COST 526

“Automatic Process Optimization in Materials Technology”

(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **August 31, 2002**

1. Reporting Period	**1.1.2002 – 30.6.2002**
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

2. Funding Situation		
Amount of money received specifically for COST		0 kEuros
Other resources partially used for the project	1PhD scholarship:	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 Saint-Dié des Vosges + project progress report

⌊ YES

Dr Ponthot and Stainier, University of Liège

4. Industry participation

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

CIRTES, St Dié des Vosges

5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

WP1: definition of optimization problems

In this first part of the project, several types design variables and objective functions have been defined :

Optimization of initial blank contours

The size and shape of the blank have both a great influence upon the quality of the workpiece. When the blank is too large, the material flow into the die cavity is limited and the risk of the excessive thinning (necking) increases. On the other hand, a too small blank size can cause wrinkling problems. The design variables are the positions of the curve control knots describing the workpiece contour (Fig.1). A parametrization with a B-spline curve is used to reduce the number of design variables. Some limitations on the design variables are introduced in order to satisfy technological requirements.

Optimization of restraining forces and drawbead design

The drawbeads are one of the most important parameters to control the material flow and thus the part quality in the sheet forming process. Too strong restraining forces prevent the sheet from draw-in and may cause the necking, but insufficient forces may lead to wrinkling.

The magnitudes and positions of the drawbeads can lead to numerous design variables.

To reduce the number of variables, a continuous line C around the die cavity and roughly parallel to its contour is taken as the drawbead line

In the sheet forming simulation, the drawbeads are replaced by equivalent restraining forces assumed to be externally normal to this line. The intensities of the restraining forces are supposed to be constant by segment on the drawbead line, and constitute the design variables vector (Fig. 2). In a limited number of practices, drawbeads of different shapes are acceptable.

The optimization can be carried out in two steps. First, the restraining forces are assumed to be continuous (positive) values, and their distribution is be obtained by an optimization computation. We then neglect the small restraining forces, regroup the restraining forces with closed values and perform the second optimization to find the optimal shapes and positions of discrete drawbeads.

Two constraints are imposed to each design variable. The lower bound is zero and the upper bound is always positive and can be defined approximately according to the yield condition.

Objective functions

The objective functions are defined to obtain at the end of the forming process a final workpiece without defects for a minimum amount of material.

In the simplified inverse approach (I.A.) ([1], [2]), the necking and wrinkling cannot be directly detected. The thickness variation appears to be a good indicator of quality, since the necking and wrinkling are often associated with a strong thinning and thickening. These considerations lead to define the first objective function J_1 as an expression of the thickness variation:

$$J = \sum_{e} J^{e} = \sum_{e} \left| \frac{h^{e} - h^{0}}{h^{0}} \right|^{p} = \sum_{e} \left| \lambda_3^{e} - 1 \right|^{p}$$

where h^0, h^e are the initial and final thicknesses, λ_3^e the thickness stretch. The exponent p is introduced to emphasize the influence of the maximal thickness variation. Some conditions can be also added as optimization constraints to impose limiting values on maximum thinning or thickening.

A second objective function is introduced to take into account the Forming Limit Diagram (FLD). A defect free part is such that at the end of the numerical simulation no principal strains couple (ε_2, ε_1) of the Forming Limit Diagram is located beyond the FLC (Fig. 3). So from the definition of the distance d and the safety margin s, we define the objective function J_2 as :

$$J = \sum_{\text{nelt}} (s-d)^2 \text{ if } (s-d) > 0$$

This optimization procedure is based on the Inverse Approach developed by the authors and a SQP optimizer. In the second part, another optimization problem is stated in order to design the drawbead producing the optimal restraining forces obtained in the first part. This second procedure is carried out by coupling the drawbead force calculation with a BFGS optimizer in order to obtain a "uniform" increase of the restraining forces in the sheet under the drawbead.

