COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

1. Reporting Period	**1.1.2003 – 30.06.2003**
Project title	Optimization of Process Parameters in Sheet Metal Forming
Project leader Organization	**Dr. Catherine Knopf-Lenoir** Université de Technologie de Compiègne Laboratoire Roberval, UMR UTC-CNRS BP 20529 – 60205 Compiègne Cedex
Main collaborators involved	**Prof. Jean-Louis Batoz,** **Dr Arnaud Delamézière** InSIC, 27, Rue d'Hellieule 88100 Saint-Dié-des-Vosges **Dr Hakim Naceur, UTC**

2. Funding Situation

Amount of money received specifically for COST 0 kEuros
Other resources partially used for the project
Funding from the french Ministery of Research (OPTIMAT project):
60 kEuros per year

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Brussels (May 27-28, 2003) + project progress report: YES

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
Meetings of the OPTIMAT group: 1st meeting: Participants: CEMEF, ENSAM, LMA, MECALOG, InSIC , UTC, TRANSVALOR	CEMEF, ENSMP, Sophia-Antipolis March 6, 2003
2nd meeting Participants: CEMEF, ENSAM, LMA, MECALOG, AMIS, InSIC , UTC	Massy Palaiseau, June 13, 2003

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

WP3: Improvement of the Response surface method

The response surface method developed to optimize the process parameters is based on the determination of an explicit approximation of the objective function obtained by MLS (moving least squares approximation):

$$\tilde{\mathbf{J}}(\mathbf{x}) = \mathbf{P}(\mathbf{x})^{\mathbf{T}}.\mathbf{a}(\mathbf{x})$$

P(x) is the polynomial basis and a the vector of coefficients obtained by solving the least square problem:

$$\mathbf{Min} \quad \frac{1}{2}\sum_{k=1}^{m} w_k \left[J^k - P(x^k)^T.a \right]^2$$

x^k , k=1,...,m are the points where the objective function has been computed and w^k the associated weights, which depends on the distances (x, x^k). Therefore, the coefficients a of $\tilde{\mathbf{J}}(\mathbf{x})$ are calculated at every point x , giving a local approximation. If a quadratic polynomial basis is used, $\tilde{\mathbf{J}}(\mathbf{x})$ can be also considered as the Taylor expansion of **J** around x:

$$\tilde{\mathbf{J}}(\mathbf{x}) = \frac{1}{2}\Delta x^T H \Delta x + \Delta x^T b + c$$

and the coefficients a correspond to approximations of the derivatives of J [2]:

$$\mathbf{a} = \left\langle \tilde{J}, \ \frac{\delta \tilde{J}}{\delta x_1}, \dots , \frac{\delta \tilde{J}}{\delta x_n}, \ \frac{\delta^2 \tilde{J}}{\delta x_1^2}, \frac{\delta^2 \tilde{J}}{\delta x_1 \delta x_2}, \dots , \frac{\delta^2 \tilde{J}}{\delta x_n^2} \right\rangle$$

These approximate derivatives called "diffuse derivatives" can be used to find the minimum of $\tilde{\mathbf{J}}$, $\tilde{\mathbf{x}}$, by solving a linear system. A new approximation is computed and the process is repeated iteratively giving a sequence $\tilde{\mathbf{x}}^1, \dots , \tilde{\mathbf{x}}^p$ until the minimum of the exact function J is reached.

If sensitivity analysis is available, the exact derivatives of J can be computed in the evaluation points x^k , k=1,...,m and a different least squares problem is solved:

$$\mathbf{Min} \quad \alpha\frac{1}{2}\sum_{k=1}^{m} w_k \left[J^k - P(x^k)^T.a \right]^2 \quad + \quad (1-\alpha)\sum_{k=1}^{m} w_k \left(\nabla J^k - \nabla P(x^k) .a \right]^2$$

The parameter α is a weighting parameter specifying the relative influence of the function and its derivatives in the approximation ($0 < \alpha < 1$)

Application

The response surface method is used to optimize the dimensions of the blank (x_1 and x_2) of the Twingo dashpot cup. The quality is related to the thickness variation (see HY Report1), and the objective function is defined by:

$$f_h(\mathbf{x}) = \left(\sum_{e=1}^{nelt} f_h^e(\mathbf{x}) \right)^{1/p} \; ; with \; f_h^e(\mathbf{x}) = \left(\frac{h^e - h_0}{h_0} \right)^p = \left(\lambda_3^e - 1 \right)^p$$

where h_0, h^e are the initial and final thicknesses, λ_3^e is the principal stretch along the thickness. The minimization of this objective function lets to attenuate the thickness variations. Therefore, it allows to improve the workpiece feasibility, because in practice a rupture is preceded by a high thinning and wrinkling is preceded by a high thickening.

Lower and upper bounds are imposed on the design variables. Local quadratic MLS approximation are built using 9 evaluation points . In order to have a graphical representation of the convergence path, many points have been evaluated to draw the isolines of the function, but they are not used to compute and minimize the response surface.

