Optimization of the blankholder force distribution with application to the stamping of a car front door panel
(Numisheet'99)

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Abstract. New materials such as dual phase steel or aluminium and complex geometries of industrial parts increase the
difficulties to obtain a defect free part by stamping. One way of solution is a better regulation of the blankholder
pressures. Our work is based on an original idea of Siegert, Häussermann and Haller [1, 2, 3]. The goal is to control the
movement of the blank under the blankholder. Thanks to a deformable flexible blankholder, it is possible to create some
independent zones. In each zone, a blankholder force can be applied on the sheet, so that a strong force can hold the
blank in a zone, and a smaller one can let it move in another zone. The methodology is presented as well as some results
dealing with the optimization of the blankholder force considering the drawing of a front door panel (Numisheet'99
benchmark test). The numerical simulations are performed using ABAQUS Explicit. The parameters of the finite
element model (mesh density, speed of punch) are set to achieve a good prediction with a minimum simulation time. The
objective function is defined to minimize the work of the punch. Three inequality constraints functions were defined to
avoid necking and wrinkling. To avoid necking, the major stress of the blank is limited to a value, which is determined
by using the modified maximum force criterion (MMFC) [4]. To avoid wrinkling, under the blankholder, the angle
between the blankholder surface and an element of the blank is limited to a value set by the user, as proposed by Gelin
and Labergere [5]. However, in the useful part of the workpiece, the major stress is limited to a value, which was
proposed by Brunet, Batoz and Bouabdallah [6]. For the localization of the optimum, we use a response surface method
computed with a diffuse approximation and coupled with an adaptative strategy to update the research space.

INTRODUCTION

Sheet metal stamping is one of the most important manufacturing processes used in the automotive
industries. In the last years the international competition is extremely severe and all companies try
to reduce manufacturing costs on one hand and increase productivity, robustness and quality of the
stamping process on the other.

Numerical simulations and mathematical methods of optimization are increasingly used to evaluate the
forming difficulties in sheet metal stamping and to achieve these goals.

In sheet metal forming various and sometimes contradictory criteria must be satisfied. Several
constraints and objective functions are necessary in order to obtain quality and the lowest product cost.
The product quality can be defined in terms of the required proper surface characteristics (without
wrinkling or other geometrical defects), uniform part thickness, minimum strains and stresses, etc. The
process parameters which can be optimized are: initial
blank thickness and contour, material properties, blank holding force profiles and locations, drawbeads, lubrication conditions influencing friction, etc.

In this paper the numerical simulation of a car front door panel (NUMISHEET’99 benchmark) is carried out using ABAQUS FEM code. The simulation parameters are chosen to ensure the accuracy of the results and to limit the computing time.

In the real situation, drawbeads are present under the blankholder in order to limit the flow of the material towards the die. In the present study these drawbeads are not modeled. Since we wish to optimize the blankholder force profile.

In the first section of this paper we evaluate the capability of FEM model for predicting the part characteristics. Some results are discussed. In the second section we describe the problem of optimization of the blankholder forces in space and discuss the obtained results.

COMPARISONS AND VALIDATION OF THE NUMERICAL SIMULATIONS

The front door panel benchmark of Numisheet’99 [10] is considered (FIGURE 1). The numerical simulation is carried out in three stages (gravity, holding and forming). The blank is meshed with shell elements with reduced integration (68738 quadrangles and 12 triangles for the blank). The tools are modeled with 4-nodes and 3-nodes, three-dimensional discrete rigid surface elements (type R3D4 and R3D3). The speed of the punch is set to 1.35m/s for the simulation. Those parameters (mesh, punch speed) allow a quick simulation (average of 13h for the forming step on a Xeon 3 Ghz with 3Go RAM, Windows XP). They have been selected after several runs to evaluate their influence on total CPU time and precision. Good results have been obtained by comparison with both experimental and numerical results.