WP2: Optimization with Inverse Approach

The Inverse Approach for sheet metal forming analysis has been presented in details by the authors ([1]). This method exploits the knowledge of the final workpiece shape: starting with a finite element mesh on the final part, we look for the nodal positions in the initial flat blank. The simple vertical projection of the nodes on the horizontal plane can be an initial estimation. These node positions are then modified by a Newton-Raphson algorithm in order to satisfy the equilibrium in the final workpiece. Two main assumptions are adopted: the proportional loading assumption allows avoiding the incremental integration of plasticity (Deformation Theory of Plasticity), the second assumption allows to use simplified pressure-friction forces instead of the contact conditions between the tools and the sheet. These assumptions lead to a total or direct method independent of the deformation history. The I.A. is very fast and does not need much memory space (only two degrees of freedom per node).

The two problems (shape of the blank contour and drawbeads optimization) have been solved by using a BFGS or SQP (Sequential Quadratic Programming) method. The Twingo dashpot cup is taken as an example to illustrate the effect of the contour shape optimization. The objective function based on thickness variation J1 is considered. Some results are presented on Fig 4 , showing that the maximum values of thinning and thickening have been significantly reduced.

The same application is considered for drawbeads design ([3]). The Fig 5 shows the optimal drawbeads obtained by minimization of the second objective function.(based on F.L.D).

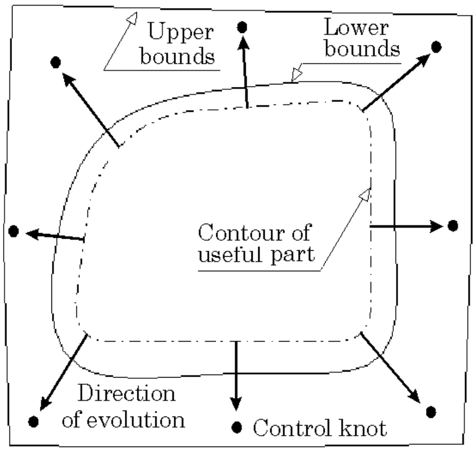


***Figure 1.* Parametrization of the contour with eight design variables**

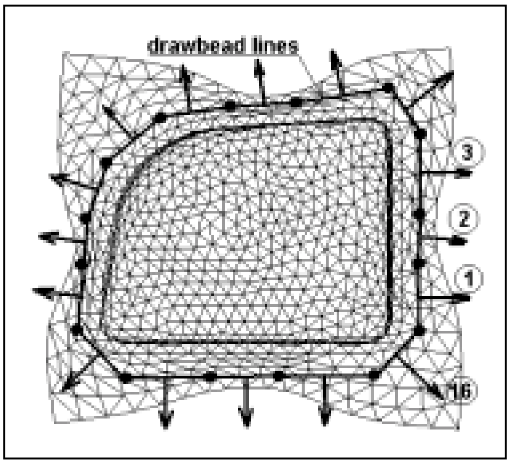
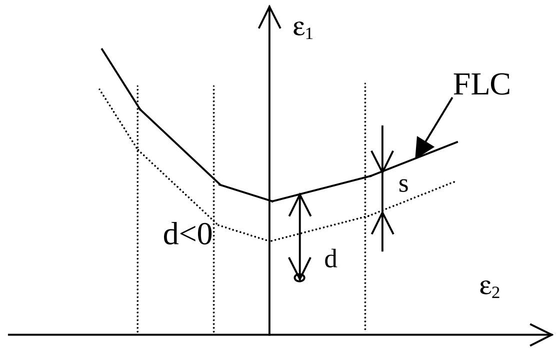


