Application of the Taguchi method for the compensation of errors determined by springback in the case of a conical lied made from metal sheets

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Abstract: Springback of draw parts considerably affects their accuracy and deviations from the theoretical profile, this instability phenomenon determining the following changes of the part shape and geometric parameters: arching of the part sidewall, modification of the angle formed by the part bottom and the sidewall, modification of the angle between the flange and the sidewall. The methods applied in order to reduce or eliminate springback are based on tools correction after designing and testing, on the utilization of special tools and devices, on the optimization of process parameters based on some methods that establish a link among springback parameters and the influencing factors of this phenomenon. These methods are expensive and necessitate a big number of experimental tests. Based on these conclusions, it is necessary the development of a method for the reduction or the elimination of the springback from the designing stage.

Keywords: springback, conical lid, tools correction, Taguchi's method

1. INTRODUCTION

The analysis of the researches concerning the drawing processes, emphasizes the following aspects concerning the springback phenomenon and the methods applied in order to increase the precision of the formed parts: springback of draw parts affects considerably the precision and the deviations from the theoretical profile, this instability phenomenon determining the following changes of the part shape and geometric parameters: arching of the part sidewall, modification of the angle formed by the part bottom and the sidewall, modification of the angle between the flange and the sidewall; blank holder force is the main process parameter that has an essential influence on springback intensity; the methods applied in order to reduce or to eliminate springback are based on tools correction after designing and testing, on the utilization of special tools and devices, on the optimization of process parameters based on some methods that establish a link among springback parameters and the influencing factors of this phenomenon. These methods are expensive and necessitate a big number of experimental tests.

Starting from the above presented aspects, we can conclude that in order to increase the accuracy of the drawing processes it is necessary the development of a method for the reduction or the elimination of the springback from the designing stage. An optimal solution can be obtained by using the process simulation in combination with a statistical modelling that allows the mathematical description of the influence of different process parameters on the draw part geometry and accuracy. For this purpose, the factorial design offers the possibility to use a statistical method – for example Taguchi method. The present paper analyses the possibilities to apply such method in the case of a conical lied made from steel sheets.

2. APPLICATION OF THE TAGUCHI METHOD

2.1. Description of optimization method

The optimization method of the forming process using Taguchi method has the purpose to reduce springback of a draw part. The Method is applied in the following six steps: 1. Definition of geometric parameters that characterize the geometric deviations of the part. 2. Selection of process parameters that influence the part geometry and its field of variation. 3. Selection of the model of linear or quadratic polynomial dependence and construction of fractioned factorial plane of experiment. 4. Process simulation according to experimental plane and the measurement of geometric deviations of the resulted 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 draw part. The above presented method and steps were applied in the case of a conical lied (Figure 1) made from steel sheets. In order to obtain the part represented in Fig. 1 the technologic process must be achieved in the following two steps: drawing operation; trimming, shearing and punching operations (Fig. 2). The geometric model considered in simulation using ABAQUS software is represented in Fig. 3.

