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ON THE DESIGN OF SHEET METAL FORMING PARAMETERS FOR SPRINGBACK COMPENSATION

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Summary. *This paper deals with the optimization of deep drawing parameters in order to compensate the springback effects after forming. A response surface method (RSM) based on diffuse approximation is used. The "U-Bending" problem in Numisheet Conference has been utilized to validate the method, and good results of springback elimination have been obtained. The final results are validated using commercial codes.*

1 INTRODUCTION

Application of optimization techniques to metal forming problems [1, 2, 7] leads often to high numbers of expensive function evaluations. This is particularly the case when cost and constraint functions are obtained via complete finite element simulations involving fine meshes, high numbers of degrees of freedom, nonlinear geometrical and material behavior. The gradient information, necessary for common minimization algorithms is not always available, especially when black-box commercial codes are used. Response surface methodology (RSM) is used as an alternative method [3, 7] for replacing a complex model by an approximate one based on results calculated at various points in the design space. RSM can thus be used to diminish the cost of functions evaluation in structural optimization. The optimization is then performed at a lower cost over such response surfaces. RSM are well established for physical processes as documented by Myers and Montgomery [3] while the applications to simulation models in computational mechanics form a relatively young research field. An application to sheet metal forming process simulated by explicit dynamics method is given by Stander [7] with an emphasis on oscillating solutions.

2 OPTIMIZATION PROBLEM

In the optimization process, the goal is to

$$\text{minimize} \quad f(\mathbf{x}),\ \mathbf{x} \in R^n \tag{1}$$

subject to a set of m constraints

$$g_j(\mathbf{x}) \le 0,\ j = 1, \ldots, m \tag{2}$$

where f is the cost function, x_i are the design variables, g_j is the j-th nonlinear constraint. The RSM approach consists in solving a problem where the cost function replaced by their approximations $\tilde{f}$ and $\tilde{g}_j$. This simplified problem may be written as

$$\text{minimize } \tilde{f}(\mathbf{x}), \mathbf{x} \in R^n \tag{3}$$

subject to a set of m constraints

$$\tilde{g}_j(\mathbf{x}) \leq 0, \; j = 1, \ldots, m \tag{4}$$

Approximations (3) and (4) are based on a set of numerical experiments with the function f. The problem of distributing the experimental points in the design space is known as DOE.

3 RESPONSE SURFACE MODEL

Given the function values for a set of experimental points $\mathbf{x}_i$ distributed according to a chosen DOE, the function $\tilde{f}$ can be defined in terms of basis functions $\mathbf{p}$ and some adjusting coefficients $\mathbf{a}$ as

$$\tilde{f}(\mathbf{x}) = \mathbf{p}^T(\mathbf{x})\mathbf{a}(\mathbf{x}) \tag{5}$$

The coefficients a_i are determined by a weighted least squares method minimizing the error $J(\mathbf{a})$ between the experimental and approximated values of the objective function

$$J(\mathbf{a}) = \sum_{i=1}^{N} w\left(\left\|\mathbf{x}_i - \mathbf{x}\right\|\right)\left(\mathbf{p}^T\left(\mathbf{x}_i - \mathbf{x}\right)\mathbf{a} - f(\mathbf{x}_i)\right)^2 \tag{6}$$

The weight functions play a crucial role by influencing the way that the coefficients a_i depend on the location of the design point $\mathbf{x}$. $Min(J)$ gives:

$$\mathbf{a}(\mathbf{x}) = \mathbf{A}^{-1}\mathbf{B}\mathbf{f} \tag{7}$$

with

$$\mathbf{A} = \mathbf{P}\mathbf{W}\mathbf{P}^T \qquad \mathbf{B} = \mathbf{P}\mathbf{W} \tag{8}$$

4 DESIGN OF EXPERIMENTS

In Figure 1 the hollow dots show a discrete set of points in design space where we decide to authorize the numerical experiments. This is what we call a virtual DOE as the experiments are designed but not yet performed at this stage. The point $\mathbf{x}_i$ was centered within the region of interest. In the actual approach, the search pattern is no more centered on $\mathbf{x}_i$ but is defined by the set of closest virtual designs and the scale of the resolution of the grid. At iteration i the pattern is defined by four solid black dots for resolution window size $2h$. The response surface is then fitted on these points. When the current design is translated to $\mathbf{x}_{i+1}$, the closest neighbors are selected with resolution refined to h. The new points are denoted by the three gray dots and the fourth one is reused from the previous pattern. In this way, the total number of experiments is reduced from 8 to 7. The gain is proportionally higher for bigger patterns.

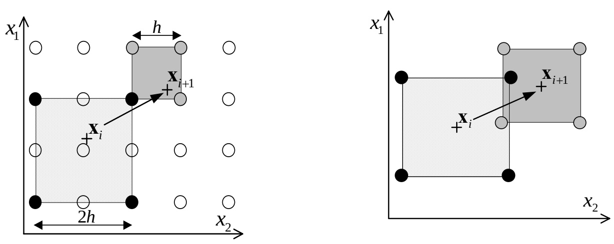

Figure 1: Multiscale pattern search with Virtual DOE

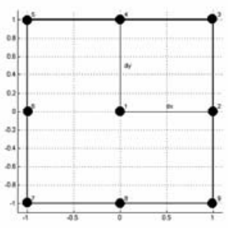

Figure 2: TCR9 pattern – 9 points

For example if we present the diffuse approximation for a simple 9 points factorial pattern TCR9 (Figure 2). A quadratic approximation of the response surface is obtained when considering coefficients a_i in expression (7) as constants.