***Figure. 2* Positions of drawbead lines and restraining forces (16 design variables)**



$$J_2 = \sum_{e=1}^{nelt} \max(0, s - d_e)^2$$

with de = distance from (ε_2, ε_1) to the FLC

***Figure 3* – Definition of an objective function based on the Forming Limit Curve.**

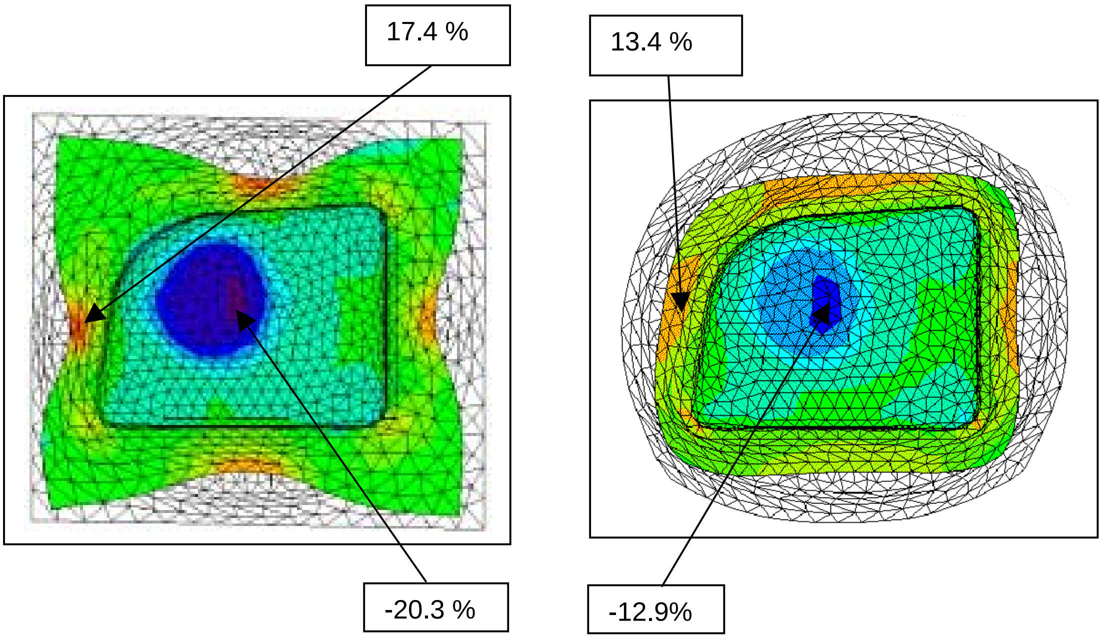


Fig.4 – Twingo dashpot cup : thickness distribution before (left) and after(right) optimization of the blank contour shape.

7. List of publications

a) Published

[1] GUO, Y.Q., BATOZ, J.L., NACEUR, H., BOUABDALLAH, S., MERCIER F., BARLET, O. "Recent developments on the Analysis and Optimum Design of Sheet Metal Forming Parts using a Simplified Inverse Approach", Int. J. for Computers and Structures, Vol. 78, p. 133-148, 2000.

[2] NACEUR, H., GUO, Y.Q., BATOZ, J.L., KNOPF-LENOIR, C., "Optimisation des forces de retenue pour le contrôle de la qualité des tôles embouties, Revue Européenne des Eléments Finis, Vol. 9, n° 1-2-3, Mars 2000, p. 151-172.

[3] NACEUR, H., GUO, Y.Q., BATOZ, J.L., KNOPF-LENOIR, C., "Optimization of drawbead restraining forces and drawbead design in sheet metal forming process" Int. J. of Mechanical Sciences, Vol.43, n°10, octobre 2001, p.2407-2434 .

b) Submitted for publications

[4] 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, accepté, à paraître 2002.

[5] BATOZ, J.L., NACEUR, H., DELAMEZIERE, A., GUO, Y.Q., KNOPF-LENOIR, C., « Design of process parameters in deep drawing of sheets to improve manufacturing feasibility », in Integrated Design and Manufacturing in Mechanical Engineering'98, Chedmail et al., Eds, Kluwer Academic Publishers, 2002, à paraître.

[6] DELAMÉZIÈRE, A., NACEUR, H., BREITKOPF, P., KNOPF-LENOIR, C., BATOZ, J.L., VILLON, P., « Utilisation de la méthode de surface de réponse pour améliorer la faisabilité d'une pièce emboutie en optimisant les paramètres du matériau », Revue Mécanique et Industries, à paraître 2002.

c) In preparation