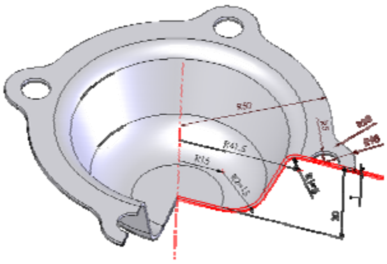

Fig.1 Geometry of the finished part

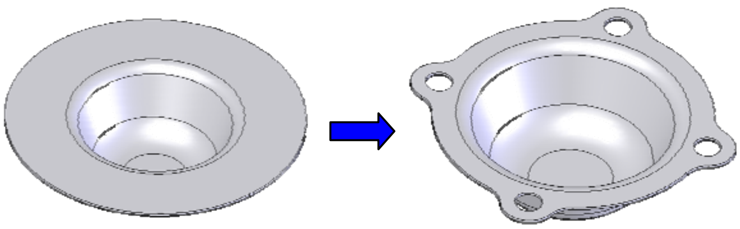

Fig. 2 Main steps of the technologic process

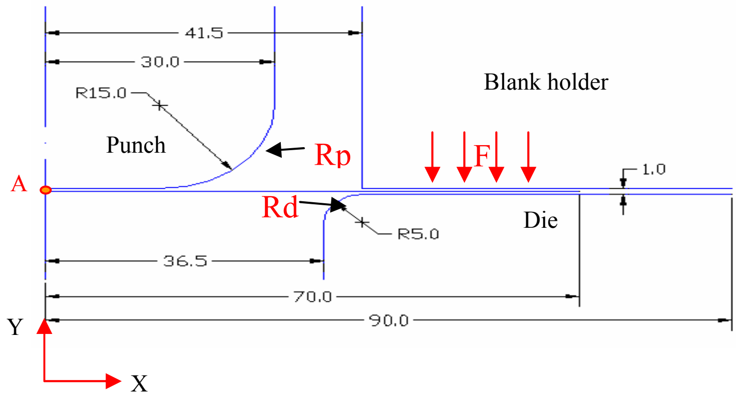

Fig. 3 Geometric model used in simulation

2.2 Parameters used in simulation:

The used blank was made from FEPO 5MBH steel having the following dimensions: diameter Ø = 140 mm and thickness g = 1 mm. The material parameters were as follows: Young's modulus = $2x10^5$ MPa; Poisson's coefficient = 0,3; density ρ = 7800 kg/m^3; for description of the material plastic behaviour 10 points from the stress-strain curve were chosen.

The integration method was Gaussian with 5 integration points equally distributed on the sheet thickness and the type of the finite element was SAX 1. The discretizing of the blank was made in 50 elements and 51 nodes. The working conditions and parameters were as follows: Friction coefficient μ = 0.075; Punch displacement in the negative sense of Y axis: 30mm; Drawing speed: 30mm/s.

In order to decrease the calculation time needed for simulation the following simplifications were applied: a bi-dimensional symmetric model was used; a condition of symmetry in the point A in comparison with the axis Y (axis of symmetry) was imposed for the blank (Fig. 3); the die components were considered as no deformable;

this condition eliminated the need of their discretization in finite elements but it imposed to associate a symbolic weight equal to 1kg for the blank holder; the die was considered as fixed, but for the punch and blank holder component a condition of displacement on Y axis was imposed.
The state of stress after springback was obtained by importing the results from simulation using the ABAQUS/Explicit module immediately after drawing, without removing the punch, die and blank holder element and their exporting in ABAQUS/Standard.
Because during simulation the ABAQUS software calculates the stresses and displacements for the nodes located on the medium axis (Fig. 4), in order to compare the results of simulation we considered the following geometric parameters as ideal for the finished part: R1 = 5,5mm and R2 = 15,5 mm.
From the simulation using the geometric model with initial tools (Rd=5mm, Rp=15mm) – shown in Fig. 3 a sheet thickness equal to 1mm, a blank holder force equal to 15 kN and a friction coefficient equal to 0,075, the geometric deflections of the part caused by springback resulted as it is shown in Fig. 5.
Because the obtained values are different from the desired ones (R1=5.5 mm, R2=41.5mm, R3=15.5mm - Fig. 4), it follows to identify the geometric parameters that must be optimized.