Experimental results [10] are available for benchmark tests carried out on three materials: mild steel DDQ, bake hardening steel BH220 and aluminum 6016T4. In this work, the simulation corresponding to the mild steel specimen was carried out. The corresponding material data and the process parameters are summarized in TABLE 1.

Our results from ABAQUS Explicit and other numerical results (PAM-STAMP and LS-DYNA [10]) are compared with experimental results in FIGURE 2 and FIGURE 3. FIGURE 2 shows the distribution of the thickness along the section defined by the equation $X=\pm 15$ mm. Our result is in agreement with the experimental result. The shift between our result and experimental result around $x \approx -380$ mm and $x \approx 380$ mm is caused by the absence of drawbeads. FIGURE 3 shows the major strain distribution along the same section. Results are also in agreement with the experimental ones, except in the blankholder regions where drawbeads affect the material flow. Our numerical results are also in agreement with the available results obtained by other researchers and published in the proceedings of Numisheet’99 [10].

In FIGURE 4 we represent the distribution thickness of the final part. The minimum and maximum of the thickness are respectively equal to 0.79 mm (-21%) and 1.14 mm (+14%).

![FIGURE 1. Geometry of the tools and blank front door panel benchmark.](image)

<table>
<thead>
<tr>
<th>TABLE 1. Materials and process parameters used for a front door panel benchmark.</th>
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</thead>
<tbody>
<tr>
<td><strong>Mechanical properties of material</strong></td>
</tr>
<tr>
<td>Young’s Modulus</td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
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<td>Yield stress</td>
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<td>Flow stress curve</td>
</tr>
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<td>$[\sigma = K(\epsilon_{\sigma} + \epsilon_p)^n]$</td>
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<tr>
<td>Anisotropy (Lankford coefficients)</td>
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<tr>
<td>Thickness</td>
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<tr>
<td>Process parameters</td>
</tr>
<tr>
<td>Friction coefficient</td>
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<tr>
<td>Blankholder force</td>
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</tbody>
</table>
FIGURE 2. The thickness distribution along the section of equation $X=-15$.

FIGURE 3. Major strain distribution along the section of equation $X=-15$.

FIGURE 4. Thickness distribution.

FORMULATION OF THE OPTIMIZATION PROBLEM

Design Variables, Objective and Inequality Functions

The design variables are the blank holding forces (BHFi). Seven zones of holding are defined (FIGURE 5) and for each zone the force is considered constant during the forming stage.

The objective function is the external work $W_{\text{ext}}$ during stamping directly linked to the energy required by the forming press:

$$f_{\text{obj}} = W_{\text{ext}}$$

1.

To avoid necking and wrinkling three inequality constraints functions are formulated. The first function is built to avoid the formation of strong undulations under the blankholder zones [11]. It is defined according to the angle of inclination $\theta_i$ between the
blankholder surfaces and an element of the blank (FIGURE 6.):

\[
G_1 = \begin{dcases}
\frac{1}{n} \sum_{i \in D_n} \left( \sin \theta_{\text{max}} - \sin \theta_i \right) & \text{if } \forall i \in D_n, \theta_i < \theta_{\text{max}} \\
\frac{1}{n} \sum_{i \in D_n} \left( \sin \theta_{\text{max}} - \sin \theta_i \right) & \text{else}
\end{dcases}
\]

2.

A third constraint function is then formulated according to \( R^w_i \):

\[
G_3 = \begin{dcases}
\frac{1}{n} \sum_{i \in D_n} \left( R^\text{limit} - R^w_i \right) & \text{if } \forall \ e \in D \ R^w_i \leq R^\text{limit} \\
\frac{1}{n} \sum_{i \in D_n} \left( R^\text{limit} - R^w_i \right) & \text{else}
\end{dcases}
\]

6.

Optimization procedure

The optimization algorithm must be carefully chosen when one single analysis requires several hours of CPU time. Stochastic methods, such as genetic algorithms, can find global minimum but need hundreds of evaluations of the functions to converge. Descent methods require the computation of the gradients of the functions. The computation of gradients by finite differences is time consuming and depends on the perturbation parameter. For the above reasons we decided to use the surface response method. A moving least squares method is used to find the optimum of surface response and then the research domain is reduced to improve the accuracy of the approximation. The methodology is shown on FIGURE 7 and FIGURE 8.

