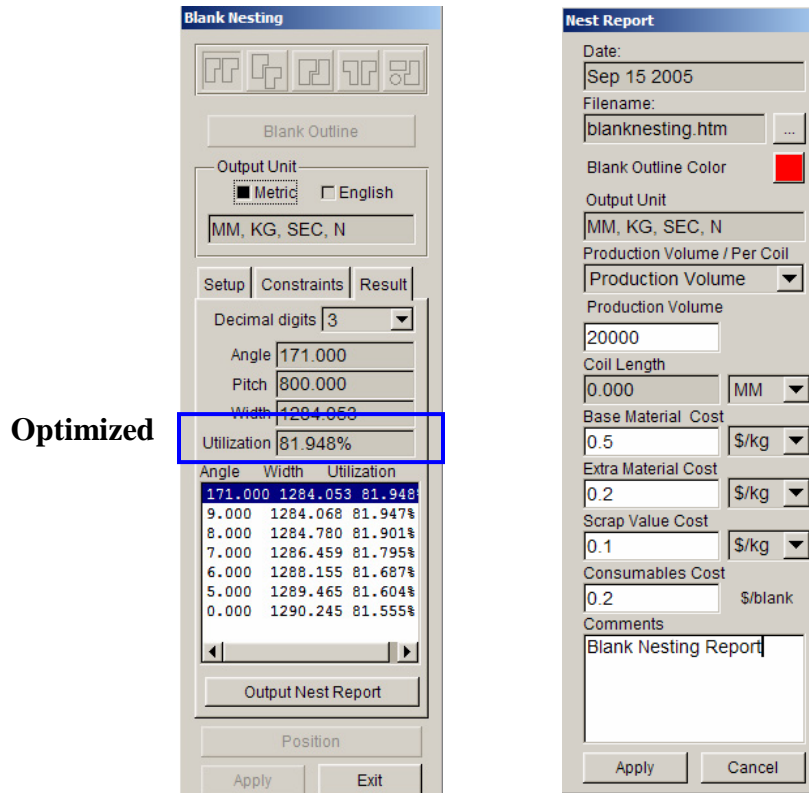

Figure 4: An illustration showing the Blank Nesting capabilities in BSE module.
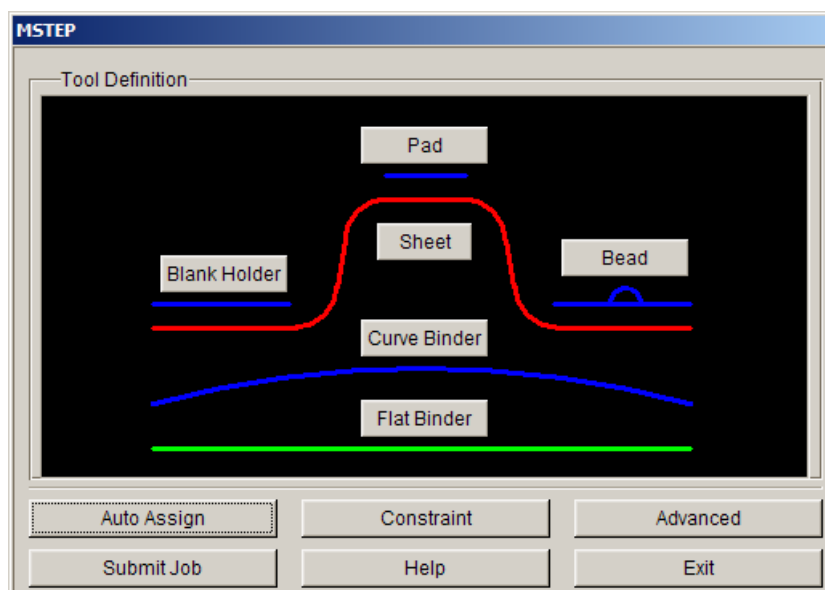

Figure 5: An illustration showing the MSTEP GUI.