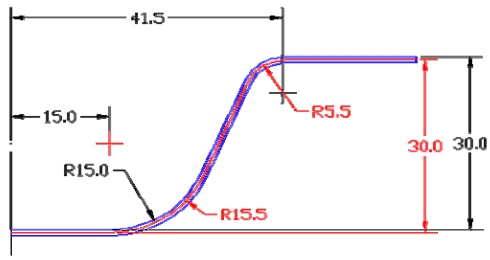

Fig. 4 Geometry of the part considered in simulation

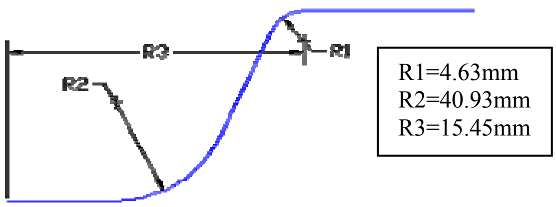

Fig. 5 Geometry of the part after drawing

2.3 Application of the optimization method
2.3.1. Basic considerations

The parameters that must be optimized in order to eliminate the effects of springback are as follows: the punch radius (Rp), the die radius (Rd) and the blank holder force F (Fig. 6). These parameters will be modified according to the experimental plane elaborated on the basis of the Taguchi method. The variation of the geometric parameters R1, R2 and R3 of the desired part shown in Fig. 6 will be also controlled.

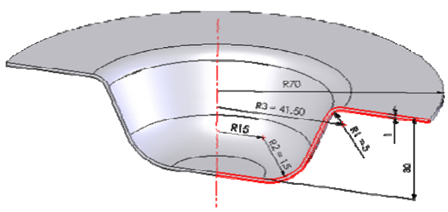

Fig. 6 Geometry of the desired part after drawing

The domain of variation for the selected parameters is indicated bellow:

	F [kN]	Rd [mm]	Rp[mm]
Min	10	4	13
Max	20	6	17

2.3.2 Linear optimization

We considered the following polynomial function:

$$Y = a_0 + a_1X_1 + a_2X_2 + ... + a_nX_n + a_{12}X_1X_2 + ... + a_{n-1,n}X_{n-1}X_n. \quad ... \quad (1.1)$$

where: Y represents the followed value (R1, R2 or R3) and $X_1..X_n$ represent the reduced values of the input parameters that must be optimized (F, Rd and Rp). Hence it result the following equations that correspond to each followed parameter:

$$R1 = a_0 + a_1F' + a_2Rd' + a_3R_p' + a_{12}F'Rd' + a_{13}F'Rp' + a_{23}Rd'Rp' \quad ... (1.2)$$
$$R2 = a_0 + a_1F' + a_2Rd' + a_3R_p' + a_{12}F'Rd' + a_{13}F'Rp' + a_{23}Rd'Rp' \quad ... (1.3)$$
$$R3 = a_0 + a_1F' + a_2Rd' + a_3R_p' + a_{12}F'Rd' + a_{13}F'Rp' + a_{23}Rd'Rp' \quad ... (1.4)$$

The reduced values (F', Rd', Rp') used in the above presented equations present a linear correspondence with the real values (F,Rd, Rp) according to the following function:

$$X' = \frac{X - \frac{X_{max} + X_{min}}{2}}{\frac{X_{max} - X_{min}}{2}} \quad ..... (1.5)$$

For example: for F = 20 (maximum value) it results F' = +1, and for F = 10 (minimum value) it results F' = -1

In order to determine the coefficients a_0, a_1, a_2...a_{12}...a_{23} corresponding to each function a series of 8 simulations was performed. The results obtained from simulations are presented in table no. 1. After calculation the following equations were obtained:

$$R1 = 5.18799 - 0.062 * F' + 0.8402 * Rd' - 0.064 * R_p' - 0.012 * F'Rd' - 0.1 * F'Rp' - 0.0041 * Rd'Rp' \quad (1.6)$$
$$R2 = 15.453 + 0.0004 * F' - 0.007 * Rd' + 1.9912 * R_p' - 0.002 * F'Rd' - 0.002 * F'Rp' - 0.002 * Rd'Rp' \quad (1.7)$$
$$R3 = 41.3697 - 0.03 * F' - 0.084 * Rd' - 0.031 * R_p' - 0.003 * F'Rd' - 0.048 * F'Rp' - 0.0002 * Rd'Rp' \quad (1.8)$$

