On the Optimization of the Punch-Die Shape: An Application of New Concepts of Tools Geometry Alteration for Springback Compensation

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ABSTRACT

This work here presented concerns the activities of stamping tools alterations of an automotive component done thanks optimization technologies. The process of nominal geometry alteration of a complete stamping die is traditionally based on the experience of the try-out people who manually modify the tools in order to compensate geometrical differences due to springback under a Trial-and-Error approach and often the restroking die needs so substantial modifications to lead to be partially re-designed . With the introduction of new steels, high tensile steels with considerable springback effects, this approach become more and more difficult.

Trial and error techniques used in the reality in the try-out phase now are possible in the development phase thanks to morphing technologies in HyperForm. But an innovative technique, developed at Altair Engineering, give the possibility to proceed automatically and systematically: the approach, general and flexible, is based on a orthonormal base of deformation functions that allows the automatic management of the geometry alteration of the die. Not least the principle to obtain a small geometry error after the cutting stages, before the restroking stage. The geometry alteration are hence applied on the draw tools.

The process is automatically managed by an optimization algorithm in Altair HyperStudy, who manages the geometrical parameters who define the die shape in order to converge to the optimal die shape.

This paper shows how the morphing approach and the automatic deformation function approach converge to the same solution and the improvements obtained in the reality.

INTRODUCTION

The world of stamping in these last ten years saw deep modifications in the cycle of die designing, since simulations got into it. The possibility to simulate any shape of the tools in order to anticipate critical problems with a good precision and solve them represents the real added value of the virtual engineering in the technology field, and it has been well interpreted by the manufacturing environment.

Another critical problem still afflicts the manufacture of dies: the geometrical error in the stamped part generated by the effect of elasticity of the material: the springback. This problem still exists and its “weight” is becoming more and more important because of the growing employment of high strength steels and newer generation of steels.

Thanks to a growing sensitivity of the software developers a lot has been done in this direction: finer algorithms in the solvers (precision is essential) and dedicated tools to locally modify geometries can help to investigate how the springback effects will change. But a deep experience in stamping is still required: the alteration of dies is very delicate because of its influence in the whole cycle and because it is time consuming as well. Optimization and massive computations can help to give an important contribution to this problem. The difficulty in this case is how to choose the optimization variables. A large number of variables can lead to unmanageable problems, a low number of variables can be insufficient: but how to choose them?

The possible solutions to this "restricted" problem can be 1) based on experience generating manually a base of locally morphed geometries and then let the optimizer to minimize the geometrical error, or 2) based on a mathematical problem centred on a base of uncoupled deformation modes automatically generated from the geometry.
The two approaches have been tested on real part and the computed solutions were converging each other: the approach has been applied on the stamping stage, unusual but efficient for very stiff parts, looking for a "good" geometry before restroking. The initial problem of 14mm of maximum geometrical discrepancy has been reduced to an average 1mm: inserting a high strength steel part into the welding machines (to do the subassembly) with a discrepancy of 14mm is a real problem who has no easy and fast solutions.

1) Generating shape functions manually with morphing techniques in Altair HyperMesh/HyperForm

The optimization is an iterative problem where algorithms manage variables, apply required constraints, evaluate results and trends of results with respect to an objective function and find the best "compromise" between the possible solutions (variables) with a reduced number of iterations.
The problem of the generation of the significant variables set can be faced with general topography approach letting any single node of a mesh to move in any direction within a specified range or using a "constrained" approach who can take in account the coherence of the shapes.
In the general topography approach the number of variables would be so large to be mathematically unmanageable and practically inefficient or unacceptable. First of all the check of undercuts and coherence of the local shapes.
To reduce the variety of variables and improve the coherence of the local shapes the constraint of dependent "displacements" between nodes has been introduced: in this way few nodes act the rule of "key nodes" which position influences the position of the other nodes who are in a specified area, the domain. The "key nodes" can be considered like a sort poles of surfaces: the handles. Modifying the handles position the domain will deform its shape as it had a certain stiffness. This can assure the coherence of the displacements. A check of the undercuts can be evaluated in the optimization loop as algorithm.