Springback Compensation Process (SCP)

The springback phenomenon, or shape change, has had a great impact to the stamping industry. This phenomenon affects and causes poor part quality and dimensional stability, as well as an increase in lead-time and associated cost. With increased use of high strength, advanced high strength steels and aluminum in automotive body design, the springback phenomena and its solutions are crucial to the automotive OEMs.
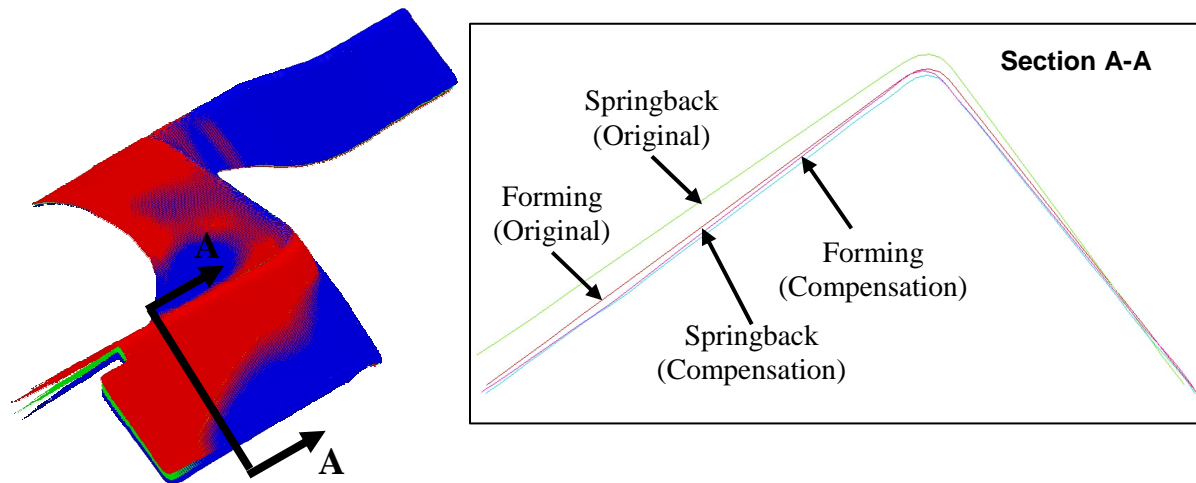

Figure 6: Implementation of DFE based springback compensation on Structural Rail. *(Image courtesy of GM)*

In recent years, the improvement of springback prediction enables the researcher to investigate the springback compensation for die face through CAE methodology. The springback compensation can be conducted using different approaches. The most noticeable one is the Spring Forward approach [17-19], which is based on stress and displacement criteria to determine the amount of springback compensation. To enhance the approach, the SCP module was developed to quickly and easily achieve the maximum allowable compensation using the undercut (or die lock) as the primary criteria [20]. As shown in Figure 6, the SCP module is utilized to perform springback compensation of a typical DP600 structural rail using iterative coupled springback compensation, formability and springback analyses. The springback of the formed part is significantly alleviated after the SCP implementation.

The SCP module also allows the user to map the original CAD die surfaces to the compensated die mesh, via its powerful *NURBS* surface engine. The NC quality mapped surfaces are then output for further die structure design. Such capability greatly reduces the time spent by the die designers to rework the compensated die surfaces. The SCP module is also available in eta/DYNAFORM 5.5.

Die Structure Analysis (DSA)

The integrity of the die structure has always been a primary concern for sheet metal stampers in terms of part quality, weight, die life, safety and cost efficiency. A die structure that is lacking in structural integrity will produce poor quality stamped parts due to the large deformation of the die during the stamping operation. Furthermore, a broken die will affect the production of the entire assembly line as the part produced by that die cannot be supplied to the assembly line.

This can result in millions of dollars in losses to the automotive OEMs. A broken die also will pose safety hazards to the employees on the job during the maintenance operation.

