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, 2004**

1. Reporting Period	**1.1.2004 – 30.06.2004**
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 Angers (May 13-14, 2004) + 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**

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

WP4: <u>Optimization with Incremental approach:</u> on the optimization and control of the blankholder force in deep drawing

The sheet metal forming process plays an important role in the manufacturing industry. The increasing use of high strength steels and the reduction of sheet thickness generate formability difficulties especially for complex parts. Wrinkling, necking and springback are the principal defects for this process which must be controlled if not avoided. The blankholder force is one of the process parameters, which is able to control effectively the flow of the metal into the die cavity and to improve quality of the workpieces. The present work is based on an original idea which was used by Siegert, Häussermann, Haller and Descamps [1, 2, 3, 4]. The goal is to control the movement of the blank under the blankholder by adjusting locally the blankholder force and/or varying it during time in independent zones according to the punch stroke. The objective function is to minimize the external work of the finite element model.

An inequality constraint function is formulated to avoid **<u>wrinkling</u>**: the angle between the die and the blank is limited to a value θmax fixed by the user, as proposed by Gelin and Labergere [5].

$$G_1 = \begin{cases} \dfrac{1}{n}\displaystyle\sum_{i\in D_n}\left(\sin\theta_{max} - \sin\theta_i\right) & \text{if } \forall\, i \in D_n\ \theta_i < \theta_{max} \\ \displaystyle\sum_{i\in D_p}\left(\sin\theta_{max} - \sin\theta_i\right) & \text{else} \end{cases}$$

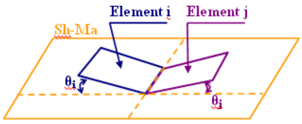


Figure 1: Geometrical criterion to detect the development of wrinkles under the blankholder surfaces

This function is built to avoid the formation of strong undulations under the blankholder zones. The value of θmax depends on the strategy of the optimization of the blankholder force (time dependent or not). At the end of the forming stage the maximum of all the θ_i angles should be less than θ_{max}.

A quality function in relation with the possibility of localized **<u>necking</u>** has been developed based on the Modified Maximum Force Criterium MMFC(adapted from the works of Swift, Hora, Brunet).

The major stress is limited to a value σ_n^{cr}. A indicator of the local risk of necking is then defined on each element el :

$$R_n^{el} = \frac{\sigma_I}{\sigma_n^{cr}}$$

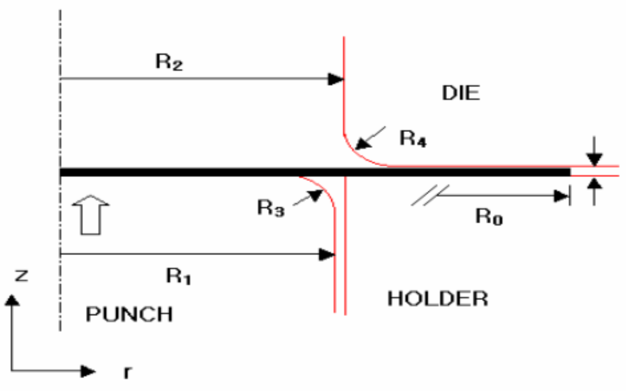
where σ_I is the major stress. A global function is then formulated according to R_n^{el} :

$$G_3 = \begin{cases} \frac{1}{n}\sum_{el}\left(R_n^{limit}-R_n^{el}\right) \text{ if } \forall\, el \in D\ R_n^{el} \leq R_n^{limit} \\ \frac{1}{n_n}\sum_{el\in D}\left(R_n^{limit}-R_n^{el}\right) \quad \text{else} \end{cases}$$

The validity of the MMFC has been studied by solving a number of stamping problems (cylindrical and square cups) where experimental results are available. The criterium is computed from the output results of the simulation code ABAQUS and leads to a new constraint function ($G_3 \geq 0$) for the optimization problem.

The optimal control problem is solved as a sequence of sub-problems corresponding to time intervals; In a given sub-problem, the design variables are the forces to be applied to the different blankholder zones during the time interval considered. The sequence of successive forces applied to the same zone defines its control law.
Each optimization step is carried out using a response surface method based on a moving least squares approximation.

The simulation + optimization approaches are applied to the Numisheet'02 cylindrical cup [6] to optimize both a constant and a time dependent blank holder force.



R_1=50.0, R_2=51.25, R_3=9.5, R_4=7.0, R_0=105.0 (Unité : mm)

Figure 2 : Tool and blank geometry of the cylindrical cup.

When the blank holding force varies during the process, a control law is used (Figure 3). Four control laws are compared to pass from the zero value of θ_{max} to a value of θ_{max}=0.9° at the end of the punch stroke (as we know that this maximal value will be certainly reached). That stroke of 40 mm is divided into four intervals of 10 mm.

