OPTIMIZATION PROCEDURE FOR THE SPRINGBACK CONTROL

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Abstract: The paper presents an optimization procedure, based on the LMecA method, which allows to determine the optimum process parameters/tool geometry whose utilization leads to a minimum amount of springback. The analysis is made in the case of cylindrical deep-drawn parts.

Keywords: optimization procedure, springback, cylindrical drawn parts

1. INTRODUCTION

The final shape and dimensions of the formed parts are strongly affected by the springback phenomenon. In its turn, springback is a function of three main categories of factors, such as material properties, process parameters and tools geometry. Hence, by controlling all these factors, one should control the springback amount in order to obtain the desired accuracy of the formed parts. For this purpose, good results could be obtained from the application of some methods and techniques of optimization.

In this paper an optimization procedure based on the LMecA method is presented, in the case of cylindrical deep-drawing process. The method consists in controlled variation of the process parameters and determination of their effects on the geometry of 3D virtual part resulted from simulation. The investigation of the process parameters is based on a factorial plan of experiments. The relations between the part geometry and the process parameters/tools geometry are determining by means of polynomial equations (first or second degree).

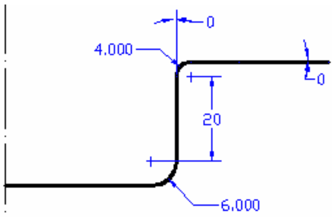
As result of the optimization procedure, virtual corrected tools are created, whose utilization, coupled with optimized process parameters, leads to a much lower springback, being thus fulfilled the conditions needed for proper manufacturing of the drawparts.

2. APPLICATION OF THE LMECA METHOD IN ORDER TO REDUCE THE SPRINGBACK EFFECT IN THE CASE OF CYLINDRICAL DRAWN PARTS

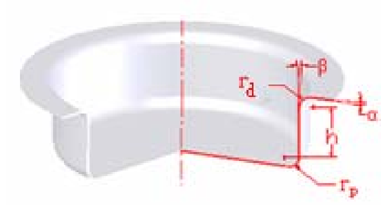
The LMecA method assumes the following six stages:
1. Definition of the parameters that characterize the geometric deviations of the part.
2. Selection of the process parameter which can influence the geometry of the part, and their range of variation to test.
3. Choice of a linear or quadratic polynomial model and construction of an experiment design.
4. Performing the simulations defined by the experiment design and measurement of the geometrical defects on the obtained virtual parts.
5. Calculation of coefficients of the polynomial models and verification of the models.
6. Optimization of the process parameters in order to obtain the desired geometric parameters of the drawn parts.

2.1 Choice of the geometric parameters of the part

The nominal geometry of the part and the geometric parameters whose variation will be investigated in order to quantify the effects of springback are presented in figure 1, where: r_d is the radius of connection between the part flange and part sidewall, r_p is the radius of connection between the part bottom and part sidewall, α is the angle of the flange, β is the inclination angle of part sidewall and h is the height of the part sidewall.



a. theoretical profile



b. analyzed geometric parameters

Fig. 1 Geometric parameters of the cylindrical part

2.2 Choice of the process parameters

The initial configuration of tool is presented in figure 2 and the part resulted by using this configuration is presented in figure 3. The used blankholder force was equal to 45kN and the punch-die clearance was set to 1mm. Because the obtained values of geometrical parameters of the drawn part are different from the nominal ones, it follows to identify the process parameters that must be optimized in order to diminish the effect of springback.

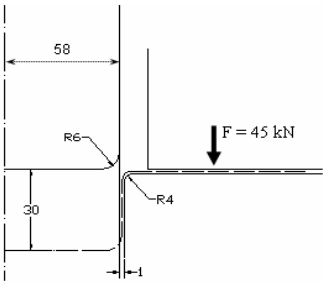


Fig. 2 Initial tools configuration

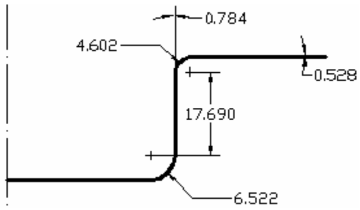


Fig. 3 Part obtained by simulation with initial tools

The selected parameters used in simulation are as fallows (figure 3): blankholder force (F), punch-die clearance (j), punch stroke (s), punch radius (Rp) and die radius (R_d). Their domain of variation was chosen according to the initial simulation results and based on their probable influence on the part geometry. These values are given in table 1.