An ill-designed die structure will also result in an over weight die, increasing the cost of die construction and maintenance. Driven by the needs for solutions to resolve the mentioned concerns, DSA [21] was developed and delivered to a major North American automotive OEM two years ago. It enabled the user to investigate the integrity of the die structure by imposing different boundary conditions. Due to popular demand, DSA is now packaged in eta/DYNAFORM 5.5 as a stand-alone module or bundled with the LS-DYNA stamping specific solver.
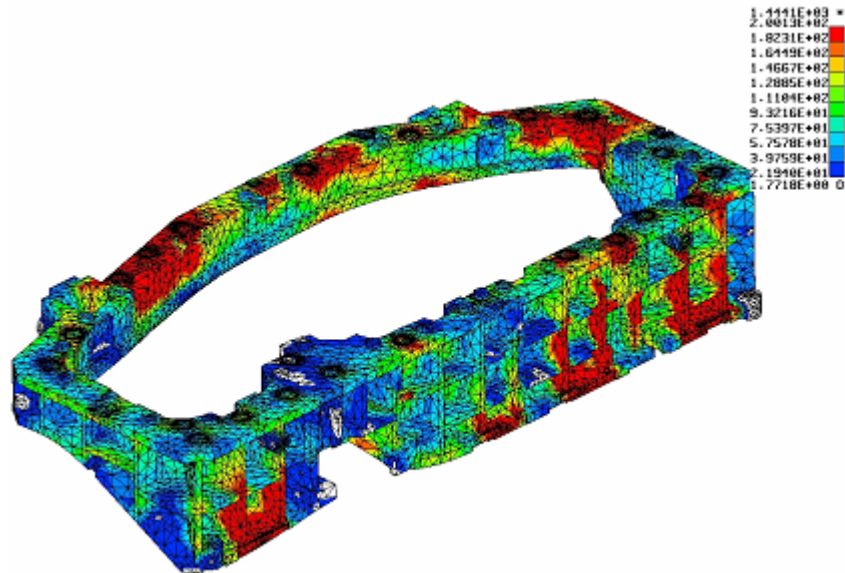

Figure 7: An Illustration showing the Stress Contour of Lower Ring of Body Side Outer subjected to Static Loading. *(Image courtesy of GM)*
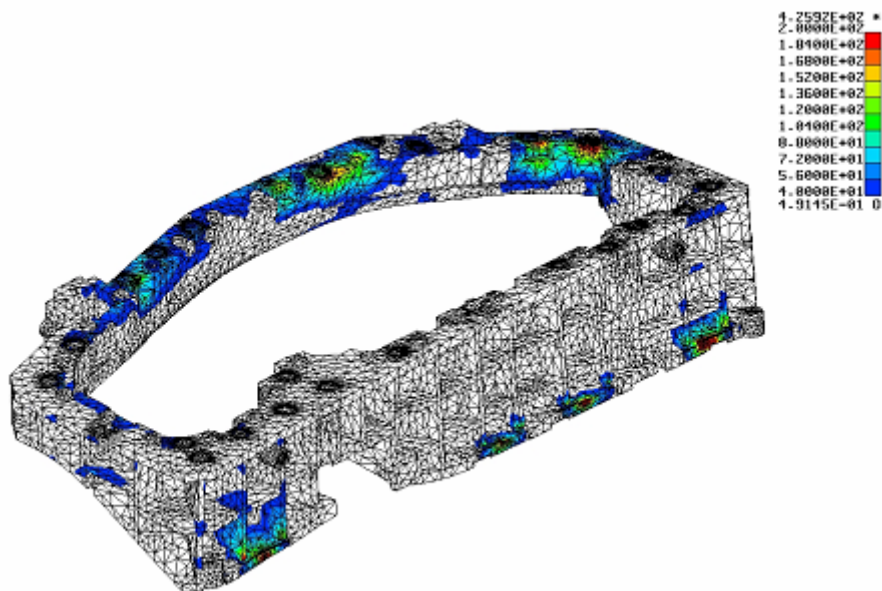