Table 1

	Modified values			Obtained values		
Nr.	F [kN]	Rd [mm]	Rp [mm]	R1 [mm]	R2 [mm]	R3 [mm]
1	10	4	13	4.3721	13.4557	41.4712
2	10	4	17	4.4240	17.4591	41.4891
3	10	6	13	6.0561	13.4636	41.2948
4	10	6	17	6.1494	17.4318	41.3422
5	20	4	13	4.4427	13.4789	41.4982
6	20	4	17	4.1522	17.4473	41.3561
7	20	6	13	6.1360	13.4490	41.3393
8	20	6	17	5.7714	17.4384	41.1664

In order to test the above presented relations, a simulation for the case when: F = 15 kN, μ = 0.075, Rp = 15 mm, Rd = 5 mm (in the centre of the domain of variation) was performed. The obtained results from simulation were compared with that obtained using the relations 1.6…1.8 (where the parameters F', Rd' and Rp' were calculated using equation 1.5). The results of these calculations are presented in table no 2.

Table 2

	Values obtained from relations (1.6) – (1.8)	Values obtained from simulation
R1 [mm]	5.187988	4.8824
R2 [mm]	15.45298	15.4375
R3 [mm]	41.36966	41.1855

From the analysis of the above presented results we can observe some differences between the two modalities of calculation, especially in the case of radius R1. Hence we can conclude that the geometric parameters of the draw part have not a linear variation in comparison with variation of the geometric parameters of tools and with variation of blank holder force. In this case it is needed to apply an optimization based on quadratic model.

2.3.3 Quadratic optimization

We considered the following polynomial function of 2nd degree:

$$Y = a_0 + a_1X_1 + a_2X_2 + ... + a_nX_n + a_{11}X_{12} + ... + a_{nn}X_{n2} + a_{12}X_1X_2 + ... + a_{n-1,n}X_{n-1}X_n \quad (1.9)$$

where: Y represents the followed value (R1, R2 or R3) and $X_1..X_n$ represents the reduced values of the input parameters that will be varied (F, Rd, Rp). For determining the coefficients of the quadratic model a_0, a_1, $a_2...a_{12}...a_{23...}a_{n-1,n}$, a number of 6 additional simulations were needed. The results of these simulations are given in table no 3.

Table 3

	Modified values			Obtained values		
Nr.	F [kN]	Rd [mm]	Rp [mm]	R1 [mm]	R2 [mm]	R3 [mm]
1	10	4	13	4.3721	13.4557	41.4712
2	10	4	17	4.4240	17.4591	41.4891
3	10	6	13	6.0561	13.4636	41.2948
4	10	6	17	6.1494	17.4318	41.3422
5	20	4	13	4.4427	13.4789	41.4982
6	20	4	17	4.1522	17.4473	41.3561
7	20	6	13	6.1360	13.4490	41.3393
8	20	6	17	5.7714	17.4384	41.1664
9	15	5	15	4.8824	15.4375	41.1855
10	8.565	5	15	5.3851	15.4496	41.4684
11	21.435	5	15	4.9008	15.4379	41.2202
12	15	3.713	15	4.2212	15.4499	41.5329
13	15	6.287	15	6.3732	15.4396	41.3184
14	15	5	12.426	4.9226	12.8889	41.2017
15	15	5	17.574	5.1296	18.0063	41.2994

From calculation the following equations were obtained:

$$R1 = 4.95896 - 0.099 * F' + 0.839 * Rd' - 0.0215 * R_p' - 0.012 * F'Rd' - 0.10004 * F'Rp' - 0.004 * Rd'Rp' + 0.077 * F'^2 + 0.17 * Rd'^2 + 0.0061 * Rp'^2 \quad (1.10)$$

$$R2 = 15.437 - 0.001 * F' - 0.006 * Rd' + 1.99028 * R_p' - 0.002 * F'Rd' - 0.00172 * F'Rp' - 0.002 * Rd'Rp' + 0.004 * F'^2 + 0.005 * Rd'^2 + 0.0066 * Rp'^2 \quad (1.11)$$

$$R3 = 41.2244 - 0.049 * F' - 0.084 * Rd' - 0.011 * R_p' - 0.003 * F'Rd' - 0.04754 * F'Rp' - 0.0002 * Rd'Rp' + 0.055 * F'^2 + 0.104 * Rd'^2 - 0.002 * Rp'^2 \quad (1.12)$$

