CAE Based Die Face Engineering Development to Contribute to the Revitalization of the Tool & Die Industry

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Abstract. Over the past two decades, the Computer Aided Engineering (CAE) tools have emerged as one of the most important engineering tools in various industries, due to its flexibility and accuracy in prediction. Nowadays, CAE tools are widely used in the sheet metal forming industry to predict the forming feasibility of a wide variety of complex components, ranging from aerospace and automotive components to household products. As the demand of CAE based formability accelerates, the need for a robust and streamlined die face engineering tool becomes more crucial, especially in the early stage when the tooling layout is not available, but a product design decision must be made. Ability to generate blank, binder and addendum surfaces with an appropriate layout of Drawbead, Punch Opening Line, Trim Line are the primary features and functions of a CAE based die face engineering tool. Once the die face layout is ready, a formability study should be followed to verify the die face layout is adequate to produce a formable part. If successful, the established die face surface should be exported back to the CAD/CAM environment to speed up the tooling and manufacturing design process with confidence that this particular part is formable with this given die face. With a CAE tool as described above, the tool & die industry will be greatly impacted as the processes will enable the bypass of hardware try-out and shorten the overall vehicle production timing. The trend has shown that OEMs and first tiers will source to low cost producers in the world which will have a negative impact to the traditional tool & die makers in the developed countries. CAE based tool as described should be adopted, along with many other solutions, in order to maintain efficiency of producing high quality product and meeting time-to-market requirements. This paper will describe how a CAE based die face engineering (DFE) tool could be further developed to enable the traditional tool & die makers to meet the challenge ahead.

INTRODUCTION

Over the past two decades, the Computer Aided Engineering (CAE) tools have emerged as one of the most important engineering tools in various industries, due to its flexibility and accuracy in prediction. Nowadays, the CAE tools are widely utilized in the sheet metal forming industry to predict the forming feasibility for a wide variety of complex components [1-6].
EVOLUTION OF CAD & CAE IN STAMPING INDUSTRY

The cutting edge computer technology in Computer Aided Design (CAD) and Computer Aided Engineering (CAE) has created a tremendous impact on the tool and die industry. Long before the implementation of CAE in tool and die industry, the CAD was adopted to create 2D and 3D die designs. However, the approach may result in poor die design and cause many unforeseen problems during tooling tryout. The traditional stamping manufacturing process employs CAD during the die design phase (shown in Figure 1). Upon the completion of die design, the die construction is carried out following by the tooling tryout to troubleshoot the new die set for major stamping defects. If the die produces parts with no stamping defects, it will be sent to stamping plant for stamping production. On the other hand, if splitting and wrinkling are spotted during the tryout, the die set needs to be reworked. Occasionally, the die set is scraped and a new die design is needed. As a result, the die manufacturing time is increased as well as cost of die making.

As shown in Figure 2, the forming simulation is introduced to the stamping manufacturing process to improve the efficiency of die design. The reliability and accuracy in forming simulation have helped to spot splitting and wrinkling on part before die construction takes place. The feedback from forming simulation prompts the die designer to modify the die design. With such implementation, the major stamping defects are minimized prior to the die construction stage. Hence, the tooling tryout process is smoother and the die set can be delivered for production much earlier. However, the robustness of the process is still limited due to the lack of interaction with product designers and tremendous amount of time are still needed to
redesigning the die structure if there are major changes in die surfaces.

The stamping manufacturing process shortfalls are further improved by the implementation of Draw Die Development or CAD based DFE and interaction with product designers. These implementations have help the die design process by solving the major stamping defects during Draw Die Development process, as well as product modification. Therefore, they greatly reduced the lead time of die design and construction, and the associated cost. The schematic flow diagram of current stamping manufacturing process is shown in Figure 3.

The advantage of CAD based DFE is effectively reducing the major stamping defects prior to the die design and construction process. However, it does not include engineering consideration. In addition, it relies on simulation engineers to perform verification of die surfaces because simulation tools are not available in CAD environment. As shown in Figure 4, the MSTEP analysis and CAE based DFE are added to the stamping manufacturing process. The MSTEP is a module embedded in eta/DYNAFORM Version 5.2 [7] which has a complete solver for quick formability analysis during the very early stage of product design cycle. It is suited for product feasibility analysis and quick verification of conceptual die surfaces.