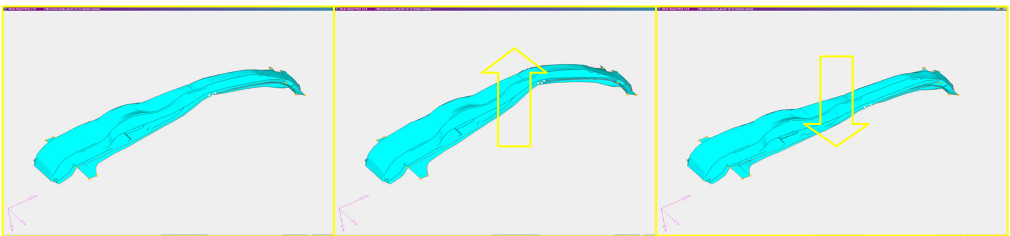

Figure 1. morphing bending mode example in HyperForm

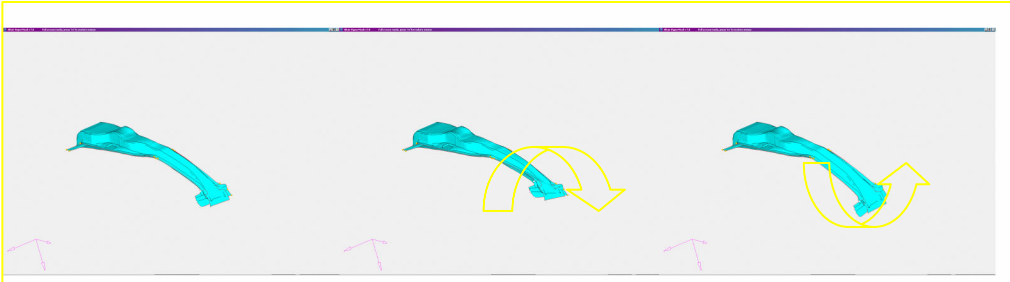

Figure 2: morphing torsion mode example in HyperForm

A base of modes can be therefore generated: bending modes, torsion modes and opening/closure of sections modes can be generated as set of reference modes who will be managed by the optimization as variables into a range of “displacements” applied to a reduced set of handles.
The definition of the modes is clearly related to the sensitivity of the user and his experience. And the subjective choice of the basic modes can affect the efficiency of the die alteration. With this base of morphed geometries an optimization is possible and this set of modes has been used as first approach.

In order to simplify this important step and reduce the dependency from experience an alternative and new approach has been formulated.

2) An alternative definition of shape functions

If we define as $\mathbf{s}$ a suitable vector being able to describe the die configuration and $\mathbf{u}$ an analogous vector being able to describe the stamped part (in a sense which will be defined more precisely later on) then we can write

$$\mathbf{u} = \mathbf{G}(\mathbf{s})$$

where $\mathbf{G}$ is the Green function describing the link between the „effects“ (the stamped configuration $\mathbf{u}$) and the „cause“ (the die configuration $\mathbf{s}$). Ls-Dyna can be seen as an evaluator of the function $\mathbf{G}$: in some sense the physical process is described algorithmically by Ls-Dyna.
The key point is how to describe a suitable representation of the configurations. If we choose to collect the nodal coordinates of the whole mesh of both punch/die and stamped part, we have to manage very large vectors, with some redundancy and waste of resources.

But if we choose a suitable set of orthonormal functions the coordinates of punch/die and stamped parts can be written as a perturbation around a given “nominal” configuration such as

$$\mathbf{X}_{\mathbf{s}} = \mathbf{X}_{\mathbf{s}}^{N} + \sum_{i=1}^{m} \alpha_i \mathbf{w}_i^{\mathbf{s}} \quad \mathbf{X}_{\mathbf{u}} = \mathbf{X}_{\mathbf{u}}^{N} + \sum_{i=1}^{n} \beta_i \mathbf{w}_i^{\mathbf{u}}$$

where $\mathbf{X}_{\mathbf{s}}$ and $\mathbf{X}_{\mathbf{u}}$ collect the die/punch and part coordinates and $\mathbf{X}_{\mathbf{s}}^{N}$ and $\mathbf{X}_{\mathbf{u}}^{N}$ collect the nominal configuration respectively

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A complete basis of function would be as great as the number of dof of the structure, making the problem of optimization unmanageable, but if we choose a reduced basis of "deformation functions" being able to describe a limited set of displacements around the nominal configuration, namely the set of functions $\mathbf{w}_i^{\mathbf{s}}$ and $\mathbf{w}_i^{\mathbf{n}}$, the vectors being able to describe both punch/die and part configuration will be the sets collecting the α_i and β_j coefficients, a much more manageable vector: the description of the whole coordinate field is devoted to a reduced set of "deformation functions" defined over the whole domain of the geometries, modulated by a set of multiplicative coefficients which can be seen as perturbations of a nominal geometry.