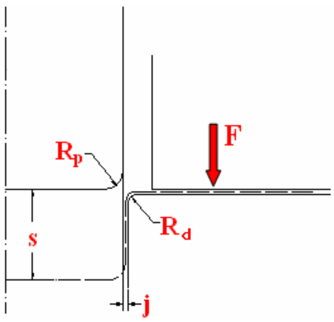


Fig. 3 Process parameters

Tab. 1

Tested process parameters and their fields of variation

Parameter	Initial value	Minimum value (-1)	Maximum value (+1)
Punch radius **(R_p)**	6 mm	5 mm	7 mm
Die radius **(R_d)**	4 mm	3 mm	5 mm
Blankholder force **(F)**	45 kN	40 kN	90 kN
Punch-die clearance **(j)**	1 mm	1 mm	1.5 mm
Punch stroke **(s)**	30 mm	30 mm	32 mm

2.3 Choice of the model and construction of the experiments design

2.3.1 Linear optimization

The first degree polynomial function which assumes a linear variation of the output from every input is the following:

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_n x_n + a_{12} x_1 x_2 + \ldots + a_{n-1,n} x_{n-1} x_n \tag{1.1}$$

where: Y represents the geometrical parameters of the part (r_d, r_p, α, β, h), x_1 … x_n represent the reduced values of the input parameters that must be optimized (R_p, R_d, F, j, s) and $x_i x_j$ represent the interactions between the considered factors.

In order to determine the coefficients a_0, a_1, a_2 …a_n corresponding to each function, for the five analyzed factors sixteen numerical experiments were needed to carry out as it is shown in table 2. In this table, the levels (-1) and (+1) correspond respectively to the minimal and the maximal value of the parameters, as it is shown in table 1.
The result of each simulation is a file of nodes, representing the nodes of the simulated formed part mesh, after the tools removing. This file was post treated in order to measure the geometric part parameters. The results are given in table 3.

Tab.2

N°	R_p'	R_d'	F'	j'	s'
1	-1	-1	-1	-1	-1
2	-1	-1	-1	+1	+1
3	-1	-1	+1	-1	+1
4	-1	-1	+1	+1	-1
5	-1	+1	-1	-1	+1
6	-1	+1	-1	+1	-1
7	-1	+1	+1	-1	-1
8	-1	+1	+1	+1	+1
9	+1	-1	-1	-1	+1
10	+1	-1	-1	+1	-1
11	+1	-1	+1	-1	-1
12	+1	-1	+1	+1	+1
13	+1	+1	-1	-1	-1
14	+1	+1	-1	+1	+1
15	+1	+1	+1	-1	+1
16	+1	+1	+1	+1	-1

Tab.3

	Rp	R_d	F	j	s	r_p	r_d	α	β	h
1	5	3	40	1	30	5.613	3.673	0.928	0.252	20.654
2	5	3	40	1.5	32	5.648	3.388	0.742	1.192	22.922
3	5	3	90	1	32	5.608	3.388	0.742	1.192	22.964
4	5	3	90	1.5	30	5.589	3.525	0.938	1.565	20.619
5	5	5	40	1	32	5.548	5.399	0.618	0.261	20.926
6	5	5	40	1.5	30	5.738	5.436	0.523	1.342	18.750
7	5	5	90	1	30	5.589	5.456	0.185	0.368	18.923
8	5	5	90	1.5	32	5.662	5.396	0.627	1.304	20.849
9	7	3	40	1	32	7.503	3.494	1.031	0.158	20.912
10	7	3	40	1.5	30	7.499	3.385	0.909	1.443	18.944
11	7	3	90	1	30	7.558	3.350	0.909	1.443	18.984
12	7	3	90	1.5	32	7.594	3.396	0.728	1.424	20.947
13	7	5	40	1	30	7.443	5.437	0.476	0.348	16.978
14	7	5	40	1.5	32	7.525	5.437	0.306	1.382	18.910
15	7	5	90	1	32	7.485	5.494	0.313	0.348	18.971
16	7	5	90	1.5	30	7.560	5.524	0.444	1.784	16.833