The optimization procedure using MLS approximation is started using four different initial points, but the same solution is obtained (figure 2). It can be observed on Table 1 that the optimal blank dimensions lead to a good thickness repartition compared to those given by the lower (maximal thickening +23%) and the upper bounds (maximal thinning –31%)

	lower bounds	**optimum blank size**	**upper bounds**
x1 (mm)	**405.00**	**435.51**	**490.00**
x2 (mm)	**365.00**	**410.24**	**460.00**
Δhmin	**- 12.94%**	**- 17.51%**	**- 31.18%**
Δhmax	**23.32%**	**20.44%**	**18.64%**

Table 1 – Design parameters and thickness variation

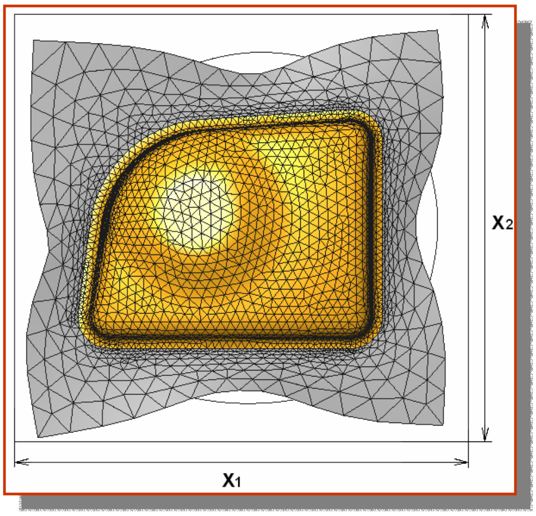

Fig. 1 – Twingo dashpot cup

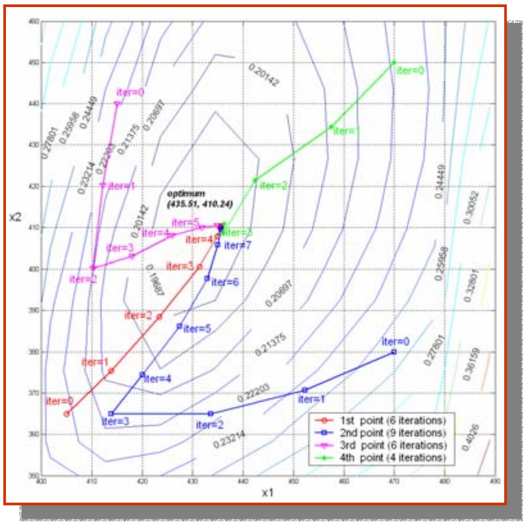

Fig. 2 – History of convergence for different starting points

The optimal design obtained with the surrogate IA model was then validated with StamPack® commercial code based on the explicit dynamic incremental approach which is known to be more accurate than one step approaches.

We have used triangular rigid elements for the tools. The die was meshed using a cordal error of 0.03 mm and a maximal length of 100 mm. Using the blank optimal dimensions

obtained by the previous optimization procedure, the blank is first meshed using triangular BST shell elements T3 with 3 degrees of freedom per node and a mapped mesh of 90×82 elements.
The maximum thickness variations obtained are +18.36 % and –18.91 % and are close to those obtained using IA. Figure 3 and Figure 4 compare the thickness distribution along profiles P_1 (parallel to x1) and P_2 (parallel to x2)

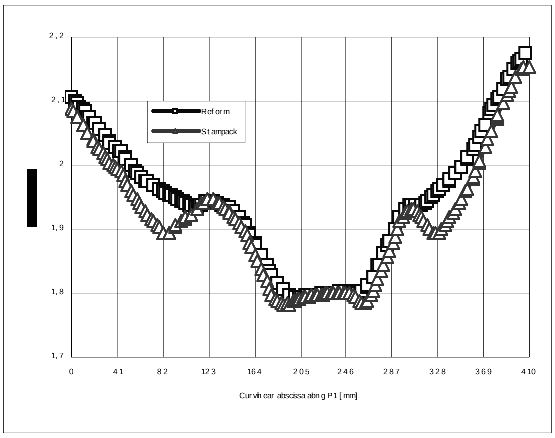

Figure 3

Thickness comparison along profile P1

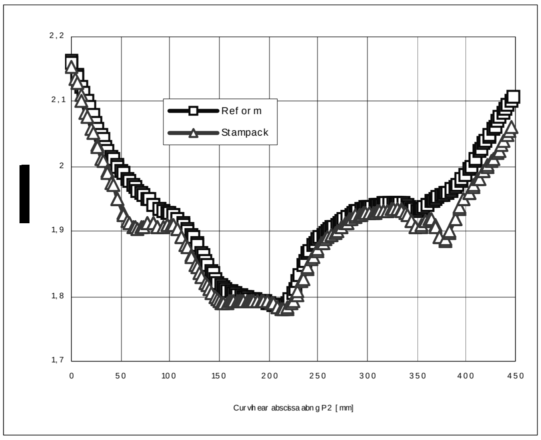

Figure 4

Thickness comparison along profile P2

7. List of publications

a) Published

[1] NACEUR H., BREITKOPF P., KNOPF-LENOIR C., VILLON P., Méthode de surface de réponse pour l'optimisation de forme des surfaces additionnelles de pièces embouties, 6ème Colloque National en Calcul des Structures, 20-23 Mai 2003, Giens (Var), France, CSMA, Actes (Ecole Polytechnique) pp 215-222 et CD-Rom.

b) Submitted for publications

[1] NACEUR, H., DELAMÉZIÈRE, A., BATOZ, J.L., GUO, Y.Q., KNOPF-LENOIR, C., « Some improvements on the optimum process design in deep drawing using the Inverse Approach », Journal of Materials Processing Technology, accepted

[2] BREITKOPF P. NACEUR H., RASSINEUX A., VILLON P., Moving least squares response surface approximation: formulation and metal forming applications, submitted to Computers and Structures

c) In preparation