It is clear that the nominal configuration of punch and stamped part are defined by the null vector:

$$\boldsymbol{\alpha}_N = \mathbf{0} \quad \boldsymbol{\beta}_N = \mathbf{0}$$

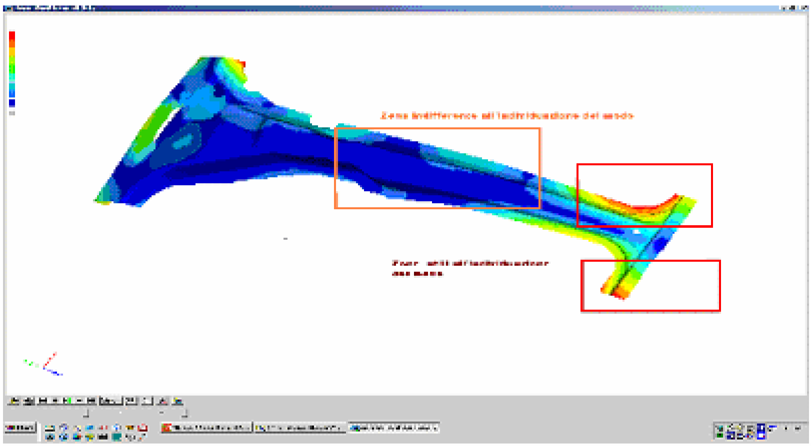

Figure 3: Typical Deformation Function

In an ideal world we should have

$$\mathbf{0} = \mathbf{G}_*(\mathbf{0})$$

but we have actually

$$\mathbf{G}(\mathbf{0}) = \boldsymbol{\beta} \neq \mathbf{0}$$

This way the problem could be reformulated as "find the die/punch configuration $\boldsymbol{\alpha}^*$ such as $\mathbf{G}(\boldsymbol{\alpha}^*) = \mathbf{0}$". But this is not always possible: due to the fact that we choose a reduced set of orthogonal functions, we can not describe all the admissible configurations of both die and punch and we have no guarantees of the existence of a zero in the reduced domain of the punch/die subset.
Due to the fact that we are limited to a subspace of the configurations the problem must be reformulated as:

"find the set of coefficients $\boldsymbol{\alpha}^*$ such as $\|\boldsymbol{\beta}^*\| = \|\mathbf{G}(\boldsymbol{\alpha}^*)\|$ is a minimum"

that is to say a classical optimization problem.

3) Search for the minimum: Altair HyperStudy and Ls-Dyna

The core statement is the previously described optimization problem. But the function $\mathbf{G}$ is actually defined by means of a procedure: it is defined algorithmically. A schematic flow chart of the "solver", that is to say the $\mathbf{G}$ evaluator, is shown in figure.