From the results of the experiment design, the coefficients of polynomial model of each output were calculated. The following equations were got:

$$\begin{aligned} r_p = {} & 6.472+0.948R_p'-0.004R_d'+0.008F'+0.029j'-0.001s'-0.014R_p'R_d'+0.02R_p'F'-0.01R_p'j' \\ & +0.007R_p's'-0.001R_d'F'+0.023R_d'j'-0.01R_d's'-0.01F'j'+0.008F's'+0.006j's' \end{aligned} \tag{1.2}$$

$$\begin{aligned} r_d = {} & 4.448-0.009R_p'+0.099R_d'-0.008F'-0.013j'-0.025s'+0.035R_p'R_d'+0.009R_p'F'+0.009R_p'j' \\ & +0.04R_p's'+0.028R_d'F'+0.014R_d'j'+0.009R_d's'+0.032F'j'+0.002F's'-0.01j's' \end{aligned} \tag{1.3}$$

$$\begin{aligned} \alpha = {} & 0.651-0.012R_p'-0.215\,R_d'-0.04F'+0.001j'-0.013s'-0.04R_p'R_d'-0.001R_p'F'-0.04R_p'j' \\ & -0.03R_p's'-0.001R_d'F'+0.038R_d'j'+0.042R_d's'+0.073F'j'+0.005F's'-0.04j's' \end{aligned} \tag{1.4}$$

$$\begin{aligned} \beta = {} & 0.687-0.053R_p'-0.096\,R_d'+0.191\,F'+0.442\,j'-0.08s'+0.02R_p'R_d'+0.018R_p'F'+0.025R_p'j' \\ & -0.13R_p's'-0.13\,R_d'F'+0.119\,R_d'j'+0.012R_d's'-0.1F'j'-0.03F's'-0.02j's' \end{aligned} \tag{1.5}$$

$$h = 19.880-0.946 R_p'-0.988 R_d'+0.006 F'-0.034 j'+1.045s'-0.024R_p'R_d'-0.01R_p'F'+0.007R_p'j' -0.04 R_p's'-0.001 R_d'F'-0.02 R_d'j'-0.02R_d's'-0.04F'j'+0.002F's'+0.015j's' \quad (1.6)$$

In order to test the assumption of linearity of the output, a numerical simulation was carried out at the centre of the domain of variation (**R_p**= 6mm, **R_d**= 4mm, **F** = 65kN, **j** = 1.25mm and **s** = 31mm). The results of the simulation were compared with those obtained using the relations (1.2 – 1.6) and are presented in table 4.

Tab. 4

Comparison of the results

	R_p'	R_d'	F'	j'	s'	Values obtained from relations (1.2 – 1.6)	Values obtained from simulation	Errors
r_p	0	0	0	0	0	6.472	6.416	0.056
r_d	0	0	0	0	0	4.448	4.462	-0.014
α	0	0	0	0	0	0.651	0.535	0.116
β	0	0	0	0	0	0.687	0.539	0.148
h	0	0	0	0	0	19.880	19.625	0.255

By analyzing the above presented results some differences could be observed between the two modalities of determination. Hence, the precision of the model could be improved by choosing a quadratic model.

2.3.2 Quadratic optimization

The following polynomial function of 2nd degree was considered:

$$Y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n + \ldots + a_{11}x_1^2 + \ldots + a_{nn}x_n^2 + a_{12}x_1x_2 + \ldots + a_{n-1,n}x_{n-1}x_n \quad (1.7)$$

where: Y represents the followed values (r_d r_p, α, β, h), x_1 … x_n represent the reduced values of the input parameters that must be optimized (R_p, R_d, F, j, s) and x_ix_j represent the interactions between the considered factors. In order to determine the coefficients of the quadratic model a number of 10 additional simulations were needed (table 5). The results of these simulations are given in table 6.

Tab. 5

Nº	R_p'	Rd'	F'	j'	s'
1	-1.719	0	0	0	0
2	+1.719	0	0	0	0
3	0	-1.719	0	0	0
4	0	+1.719	0	0	0
5	0	0	-1.719	0	0
6	0	0	+1.719	0	0
7	0	0	0	-1.719	0
8	0	0	0	+1.719	0
9	0	0	0	0	-1.719
10	0	0	0	0	+1.719