FIGURE 7. Domain for the response surface

A central composite design experiment was applied. Indeed, for \( n \) independent variables, the central composite design requires \( 2^n + 2n + 1 \) function evaluations: \( 2^n \) factorial designs augmented by \( 2n \) axial points and one centre point. Thus, for seven blankholder forces 143 numerical simulations are necessary for each design of experiments. To reduce the number of evaluations we chose to solve the optimization problem in two stages (FIGURE 8.).

In the first stage, four blankholder forces will be optimized (\( \text{bh}_n^1, \text{bh}_n^2, \text{bh}_n^3 \) and \( \text{bh}_n^4 \)). The blankholder (5, 6 and 7) will be replaced by one blankholder with a force to 100 kN. In the second stage, we continue the optimization only with the three blankholder forces (5, 6 and 7) by using the optimum forces obtained in the first stage. Thus, 25 and 15 numerical simulations are necessary for each design of
experiments corresponding respectively to the first and the second stage.

![Stage n°1 and Stage n°2](image)

**FIGURE 8.** Blank holder forces optimized for each stage

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**RESULTS AND DISCUSSION**

The optimization results obtained for the industrial application by using the methodology of optimization describes previously is presented. This application presents significant wrinkles, specially in the zone under the blank holder. The maximum angle of inclination is found equal to five degrees. For each optimization stage the optimum solution is carried out after three actualizations of the research domain. Indeed the total number of numerical simulations to carry out is equal to 120. In **FIGURE 10** we present the optimum forces obtained for each blankholder. After optimization we succeed to limit the maximum inclination angle to one degree. The indicator of wrinkling in the zone under the punch $R^w_{el}$ is equal to 4.5 and the indicator of necking $R^n_{el}$ is equal to 0.975. In **FIGURE 11** we present the thickness distribution for a total unique blankholder force equal to 300 kN and for seven optimum blankholder forces obtained through the optimization process.

![Optimization flowchart](image)

**FIGURE 9.** Optimization procedure

![Thickness distribution](image)

**FIGURE 10.** Optimum blankholder forces distribution (N)

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It should be noted that the sum of the optimum blankholder forces (351 kN) is almost equal to the initial blankholder force (300 kN). Indeed by adjusting the blankholder forces in space we can limit the
FORMATION OF STRONG ONDULATIONS UNDER THE BLANKHOLDER. AND ALSO AVOID DRAWSHEADS. THE TOTAL EXTERNAL WORK REQUIRED BY THE FORMING PRESS WAS REDUCED BY 1.6%. IN FIGURE 12 WE PRESENT THE MAJOR AND MINOR STRAIN DISTRIBUTION BEFORE AND AFTER OPTIMIZATION. WE NOTICE THAT ALL THE POINTS ARE BELOW THE CLF WITH A SECURITY MARGIN (S=0.015). THE MINIMUM AND MAXIMUM OF THICKNESS IS NOW EQUAL TO 0.788 MM (-21.2%) AND 1.1 MM (+10.4%)

FIGURE 12. MAJOR AND MINOR STRAIN DISTRIBUTION BEFORE AND AFTER OPTIMIZATION

CONCLUDING REMARKS

In the present study the analyses were performed using an incremental dynamic FEM code (ABAQUS). Overall satisfactory numerical results are obtained, compared with experimental results and other existing numerical results.

Regarding the optimization technique we developed a strategy based on an adaptive response surface method where at each response set the minimum of objective function is found taking the constraints into account. Three inequality constraints functions were defined to avoid necking and wrinkling. Overall satisfactory results are obtained to achieve a better control of the strains in the sheet.

The methodology is presently developed when a one-step FEM simulation is used to estimate the forming difficulties.

ACKNOWLEDGMENTS

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