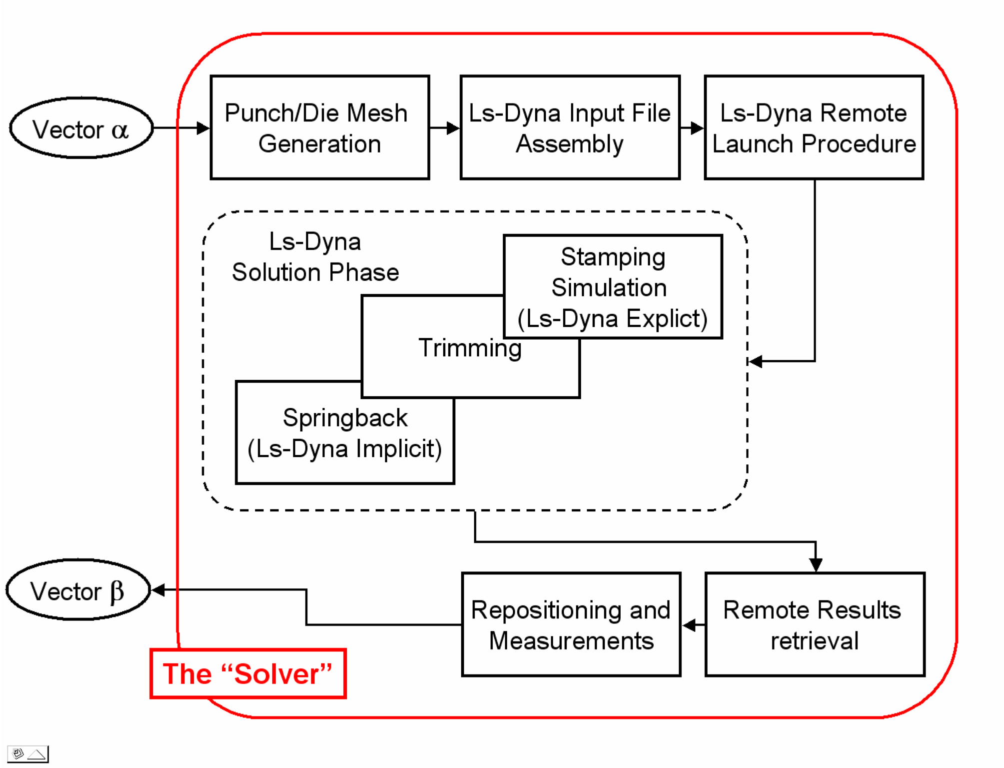

Figure 4: The Solver definition

The determination of the set of β_i components is essentially a measurement problem: we have to compare a deformed configuration with a set of "deformation functions", generally defined on a different mesh in a different reference frame. The procedure must tackle a problem of interpolation and repositioning of different meshes: all this procedure is delegated to a suitable script interacting with Altair HyperMesh. The $\mathbf{G}$ function involves the whole process of punch stroke, trimming, springback, repositioning and measurement. We want here to stress the attention to the variation of the input vector $\boldsymbol{\alpha}$.

To solve the abovementioned optimum problem we used Altair HyperStudy, a "Solver controller" being able to perform DoE studies as well as Stochastic and Random analysis, but we mainly used the optimization capabilities of HyperStudy.

The logical block "Solver" has as input data the $\boldsymbol{\alpha}$ and is being able to compute a vector $\boldsymbol{\beta}$. Now the problem is to find a way to control the solver, varying in a suitable way the input vector $\boldsymbol{\alpha}$. This task is devoted to HyperStudy, which is being able to control the vector $\boldsymbol{\beta}$ and modify the vector $\boldsymbol{\alpha}$ accordingly.