Tab. 6

	Rp	Rm	F	j	s	r_p	r_m	α	β	h
1	5	3	40	1	30	5.613	3.673	0.928	0.252	20.654
2	5	3	40	1.5	32	5.648	3.388	0.742	1.192	22.922
3	5	3	90	1	32	5.608	3.388	0.742	1.192	22.964
4	5	3	90	1.5	30	5.589	3.525	0.938	1.565	20.619
5	5	5	40	1	32	5.548	5.399	0.618	0.261	20.926
6	5	5	40	1.5	30	5.738	5.436	0.523	1.342	18.750
7	5	5	90	1	30	5.589	5.456	0.185	0.368	18.923
8	5	5	90	1.5	32	5.662	5.396	0.627	1.304	20.849
9	7	3	40	1	32	7.503	3.494	1.031	0.158	20.912
10	7	3	40	1.5	30	7.499	3.385	0.909	1.443	18.944
11	7	3	90	1	30	7.558	3.350	0.909	1.443	18.984
12	7	3	90	1.5	32	7.594	3.396	0.728	1.424	20.947
13	7	5	40	1	30	7.443	5.437	0.476	0.348	16.978
14	7	5	40	1.5	32	7.525	5.437	0.306	1.382	18.910
15	7	5	90	1	32	7.485	5.494	0.313	0.348	18.971
16	7	5	90	1.5	30	7.560	5.524	0.444	1.784	16.833
17	6	4	65	1.25	31	6.416	4.462	0.535	0.539	19.625
18	4.28	4	65	1.25	31	4.793	4.307	0.801	0.831	21.799
19	7.72	4	65	1.25	31	8.402	4.457	0.709	1.378	18.017
20	6	2.28	65	1.25	31	6.535	3.31	0.674	0.949	21.082
21	6	5.72	65	1.25	31	6.627	6.176	0.088	1.116	18.151
22	6	4	22	1.25	31	6.545	4.355	0.58	0.107	20.049
23	6	4	108	1.25	31	6.661	4.446	0.58	0.818	19.808
24	6	4	65	0.82	31	6.528	4.34	0.406	1.197	18.336
25	6	4	65	1.68	31	6.696	4.439	0.528	1.971	19.808
26	6	4	65	1.25	29.28	6.626	4.45	0.612	0.859	21.606
27	6	4	65	1.25	32.72	6.701	4.439	0.528	1.844	19.803

The first sixteen experiments coupled with these ten new experime
quadratic model:

$$r_p = 6.378+0.975R_p'+0.004R_d'+0.015F'+0.034j'+0.005s'-0.014R_p' \ldots 0.001R_d'F'+0.023 R_d'j'-0.01 R_d's'-0.01F'j'+0.008F's'+0.006j' \ldots 0.01j'^2+0.007s'^2 \quad (1.8)$$

$$r_d= 4.417+0.005R_p'+0.954R_d'+0.001F'-0.001j'-0.019s'+0.034R_p'R_d'+0.008R_p'F'+0.008R_p'j'+0.04R_p's'+ 0.028R_d'F'+ 0.014 R_d'j'+0.009 R_d's'+0.032F'j'+ 0.002F's'-0.01j's'-0.03R_p'^2+0.091R_d'^2-0.025F'^2- 0.029j'^2-0.01s'^2 \quad (1.9)$$

$$\alpha = 0.501-0.015R_p'-0.202R_d'-0.03F'+0.010j'-0.016s'-0.04R_p'R_d'-0.001R_p'F'-0.044R_p'j'-0.03R_p's' – 0.001R_d'F'+0.038R_d'j'+0.042R_d's'+0.073F'j'+0.005F's'-0.04j's'+0.097R_p'^2-0.03R_d'^2+0.037F'^2- 0.001j'^2+0.034s'^2 \quad (1.10)$$

$$\beta = 0.593 +0.081R_p'-0.056R_d'+0.195F'+0.383j'+0.018s'+0.019R_p'R_d'+0.017R_p'F'+0.025R_p'j'-0.013R_p's'- 0.013R_d'F'+0.119 R_d'j'+0.012 R_d's'-0.1F'j'-0.03F's'-0.02j's'+0.02R_p'^2 -0.001R_d'^2-0.198F'^2+0.181j'^2 +0.103s'^2 \quad (1.11)$$

$$h = 19.899-0.987R_p'-0.951R_d'-0.014F'+0.091j'+0.621s'-0.024R_p'R_d'-0.007R_p'F'+0.007R_p'j'-0.04R_p's'-0.001R_d'F'-0.02R_d'j'-0.02R_d's'-0.04F'j'+0.002F's'+0.015j's'+0.016R_p'^2-0.08R_d'^2+0.023F'^2-0.267j'^2+0.285s'^2 \quad (1.12)$$

In order to test the above presented relations a simulation was carried out at the centre of the domain of variation (**R_p**= 6mm, **R_d**= 4mm, **F** = 65kN, **j** = 1.25mm and **s** = 31mm). The results of the simulation were compared with those obtained using the relations (1.8 – 1.12) and are presented in table 7.