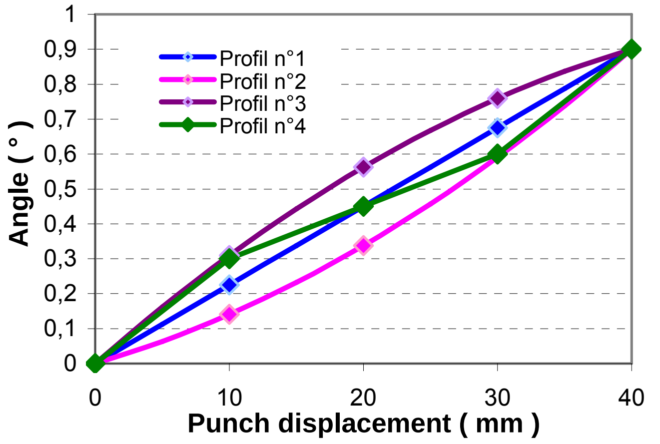


Figure 3: Control laws considered.

The optimization results for the control law 3, are shown in Table 1. For each of the four displacement steps, three response surfaces have been necessary to achieve convergence, and five numerical simulations are needed to compute one surface. When the optimum value is obtained a simulation is performed using it. Other response surfaces are computed to optimize the force value for the next step. ABAQUS restart files are used to limit the CPU time.

Punch displacement (mm)	Number of surface response sets	Optimum (kN)	Objective Function (J)	Constraints
0	-	6.64	0	0
10	3	6.64	244.2	0.016
20	3	9.22	985.88	-0.00182
30	3	15.4	1901.56	-0.000216
40	3	19.83	2849.37	-0.001016

Table 1: Optimization Results for a variable BHF (Numisheet'02 cylindrical cup).

These result show that the constraints are satisfied at the end of the forming. The optimal forces specified by the optimal control law limit the wrinkling and the risk of necking: the approach has been thus validated on a simple example with one variable force; a more complex industrial application will be studied in the next period.

References:

[1] K. Siegert. Research and Development in the Field of Sheet Metal Forming Technology of the Institute for Metal forming Technology (IFU) of the University of Stuggart in New Developments in Sheet Metal Forming ISBN 3-88355-292-5, Klaus Siegert (Editor), pp277-308, Fellbach, Germany, 23-24 May (2000).

[2] M. Häussermann. Multipoint-Cushion-Technology Advances and Die Design, in New Developments in Sheet Metal Forming ISBN 3-88355-292-5, Klaus Siegert (Editor), pp341-366, Fellbach, Germany, 23-24 May (2000).

[3] D. Haller. Controllable Nitrogen Gas Spring Systems for stamping applications, in New Developments in Sheet Metal Forming ISBN 3-88355-292-5, Klaus Siegert (Editor), pp341-366, Fellbach, Germany, 249-276 May (2000).

[4] R. Descamps, B. Chamont, R. Kergen. Blankholder Force Control in Deep Drawing (Application on a Critical Industrial Part), in New Developments in Sheet Metal Forming ISBN 3-88355-292-5, Klaus Siegert (Editor), pp229-247, Fellbach, Germany, 23-24 May (2000).

[5] J.C. Gélin, C. Labergère. Numerical design and optimal control for sheet forming and tube hydroforming processes, 7th Int. Conf. in Numerical Methods in Forming Processes, NUMIFORM 2001, Toyohashi, Japan, 18-20 June 2001, in Simulation of Materials Processing, Ed. By K.I. Mori, pp897-902, 2001.

[6] Dong-Yol Yang, Soo Ik Oh, Hoon Huh, Yong Hwan Kim 5th Int. Conf. Numerical Simulation of 3D Sheet Metal Forming processes, NUMISHEET'02, Jeju Island, Korea, 2001.

7. List of publications

a) Published

[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 »*, Volume 146, Issue 2, 28 February 2004, Pages 250-262*

[2] NACEUR, H., BEN-ELECHI S., KNOPF-LENOIR, C., BATOZ, J.L. " Response Surface Methodology for the Design of Sheet Metal Forming Parameters to Control Springback Effects using the Inverse Approach", International Conference on

Numerical Methods in Industrial Forming Processes, NUMIFORM 2004, 13-17 June, Columbus, Ohio, USA, 2004

[3] BEN AYED L., DELAMÉZIÈRE A., BATOZ J.L. *, KNOPF-LENOIR C., "Optimization of the blankholder force with application to the Numisheet'02 deep drawing benchmark test B1", 8th International Conference on Numerical Methods in Industrial Forming Processes, NUMIFORM 2004, 13-17 June, Columbus, Ohio, US, 6 pages.

[4] BEN AYED, L, DELAMÉZIÈRE, A., BATOZ J.L., KNOPF-LENOIR C., ' OPTIMIZATION and control of the blankholder force in sheet metal stamping with application to deep drawing of a cylindrical cup', European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS 2004, P. Neittaanmäki, T. Rossi, S. Korotov, E. Oñate, J. Périaux, and D. Knörzer (eds.), Jyväskylä, 24—28 July 2004

b) Submitted for publications

[5] 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

Colloque Calcul des Structures (GIENS, France, May 2005)