Figure 8: An illustration showing the Stress Contour of Lower Ring of Body Side Outer subjected to Impact Loading. *(Image courtesy of GM)*

The module is equipped with two types of automatic 3-D solid meshing capabilities: 4-node tetra element and 10-node tetra element. Furthermore, the quality of solid mesh can be easily checked using the model check function. Upon completion of the solid mesh, the user can easily define the loading and boundary conditions for either static and/or impact analysis. For static analysis, the loading condition is the static weight of the die, while the loads during the stamping operation are adopted for impact analysis. Examples of static and impact analyses for the lower ring of a typical body side outer are shown in Figure 7 and Figure 8, respectively.

DSA enables the user to check the deflection and stress distribution of the die under given imposed boundary conditions. It also provides the fatigue life analysis capability that allows the user to calculate the fatigue life of a set of dies. As shown in Figure 9, the fatigue life distribution of the lower ring of a typical body side outer can be easily obtained by utilizing DSA.
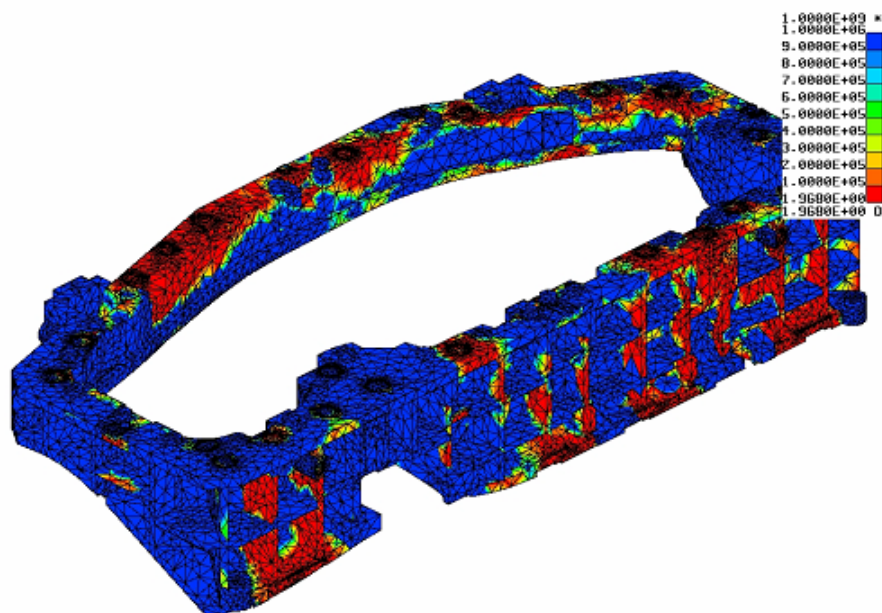

Figure 9: An illustration showing the Fatigue Life Cycle prediction for Lower Ring of Body Side Outer. *(Image courtesy of GM)*

Tubular Hydroforming (THF)

During the past few years, tubular hydroforming has significantly impacted the automotive structural designs by providing benefits such as part consolidation, cost reduction and improved structure performance. Increased applications of hydroformed parts in the automotive industry has become a driving force for the development of hydroforming simulation software. The evaluation of the hydroforming process is similar to conventional stamping, albeit with some specific requirements such as tube bending, pressure loading, etc.

