An Automatic Die Face Design System in Early Tool Process Feasibility in Sheet Metal Forming

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Abstract

Stamping Simulation is now used across the entire process, from initial cost estimation and early feasibility to final virtual try-out and inspection. However, the need to shorten the cycle time, mainly in the early stages of the process, is still critical.

Die Starter, a new system developed by ESI Group, allows the user to drastically reduce the number of iterations during the early tool process feasibility. This innovative system automatically designs the first quick die face, generating binder and addendum surfaces (NURBS surfaces) by taking account the full die process. Die Starter also improves the initial die face based on feasibility criteria (avoiding splits, wrinkles) by automatically generating geometrical modifications of the binder and addendum, and bead restraining forces with minimal material usage.

This paper presents a description of the new system and methodology of Die Starter. Some industrial examples are presented; from the part geometry to final die face including automatic developed flanges, part on binder and inner binder specifications.

Keywords: Sheet metal forming, die face generation, Die Starter, Feasibility, Optimization

Introduction

Today, sheet metal forming simulation is completely integrated into the core business of die engineering of OEM and suppliers, from early feasibility assessment and initial cost estimation to virtual try-out and final inspection. Different CAE (Computer Aided Engineering) solutions are proposed in order to cover all the different phases of the stamping process and allow users to concentrate more on the engineering tasks. For example, the combination of ESI's Visual DIEMAKER (VDM) or PAM-DIEMAKER for CATIA V5 with PAM-STAMP provide a powerful toolset capable of working through the entire process, from tipping, part preparation, binder, addendum and analysis to trimming and flanging.

Despite the progress, early tooling feasibility process still requires multiple iterations. The modifications of tool feasibility are based on trial and error and require skilled users. Also, even if best practices for die face design have been integrated into die design strategies, there remain issues including:

-   Die face design will vary, depending on the user
-   Die face design is not necessarily optimal for a given set of requirements and constraints
-   Creation of an acceptable die face solution is simply too slow, especially for complex parts.

Accordingly, there is clearly a demand for a robust, repeatable and streamlined die face engineering process that addresses early stage of feasibility assessment, when effective product design decisions must be made. Furthermore there is a critical need to greatly shorten the cycle time between part design and early tooling feasibility.

For those reasons a new approach has been proposed and developed by ESI Group and is now industrialized as a new solution, Die Starter. This new software module enables engineers to manage early feasibility in sheet metal forming by automatically generating,

from minimal input parameters, a quick die face design (also known as "initial die face"), defining binder and addendum surfaces (NURBS surfaces) . Based on the use of parametric geometry, modifications and improvements of initial die face can be performed quickly and automatically using a mathematical optimization algorithm procedure.

The following sections will review and discuss:

- Die Starter workflow (Input and output files, part preparation, design)
- Die Starter – a general description (overview)
- Die Starter benefits and capabilities (quick design and optimization)
- Industrial examples

Die Starter Workflow

Die Starter is completely integrated into ESI Visual DIEMAKER (VDM, on ESI's Visual Platform) and ESI PAM-DIEMAKER for CATIA V5 (CDM, on Dassault Systèmes, CATIA V5 platform), and provides solutions for early up-front feasibility assessment with detailed process validation.

Die Starter standard workflow:

Before running Die Starter, the part must be prepared properly in VDM or CDM in order to ensure an accurate first quick die face design and optimization. Those steps are:

- Part and mode definition:
  - Simple or double attached part, symmetry plane for symmetrical part
  - Select flange surfaces in order to be developed automatically into addendum or binder
  - Select part surfaces belonging to the binder
- Define tipping position
- Prepare the part to achieve a defined part outline (fill holes, part boundary smooth if required)

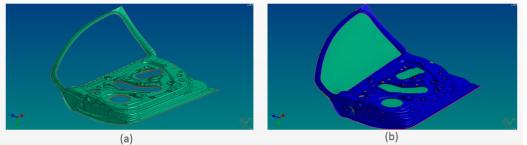Executing Die Starter for a quick die face design automatically generates the following output:

- Binder surfaces (outer and inner binder): IGES format
- Addendum surfaces (outer and inner addendum): IGES format
- Bead Center Lines: IGES format
- Blank outline: IGES format
- Results, including thinning, strains and part quality, are presented for design check