The CAE based DFE is a module packaged in the eta/DYNAFORM Version 5.2 to allow stamping engineers to quickly derive a suite of draw die surfaces, including binder and addendum from the part geometry. The architecture of DFE in eta/DYNAFORM Version 5.2 provides one-code, one-environment pre-processor for...
stamping simulation. It allows the user to easily design and re-engineer the die tooling using the numerous automated functions provided in the software. The draw die surfaces from DFE consists of both mesh and CAD based surfaces. The mesh based surfaces can be directly adopted to conduct formability analysis. The implementation of MSTEP and DFE helps to further reduce iteration time for tooling design and development cycles as well as the associated cost.

**DFE TECHNOLOGY DEVELOPMENT CHALLENGES**

The increased reliance on CAE tools in stamping industry has prompted the major CAE software companies like ETA to heavily invest in technology development on its stamping simulation software eta/DYNAFORM. Such investment is vital for ETA to efficiently tackle the challenges in CAE tools development. One of the biggest challenges is to enhance the robustness and user-friendliness of User’s Graphic Interface (GUI). This improvement may help many designers from the tool and die industry who may not have knowledge of utilizing advanced CAE application to adopt CAE tools such as eta/DYNAFORM during the tool design phrases.

Another big challenge is the implementation of CAD Native Library in eta/DYNAFORM to facilitate reading of product design in eta/DYNAFORM without missing CAD data. Furthermore, the software is equipped with the capability of creating Non Uniform Rational B-spline (NURB) surfaces. The capability is important for output of NC quality surfaces using the CAE based DFE. It minimizes the time spend on repairing die surfaces during the die design stage.

A bigger challenge and responsibility for ETA is to enhance its CAE based DFE tool with implementation of parametric control and associativity among binder, addendum, PO line, profiles, etc. In addition, ETA has achieved great progress on the developing new technologies such as DFE based springback compensation [8] and re-engineering capabilities within its DFE environment. The DFE based springback compensation tools enable the designers to find out the best compensation solution by doing rapid iterations. The re-engineering tools allow the designers to quickly replace the product design on existing die face development with the same product which has minor product changes.

With continuing improvement on existing capabilities and development new and advanced technologies, the CAE based DFE tools have accelerated in fast paces than ever. It is expected that the advanced development in CAE based DFE, as well as simulation software will eventually help to bypass the necessity of hard tool tryouts during the stamping process (as shown in Figure 5). Therefore, the automotive OEMs and tool and die industry will significantly shorten the die manufacturing lead time, reduces the associated cost and deliver the die sets in time.

**REVITALIZATION OF TOOL & DIE INDUSTRY**

The tooling and die industry in the developed regions, such as North America is experiencing several issues that are affecting its ability to remain competitive in the marketplace. Among the most significant challenges are: overcapacity, growing international competition, technology improvements, decreasing demand from automotive customers and increasing pressure from customers to lower prices and expand services [9]. The challenges have resulted in many tool and die makers going...
out of business during the first few years of the new millennia.

To survive and remain competitive in the marketplace, the tool and die makers has to adopt new practices such as lean process manufacturing and collaborative practices. These practices have been shown to result in reducing cost and increasing manufacturing performance. One of the innovative practices is the implementation of high tech CAE tools to enable early evaluation of the product and die surface development. Furthermore, the tool and die makers shall employ highly efficient and process oriented tools to enable the designers to utilize the CAE tools.

By utilization of forming simulation and die face development in early stage of tooling design, the tool and die makers can confidently identify costly errors before die construction begins. The application of advanced CAE technology helps tool and die makers to minimize tryout time and maximizing efficiency of die construction process. To the end, the tool and die makers can remain competitive by producing quality dies at a reducing cost.

DESCRIPTION AND VALIDATION OF CAE BASED DIE FACE ENGINEERING (DFE) TOOLS

Traditionally, the die face is designed using CAD package(s) to define lines/surface of Binder, Addendum, Punch Opening Lines and drawbead layout, etc.

The proposed CAE based DFE tools include not only the traditional CAD based tools such as lines, surfaces but also a set of FE meshed based tools and techniques to speed up the processes and add one more dimension of engineering consideration such as “stretch of material” into consideration using a one-step forming solver, if desired. The other functions included in DFE are listed as following:

1. Unflanging
2. Fillet Modification
3. Outer Smooth and Inner Fill
4. Tipping, Undercut Check
5. Binder Generation and Morphing
6. Addendum Profile Generation , Modification, Morphing and Smoothing
7. Drawbar Generation
8. Drawbead Generation
9. Mesh-to-Surface, Surface-to-Mesh

The CAE based DFE tools provided in eta/DYNAFORM is capable of generating a conceptual die face design in a very short period of time. To further validate its application, an establishment of a typical body side outer panel die face is illustrated. The steps to generate the conceptual die face is listed below:

Step 1. Import product design
The CAD surfaces the body side outer panel is read into eta/DYNAFORM database via the UG translator. An illustration of the body side outer panel is shown in Figure 6.