eta/DYNAFORM 5.5 is packaged with a brand new process oriented tubular hydroforming module, as shown in Figure 10. This module enables the user to setup tube-bending simulation with and without mandrel assembly. To further enhance the capability, several types of mandrel systems are made available for the user. As for hydroforming capabilities, the user can quickly

setup the preform and hydroform stages via the streamline process guidance *GUI*. The user can select either "Pressure" or "Volume" control during the hydroforming process.
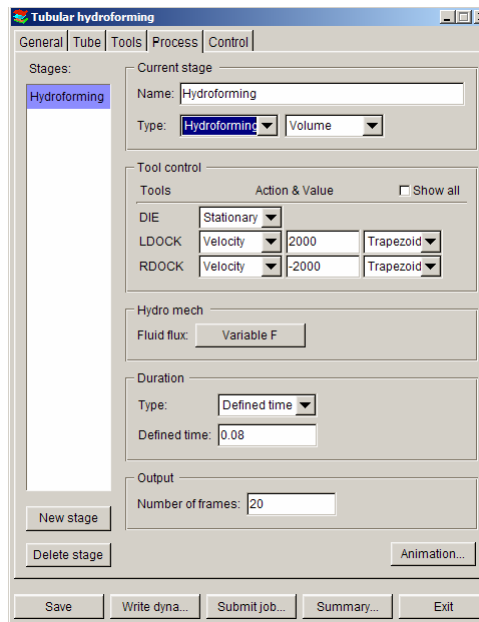

Figure 10: The process oriented Tubular Hydroforming Module implemented in eta/Dynaform 5.5.

Future Technology Challenges

The future technology challenges include continuing improvement of the existing capabilities of eta/DYNAFORM and development of new and advanced technologies in the areas of die design, stamping simulation and process design. One of the biggest challenges is to enhance the robustness and user-friendliness of the DFE GUI. This improvement may help many designers from the tool and die industry that may not have knowledge of adapting advanced CAE applications, such as eta/DYNAFORM, during the tool design phases.

Another big enhancement is the implementation of a CAD Native Library in eta/DYNAFORM to facilitate reading of the product design without missing CAD data. Furthermore, the software is equipped with the capability of creating NURB surfaces. The capability is important for output of NC quality surfaces using the CAE based DFE. It minimizes the time spent on repairing die surfaces during the die design stage. It is expected that the advanced development in DFE, as well as simulation software, will eventually help to bypass the necessity of soft/hard tool tryouts during the stamping process. Therefore, the automotive OEMs and tool and die industry will significantly shorten the die manufacturing lead time, reduce the associated cost and deliver the die sets on time.

The increased application of BSE in the tool and die industry has driven the demand for a "strip layout" function for progressive stamping. This function will allow the user to input the blank nesting result, number of stations and type of station (pierce/trim/form/idle/restrike). The output of a sample strip layout includes the required press tonnage, general die dimension, guideline for press speed, potential failure within the strip and estimation of wear areas in the die due to high

friction or shear surfaces. The future development of BSE will heavily depend on feedback and demands from the tool and die users.

The springback prediction and resolutions are the most difficult tasks in stamping CAE. The authors envision the pace of development in SCP and related activities will continue at a faster rate into the future. New processes such as line die, die kinematics, scrap shedding, panel handling, hot stamping and hot gas forming need to be simulated. With continued evolution in computer hardware technology and software engineering, the authors also envision the implementation of a coupled DSA and formability analysis software. Such capability will move the digital tryout prediction much closer to reality.

Conclusions

This paper presents the evolution of the state-of-the-art LS-DYNA based, sheet metal forming simulation technology – eta/DYNAFORM. For nearly a decade, the software has evolved dramatically to provide the best stamping simulation technology for the tool and die industry, as well as the stamping industry and automotive OEMs. The recent impressive capabilities implemented in eta/DYNAFORM 5.5 include DFE Re-Engineering, Blank Size Engineering, Springback Compensation Process, Die Structure Analysis and Tubular Hydroforming. These brand new capabilities aim to help the stamping CAE engineers to resolve the stamping engineering problems during the vehicle development cycle. Continuous improvement and development of new stamping CAE technology is the key to ensure successful implementation of stamping CAE in the vehicle development cycle, as well as stamping manufacturing. The requirements by the tool and die industry, coupled with the computer hardware evolution and software engineering will continue to push the boundaries of stamping CAE for the next few decades.

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