In order to improve the initial die face geometry, a mathematical optimization technique is used. Performed automatically, the computation time depends on the number of elements and complexity of the draw part since multiple analysis are required. Different types of optimization are offered, specific to the binder, addendum surfaces or bead restraining forces. Die Starter optimization generates the same types of data as for the initial die face step. Figure 1 illustrates the Die Starter process applied for a door inner.
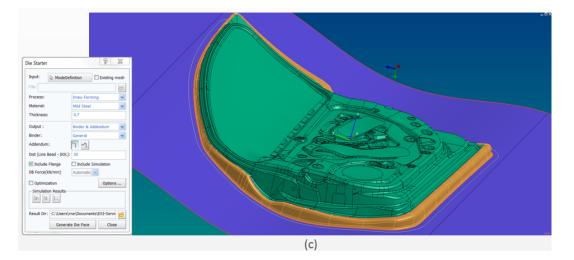
Once the full die face is created from Die Starter, process information and geometrical results, including draw beads restraining forces are exported to PAM-STAMP via a Quick-Link to achieve nearly automatic simulation set-up and analysis. The user can also modify or redesign their own die face based on Die Starter geometry by using Visual DIEMAKER functions (Figure 2)

Finally, Die Starter results can be exported to any CAD system (CATIA, Unigraphics, SolidWorks…) for manual modifications.
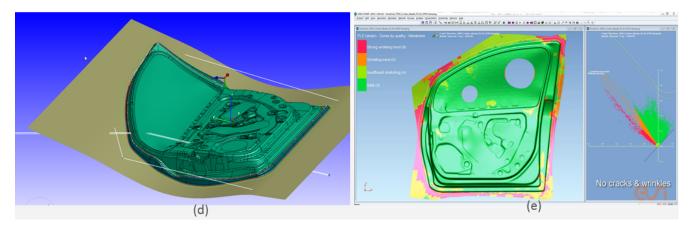
(a)   Part geometry, (b) Die Starter part preparation (fill holes, smooth part outline)

(c) Die Starter input deck and initial die face (binder, addendum, and bead center line) results

(d) Improved die face after die starter optimization (binder – bead – addendum); (e) PAM-STAMP Analysis from die starter optimization results after few manual improvements (added holes,..)

Figure 1: Door Inner: Die Starter full process steps: (a), (b) part preparation, (c) initial die face solution, (d) final die face solution from optimization and (e) PamStamp analysis results after few manual improvements from optimized solution..
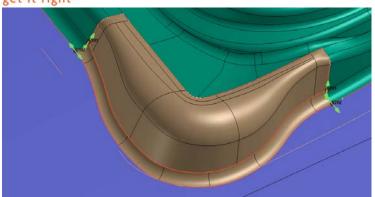
Figure 2: Manual local addendum modification (brown) in VDM based on Die Starter initial results

Die Starter General Description

There are three major steps in the Die Starter methodology:

Customized Die Face: From an entire die face geometry already defined, Die Starter will perform automatically quick formability analysis and beads optimization (restraining forces values and segmentation) for a better formability.

Quick Die Face (or Initial Die Face): Binder and addendum surfaces are automatically generated based on geometrical and standard criteria for die face design. Also, some geometrical constraints can be applied in order to generate specific binder designs, such as double curvature binder, part on binder and inner binder. The connection between the part contour and the binder, defined as addendum surfaces, are also generated automatically.

After generating an initial die face, a quick formability analysis is performed automatically in order to complete the first feasibility assessment of the draw-part (no preparation needed). The Die Starter analysis is completed by an FEA (finite element analysis) method that evaluates the large elasto-plastic deformations of the draw-part [1 - 2]

Optimization (improved die face): The optimization step addresses improvement of initial die face by automatically changing binder and addendum surfaces, including bead restraining forces values and blank contour, and uses a mathematical optimization algorithm [3 -5] combined with a formability analysis with a defined objective function with or without constraints (geometrical and mechanical)
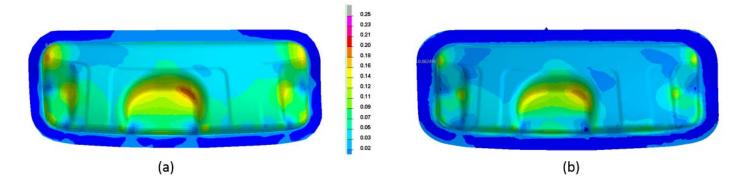
Die Starter Benefit and Capabilities

As stated, the main characteristics of Die Starter are automatic initial then improved die face design and bead optimization on customized die face.

Characteristics: Customized die face:

Based on the entire die face geometry (part, binder and addendum surfaces), Die Starter will perform a quick formability analysis on the full die face by initially imposing a uniform bead restraining force. Automatic bead optimization will also provide non uniform bead restraining forces for improved formability. Output are bead center line and blank contour (IGES format) as well as different bead restraining forces.