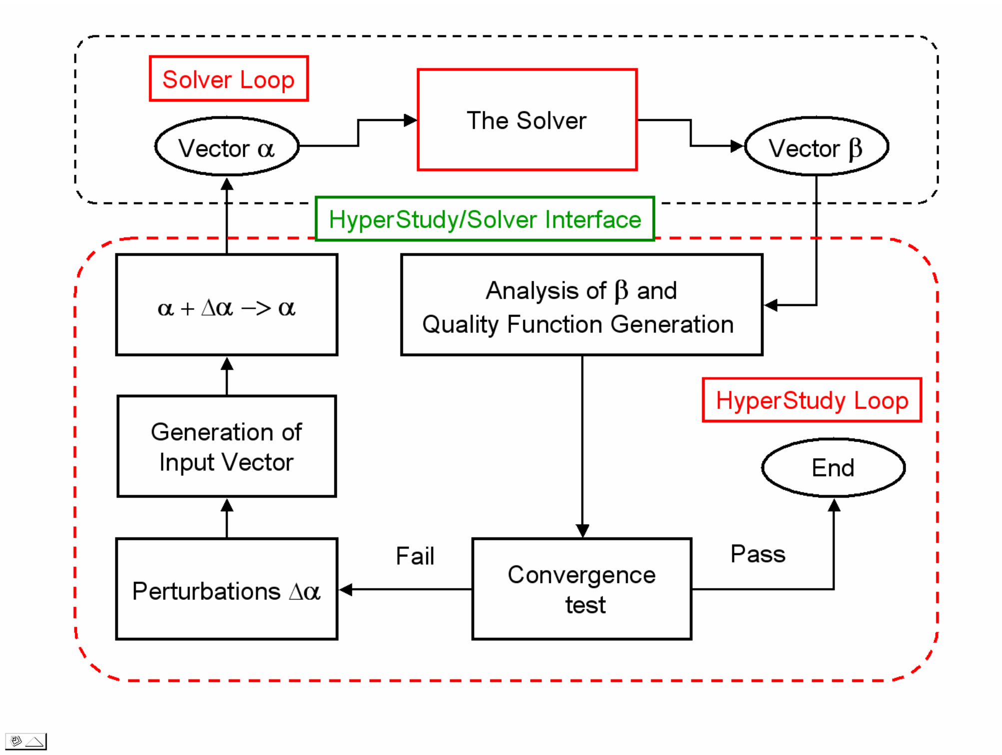

Figure 5: The Solver control and optimization loop

As a natural starting point configuration of the stamp we choose to use the nominal configuration, that is to say $\boldsymbol{\alpha}^0 = \boldsymbol{\alpha}_N = \mathbf{0}$. HyperStudy then start to perform a sensitivity analysis in the neighborhood of the initial configuration, being able to build up a Jacobian-like matrix of the transformation between the $\boldsymbol{\alpha}$-space and the $\boldsymbol{\beta}$-space. The “Quality Function” of the responses, in its simpler form, compute the Euclidean norm of the vector $\boldsymbol{\beta}$, searching for a minimum. If a convergence test fail to pass, a new perturbation of the vector $\boldsymbol{\alpha}$ gives another configuration of the die, restarting the loop.

4) Convergence Curve and Results

The method converge fairly well, providing that a suitable set of deformation function describing the die is chosen. This must be accomplished by a preliminary sensitivity analysis, pointing out which deformation functions are good enough to have a strong effect in the stamped part. A typical convergence curve, reporting the number of iteration in abscissa and an arbitrary norm in logarithmic scale of the displacement field induced by the $\boldsymbol{\beta}$ vector is shown. As it can be seen, there is a scale-down of more than two orders of magnitude of the deformed geometry from the initial configuration to the last iteration.

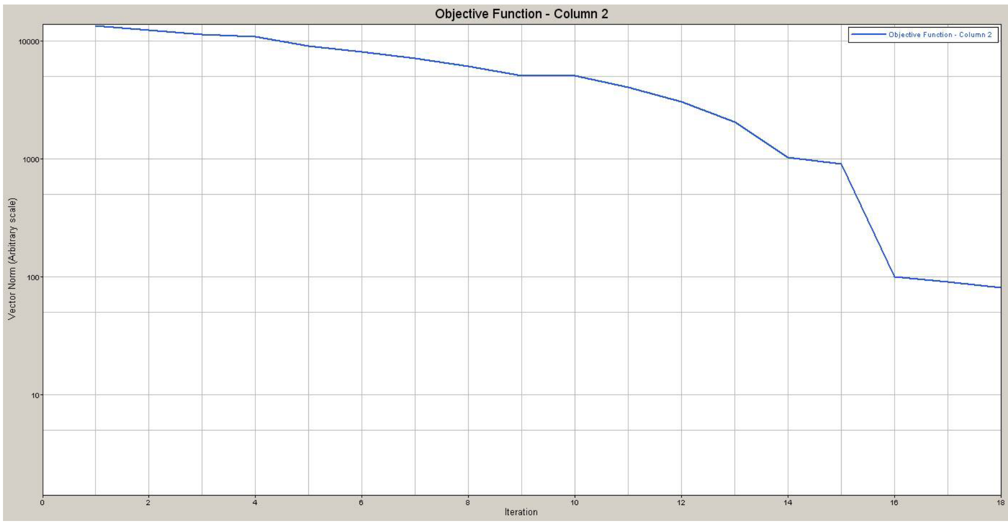

Figure 6: Variation of the objective function

We want to stress here two key points: the first one being that the final result are fully comparable with the method obtained by a shape functions generated by HyperMesh morphing techinques, being the last one essentially decided by the experienced user and with no guarantees of independency of the deformation sets. In both cases the maximum displacement from the nominal configuration is about 3.0 mm in non critical zones, that is to say in zones not directly involved in subsequent assembly operations of the stamped part. But the second key point is much more important: we are able to generalize the procedure, making it a new and innovative method to deform the dies in a rational way without totally relying on the experience of the analyst; of course it is still very important but this tool can give a significant aid in case of very difficult problems.

Summary and Conclusions

The described approaches were converging to similar geometries, but the morphed base highlighted the limitations typical of an experience-related solution. With a good choice of morphed base the computation reached the minimum average discrepancy in 12 iterations, but the base required several trials to be satisfactory. The modal shape functions converged in 58 iterations instead without any experience-related revision.
The final solution was transformed in CAD environment with all the required specifications for milling (smoothness) for each of the two iterations. A trial die was made and subsequently modified. The first optimization-trial leaded to 5mm of maximum discrepancy (original was 14mm) .
A second iteration of optimization due an enhanced revision of the algorithms and base leaded to a maximum discrepancy of 3mm and average 1mm.

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