Step 2. Meshing the part and the surface of the intended glass/window area
As shown in Figure 7, the part is meshed using a robust auto-mesher provided in eta/DYNAFORM. The inner fill function from DFE is used to fill in the intended glass/window area.

FIGURE 6. A schematic view of a typical body side outer panel.
FIGURE 7. Meshing body side outer panel and filling the window area.

FIGURE 8. An illustration of the meshed binder surface generated in DFE.

FIGURE 9. An illustration showing the generation of inner binder.
Step 3. Tipping the part
The auto-tipping function in DFE is then utilized to tip the meshed part into drawing position. The manual tipping function is also available in DFE to enable the designers to adjust the final tipping to avoid severe undercut and adjusting draw depth.

Step 4. Generating an overall binder surface
Upon the completion tipping, the overall binder surface is generated using *Free Form Binder* function. The NURB based CAD surface is then meshed using the auto-mesher. An illustration of the meshed binder surface is shown in Figure 8.

Step 5. Generating inner binder surfaces and addendum
As shown in Figure 9, the inner binder surfaces and addendum are generated to fill the door aperture areas using the *Binder* and *Addendum* tools provided in DFE.

Step 6. Generating outer addendum
Next, the *Addendum* function in DFE is used to generate varies types of segmental addendum. There are many functions such as modify, patch, morph, orient, etc available in the *Addendum* GUI. These functions enable the designers to easily and quickly modify the existing addenda design. At the end of addendum generation, the NURB based CAD surfaces and PO line will be created. An illustration of showing the outer addendum is shown in Figure 10.

Step 7. Trimming outer binder surface
The *Binder Trim* function is then applied to trim the outer binder surface. The PO Plus line generated from *Addendum* function is selected as the trim line. An illustration of trimmed binder surface is shown in Figure 11.

FIGURE 10. An illustration showing generation of outer addendum.

FIGURE 11. An illustration of the trimmed binder surface.
Step 8. Polishing all details and to finalize the die face design
After performing the outer binder trimming operation, final touch ups such as color and mesh quality check are done to polish all details. The final conceptual die face design as shown in Figure 12 is then used to conduct the subsequent forming simulation along with the blank geometry and designated material properties.

Step 9. Conducting forming simulation
The model of forming simulation is prepared using eta/DYNAFORM Quick Setup module [7]. After finishing the model setup, the forming simulation is conducted using non-linear explicit LS-DYNA solver [10] packaged in eta/DYNAFORM.

As illustrated in Figure 13, the Forming Limit Diagram reveals the potential of severe splitting taking place on the product surfaces, as well as the addendum surfaces. In addition, stamping defects such as low stretch and wrinkling are also noticed. The results obtained from forming simulation are then feedback to the designers to modify the die face design and request for product concession to fix the potential stamping defects. Several iterations will be performed until a satisfactory die face design is obtained.

FIGURE 12. An illustration showing the final conceptual die face design.

Step 10. Delivering the CAE based Die Face Design to Tooling Design Group in NC Quality Surfaces or like-to-like of the original product CAD Surfaces given.

At the end of forming simulation, the NURB based die face design with NC quality or like-to-like of the original product CAD surfaces is delivered to the tooling design group for die design and construction. An illustration of the final CAD surfaces of body side conceptual draw die design is shown in Figure 14.

FIGURE 14. An illustration of the final CAD surfaces of body side conceptual draw die design.

CONCLUSIONS AND RECOMMENDATIONS

There is evidence to show that low cost producers in Asia are adopting this methodology for the simple reason that it works. For instance, the Chinese tool makers carries no legacy baggage of already outdated processes and technology. With nothing to loss, why not start with the most advanced CAE technology which is cheaper than the CAD only solution in terms of time-to-market and extra expenses of using CAD system to generating all in CAD environment.

While developing industry is practicing the latest technology, the developed industry should even more aggressively to fully use this CAE based die face engineering tools to revitalize the out-of-date process which was established before the computing age.

REFERENCE


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