Figure 3 shows the improved formability of front hood reinforcement (FHR) die face with optimization of bead restraining forces using customized die face process

Figure 3: Customized die face of front hood reinforcement: (a) thinning color map before bead optimization; (b) thinning color map after bead optimization (improved formability)

Characteristics: Automatic initial die face:

Based on minimal part preparation, Die Starter provides within a few minutes a first pass at a complete die face design that is usually acceptable and accurate. The initial design is based only on geometrical and process criteria. The different characteristics are:

- Binder surfaces (NURBS Surfaces) based on developable (also wrapable) binder criteria in most cases, including part on binder and inner binders. Binder orientation is also defined automatically. Options for double curvature binder and flat binder are also available

- Addendum surfaces (NURBS Surfaces) are a combination of the two principal profiles concept (Standard addendum and Step/Bar addendum) which represent the majority of parts. An automatic global smoothing technique is used to provide clean and smooth punch and die opening lines; both critical in die face design principles. Inner addendum surfaces are also defined automatically.

- A quick formability analysis is automatically performed just after initial die face design in order to provide an estimation of the feasibility of the draw-part. This first feasibility assessment can guide the next steps, such as direct PAM-STAMP analysis if the part appears feasible or Die-Starter optimization if thinning (high or low) needs to be corrected.

Characteristics: Automatic Optimization:

Creation of parametric surface geometry for the initial die face enables automatic optimization of tool geometry (binder and/or addendum). Built on parametric surfaces engine, Die Starter has the capability to automatically modify or redefine the tooling geometry during optimization steps.
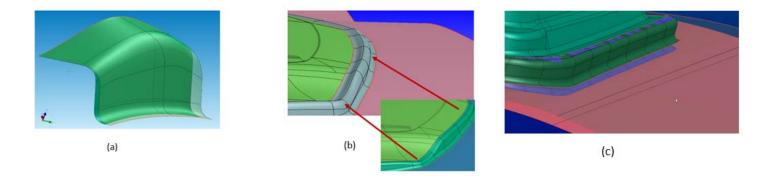
The use of fast feasibility assessment allows the optimization of both tooling geometry and process parameters in order to deliver at an early stage a feasible part with a stable and robust press tool process. The different optimization options are:

- Binder optimization:
- Full addendum optimization: Punch radius, wall addendum and draw bar height (if required)
- Draw beads sections with associated restraining forces (also available for customized die face process)

- All of the above, individually and in combination (and all combinations between them)

Figure 4 shows some results on different types of optimization:

Figure 4: Examples of Die Starter optimization options: (a) changing automatically punch radius, (b) changing addendum by creating draw-bars, (c) changing automatically binder

Benefits:

Initial die face design, including design check (quick analysis), can be performed automatically in few minutes, starting with only a few user input parameters (basic parameters related to material and process) for a prepared part.

From an initial die face geometry, Die Starter optimization automatically allows the geometrical modifications of binder and addendum and also process parameters for better formability. Optimization always keeps material usage minimal when trying to eliminate (or reduce) high thinning and low thinning (into part).

The Die Starter die face geometry (initial or optimized) can be loaded into any CAD system for manual modifications and improvements.

Any die face generated from Die Starter can be imported into VDM (Visual DIEMAKER) with the addendum profiles. Any addendum generated by Die Starter can be directly integrated into VDM via different profiles. Those profiles can be modified manually and then automatically regenerated in order to create a new set of addendum surfaces.
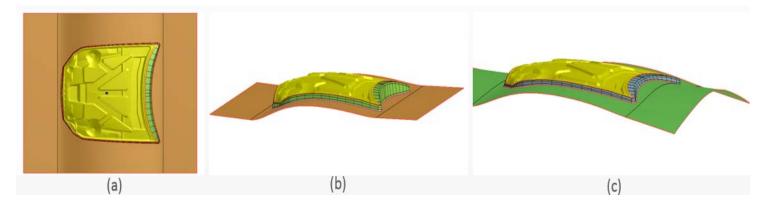
Capabilities:

- Develop flanges into addendum automatically
- Develop flanges into binder automatically
- Define binder and addendum surfaces automatically (initial or optimization)
- Define inner binder/addendum surfaces automatically (initial or optimization – case of body-side, liftgate, ..)
- Develop automatically part on binder
- Handle symmetric parts: create complete symmetrical die face (initial or optimization)
- Provide good surfaces quality for binder and addendum automatically. (At this stage of the process, this is very important and can have a significant impact on time for creating the final die design in the master CAD system.)
- Only few input parameters are required, related to material, process and optimization target (maximum and minimum thinning and number of iterations)
- First initial die face and design check, is completed in a few minutes and optimization of early design in few hours calculation time. Minimal human intervention is required during the Die Starter process.
- Perform quick feasibility analysis and bead optimization (restraining forces and segmentation) on a pre-defined full die face.
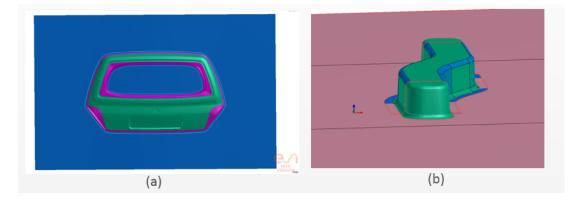
Industrial Examples

This section shows some examples ran in Die Starter for initial die face and optimization.