Tab. 7

Comparison of the results

	R_p'	R_d'	F'	j'	s'	Values obtained from relations (1.8 – 1.12)	Values obtained from simulation	Errors
r_p	0	0	0	0	0	6.378	6.416	-0.038
r_d	0	0	0	0	0	4.417	4.462	-0.045
α	0	0	0	0	0	0.501	0.535	-0.034
β	0	0	0	0	0	0.593	0.539	0.054
h	0	0	0	0	0	19.899	19.625	0.274

From the above presented results a diminution of the differences between the values obtained from the two modalities of determination is emphasized.

2.4 Optimization of the tool geometry and process parameters

The previous mathematical relations were used to determine the values of process parameters which allow to obtain the best values for the geometrical part parameters (as close as possible to the target values). The principle consists in minimizing a function equal to the sum of deviation between the theoretical and the desired output. In order to keep this sum positive, the deviations are squared:

$$\Phi = (r_p - 6)^2 + (r_d - 4)^2 + (\alpha - 0)^2 + (\beta - 0)^2 + (h - 20)^2 \quad (1.13)$$

The function Φ presents a minimum for the values of the process parameters indicated in table 8.

Tab. 8

Optimum values of the tool geometry and process parameters

	R_p [mm]	R_d [mm]	F [kN]	j [mm]	s [mm]	r_p [mm]	r_d [mm]	α [°]	β [°]	h [mm]
Values resulted from optimization	5.56	3.62	48	1	31.90	6.122	3.988	0.328	0.411	19.936

In order to validate the optimization algorithm a new simulation was performed, using as input data the optimized process parameters and tool geometry. The results of quadratic optimization, of finite element simulation and the nominal values of the part geometrical parameters are compared in table 9.

Tab.9

Comparative analysis of the results

	R_p	R_d	F	j	s	r_p [mm]	r_d [mm]	α [°]	β [°]	h [mm]
Values resulted by using initial tools design	6 [mm]	4 [mm]	45 [kN]	1 [mm]	30 [mm]	6.522	4.602	0.528	0.784	17.69
Values resulted from DOF	5.56	3.62	48	1	31.90	6.122	3.988	0.328	0.411	19.936
Values resulted from simulation	[mm]	[mm]	[kN]	[mm]	[mm]	6.105	4.062	0.286	0.405	20.122
Nominal values						6.000	4.000	0.000	0.000	20.000

A good concordance between the estimated values by minimizing the function Φ and that obtained from simulation could be observed. Also, the accuracy of part obtained by using the optimized process parameters/tool geometry is much improved compared to that obtained by using the initial process parameters/tool configuration. The new geometry of tool and the drawn part resulted by using this geometry are presented in figure 4 and figure 5, respectively.

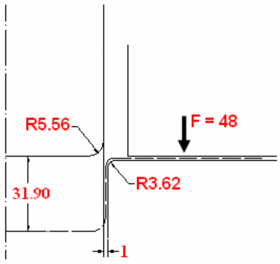


Fig. 4 Optimized geometry of tool and the optimized process parameters

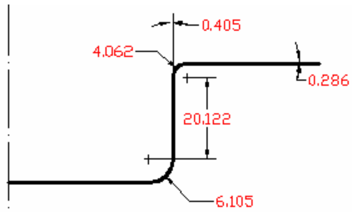


Fig. 5 Resulted part by using the optimized tool and process parameters

3. CONCLUSIONS

a. In order to diminish the effect of springback on the part geometrical accuracy, an optimization procedure based on the LMecA method coupled with the finite element method was presented. The proposed method allows optimizing the tools geometry and process parameters in order to compensate the elastic deflections of the part.

b. Good results were obtained by using the quadratic model. As result of the performed optimization, the deviations of geometrical parameters of the part reported to the nominal profile decreased as follows: with 78.5% for the radius of connection between the part bottom and part sidewall r_p, with 88.3% for the radius of connection between the part flange and part sidewall r_d, with 94.8% for the height of the part sidewall h, with 54.2% for the flange angle α and with 51.7% for the sidewall inclination angle β.

c. As a consequence, the presented method could be successfully used to control the springback phenomenon in the case of cylindrical drawn parts.

4. REFERENCES

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