In order to test the above presented relations, a simulation for the case when: F = 15 kN, $\mu = 0.075$, Rp = 15 mm, Rd = 5 mm (in the centre of the domain of variation) was performed. The obtained results from simulation were compared with that obtained using the relations 1.10-1.12 (where the parameters F', Rd' and Rp' were calculated using equation 1.5). The results of these calculations are presented in table no 4.

Table 4

	Values obtained using the relations 1.10…1.12	Values obtained from simulation
R1 [mm]	4.95896	4.8824
R2 [mm]	15.437	15.4375
R3 [mm]	41.2244	41.1855

From the above presented results we can observe a diminution of the differences between the values obtained using the both modalities of calculation. We can also observe that in case of quadratic model the differences are smaller than in case of linear model.

3. OPTIMIZATION OF THE TOOL GEOMETRY

In order to optimize the tool geometry we tried the simultaneous accomplishment of the three conditions of optimization (R1 = 5 mm, R2 = 15 mm, R3 = 41.5 mm) by using the following function:

$$L\,(R1, R2, R3) = (R1 - 5)^2 + (R2 - 15)^2 + (R3 - 41.5)^2 \qquad (1.13)$$

For the domain of variation between -1 and +1 in the case of reduced values, the function 1.13 presents some minima but any of these are not equal to 0 (L = 0 for R1 = 5 mm, R2 = 15 mm, R3 = 41.5 mm). Thus we must choose for this domain the smallest values of function L as being the optimum value for which the three conditions of optimization are better and simultaneous satisfied. The function L will present a minimum for the values indicated in table no.5.

Table 5

<table>
<tr><td rowspan="2"></td><td colspan="3">Values for which the function L has a minimum value</td><td colspan="3">Values resulted for the followed parameters</td></tr>
<tr><td>F[kN]</td><td>Rd[mm]</td><td>Rp[mm]</td><td>R1[mm]</td><td>R2[mm]</td><td>R3[mm]</td></tr>
<tr><td>Values obtained from calculation (eq. 1.10…1.12)</td><td rowspan="2">11.0327</td><td rowspan="2">5</td><td rowspan="2">15</td><td>5.00176</td><td>15.403</td><td>41.4804</td></tr>
<tr><td>Values obtained from simulation</td><td>5.5108</td><td>15.4587</td><td>41.5229</td></tr>
</table>

From the results presented in table 5, we can conclude that it is not need to modify the geometry of the initial tools considered in the optimization procedure. But, taking into account the deviations of the parts resulted after their measurement, the geometry of the used tools must be modified. In order to optimize the drawing process we must only adopt the blank holder force equal to 11kN. The geometry of the corrected tools and the parameters of the drawing process (optimized values) are indicated in Fig. 7.