The first example (figure 5) is a full symmetrical initial die face of a hood inner (symmetric part) calculated with different binder design options. Die Starter performs automatically a developable binder (single curved binder) or also a double curved binder (useful for minimization of material usage)

(a)   (b)   (c)

Figure 5: Example of Die Starter – Fully symmetrical die face of hood inner (a) with single curved binder (a) and double curved binder option (c)
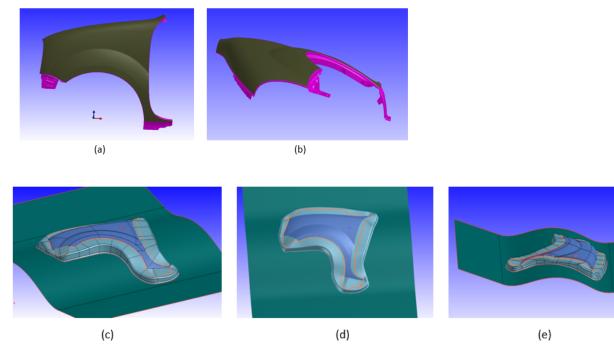
The second example (figure 6) shows the initial die face of liftgate outer with inner binder/addendum (complete die face is performed automatically) and initial die face of S-Rail with full part contour on the binder (case of part on binder with no addendum)

(a)   (b)

Figure 6: Example of Die Starter: (a) Liftgate outer with inner binder and addendum (Binder inner/outer in blue and addendum inner/outer in purple). (b) S-rail initial die face with part contour on binder

The third example (figure 7) is the initial die face of a fender outer with automatic development of flanges into the addendum (direct trimmed line from developed flange outline).

(a)

(b)

(c)

(d)

(e)

Figure 7: Die Starter fender initial die face with developed flanges: (a), (b) fender part with flanges; (c), (d), (e) initial die face with automatic developed flanges into addendum (developed trim line in orange)

The last example (figure 8) is a hood inner panel, performed for initial and optimized die face. During optimization, the rear corner areas of the addendum have automatically been changed in order to meet the maximum thinning requirement (no split after optimization). After running a validation analysis (PAM-STAMP) using the optimized die face, the feasibility of the panel is good (no splits, no wrinkles).
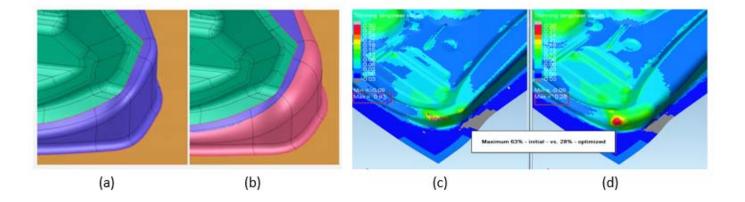

(a)

(b)

(c)

(d)

Figure 8: Die Starter hood inner rear corner: (a) Initial die face, (b) optimized die face, with (c), (d) thinning results comparison in PAM-STAMP

Conclusions and Future Developments

ESI Die Starter, a new solution module integrated into Visual DIEMAKER (built on ESI Group's Visual Platform) and PAM-DIEMAKER for CATIA V5, has been presented in this paper. For the early stage of tool feasibility in sheet metal forming, Die Starter automatically generates a complete die face including binder and addendum surfaces, bead center lines and restraining forces associated for a prepared part. An initial (quick) die face can be created in a few minutes, based only on geometrical constraints and requirements (including a quick formability analysis). A mathematical optimization method automatically modifies the initial die face (binder shape, punch radius, wall addendum, draw-bar, and draw beads forces) in order to meet the formability specifications and requirements for minimum material usage.

Die Starter solutions (geometry, draw beads characteristics) can be further modified in any CAD system or processed through Visual DIEMAKER/ PAM-DIEMAKER for CATIA V5 to PAM-STAMP, if required. Using ESI's Visual Platform (VDSS) full automation of the simulation chain can be achieved to dramatically reduce the time and effort needed to achieve the desired objectives; feasible and optimal parts and tooling.

Acknowledgments

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