5 NUMERICAL APPLICATIONS

5.1 "U-Bending" Springback Benchmark

This example was proposed as a benchmark in the international conference Numisheet'93 [2]. It consists of a rectangular sheet of 35 mm of width and 350 mm of length (Figure 3), the material and geometrical characteristics are given in [2]. At the end of the forming operation, and after removing tools, the "U" shape is not conserved. Our goal is to determine the opening parameters: θ_1, θ_2 and ρ [2]. A modified inverse Approach is used to simulate the forming operation in "one step", including initial solution to speed up the convergence process. Figure 4 shows the bending moment along the curvilinear abscissa S of the stamped "U" sheet. We can observe clearly a good tendency of the obtained results when compared to those of STAMPACK® (explicit dynamics) [5].

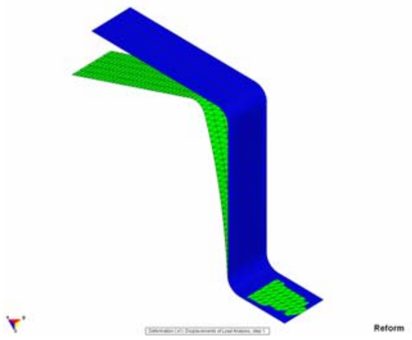

Figure 3: "U" shape before and after removing tools

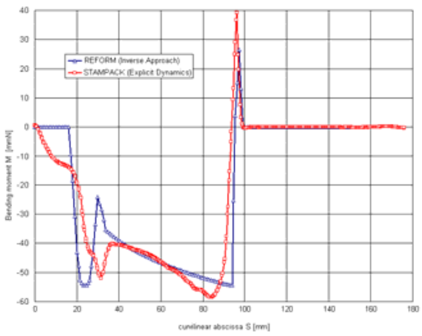

Figure 4: Bending moment distribution

Springback results are summarized in Table 1. We can observe that Results of the modified Inverse Approach obtained using only 800 DKT12 shell element $\rho = 233.62\ mm$ are in good agreement with those of Numisheet'93 reference solution and ABAQUS.

Method	F.E. mesh	θ_1 [°]	θ_2 [°]	ρ [mm]	CPU time
Explicit Dynamics (STAMPACK®)	4000 BST	97.98	80.02	335.01	1h 18m 49s
Implicit Static (ABAQUS®)	4640 S4R	97.88	80.98	239.09	29h 56m 24s
Inverse Approach	800 DKT12	99.94	80.08	233.62	5 s
Numisheet'93 Simulation	---	99.00	82.00	240.00	
Numisheet'93 Experience	---	99.20	82.10	---	

Table 1: Principal results of the springback simulation

5.2 Tools Geometry Optimization

Two radii are considered, the punch radius denoted by R_p and the die radius R_d. We choose initial values for the two radii as $R_p = R_d = 5\ mm$ and the objective function represents the maximum opening of the "U" sheet:

$$J = \sqrt{\sum_{i=1}^{nnt} \left(\vec{d}_i^T \cdot \vec{d}_i \right)} = \sqrt{\sum_{i=1}^{nnt} \left(u_{Xi}^2 + u_{Yi}^2 + u_{Zi}^2 \right)} \tag{9}$$

where d_i represent the distance at each node from the opened final part and its original position obtained at the end of forming operation.

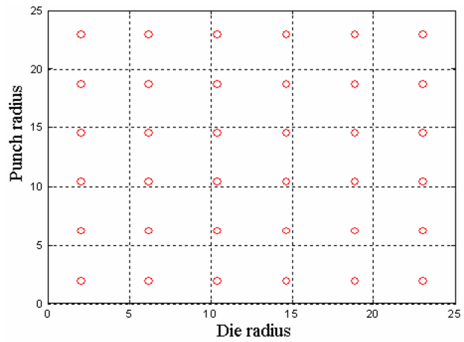

Figure 5: Mapping grid for the model

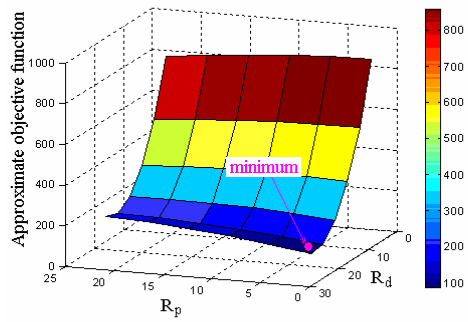

Figure 6: Response Surface Model

The optimization problem is carried out using global optimization procedure. An initial mapping of 6×6 points equally spaced (Figure 5) was used to evaluate the real objective function delimited inside the bounds $R_{\min} = 2\ mm$ and $R_{\max} = 23\ mm$. Figure 6 shows the Response Surface Model obtained using Diffuse Approximation. The minimum obtained corresponds to $\left(R_p = 2.23mm,\ R_d = 22.97mm\right)$.

6 CONCLUSION

We proposed a new response surface method involving Diffuse Approximation technique and pattern search optimization. The resulting response surface algorithms involve iterative improvement of the objective and constraint functions employing locally supported nonlinear approximations. The resulting procedure was applied successfully for the design tools geometry (tools radii) in order to minimize the springback effects of the "U" bending benchmark of Numisheet'93 international conference.

7 REFERENCES

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