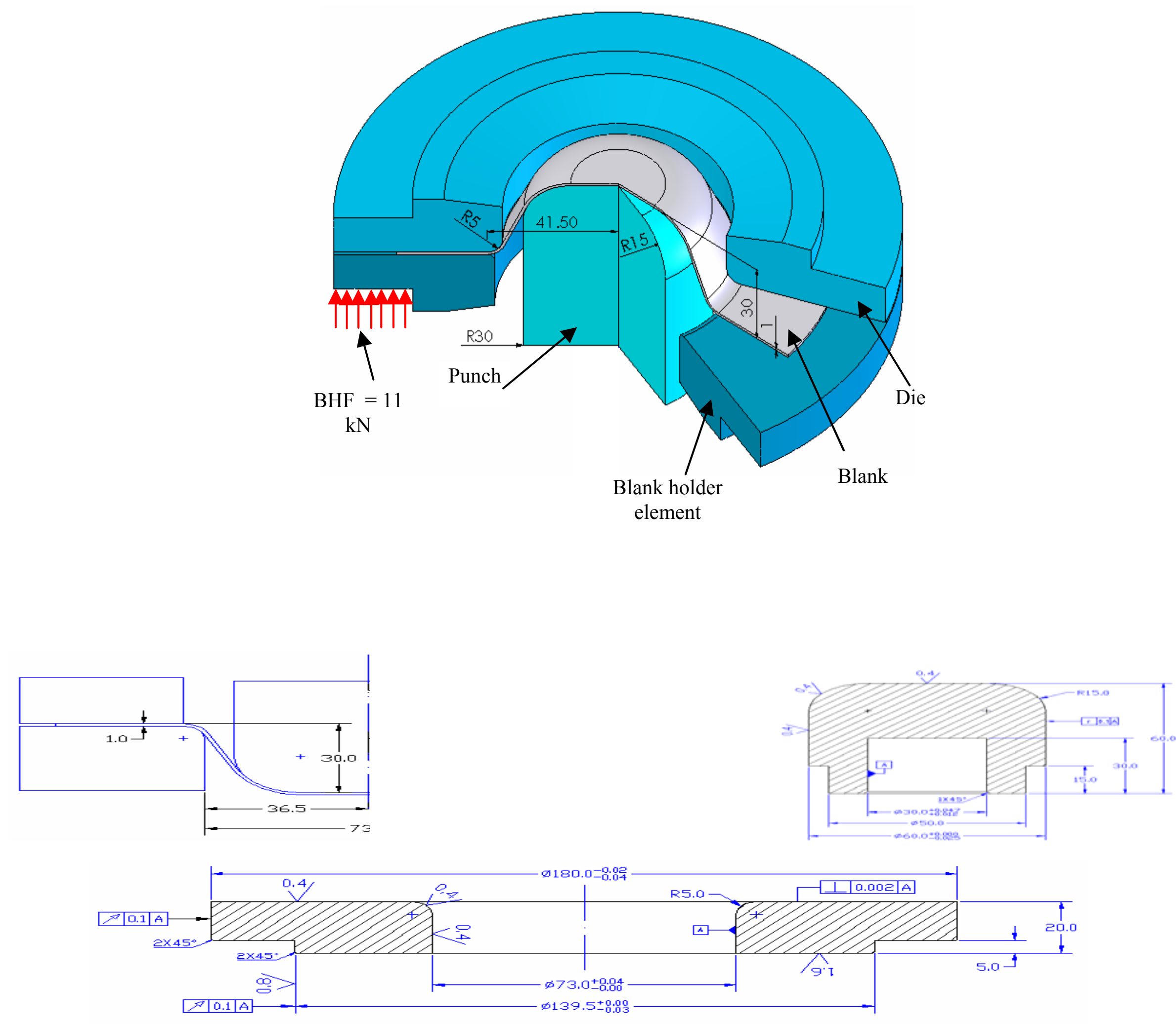

Fig. 7 Geometry of tools and the parameters of the drawing process (optimized values)

Note: we must mention that the values resulted from simulation represent the values calculated on the medium axis of the blank. Hence on the blank surface the geometric parameters of the part will be as follows: R1 = 5.0108 mm, R2 = 14.9587 mm and R3 = 41.5229 (real values).

4. CONCLUSIONS

1.The selection of the process parameters and geometric parameters of the part must be performed taking into account that these parameters must be independents. For each combination of the process parameter values will be achieved a FEM simulation and from the data post-processing will result the desired geometric parameters of the draw part.

2.The best results were obtained by using the polynomial quadratic functions that offered the possibility of a global optimization of the factors of influence of the drawing process.

3.Based on the optimized parameters it is possible the correction of the tools geometry in their designing stage and also the determination of the optimum process parameters. In this way, a minimization of the springback effects will be obtained.

4. The method applied for the conical lied can be extended for all drawing processes of metal sheets, indifferently by the parts configuration.

Acknowledgments

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