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OPTIMIZATION SYSTEM BASED ON LMecA AND FUZZY LOGIC METHODS FOR THE COMPENSATION OF ERRORS IN THE CASE OF DRAW PARTS

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Abstract: *The present paper analyses the conditions and steps needed in the application of the LMecA - Taguchi's/Fuzzy Logic methods in the case of drawing processes. The optimization system based on the above mentioned methods, had as main purpose the optimization of the drawing tools geometry and process parameters by reducing or eliminating the springback effects.*
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Key words: *springback, draw parts, tools correction, optimization* system
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1. INTRODUCTION

The drawing of the sheet metals is a complex process, characterized by a series of phenomena, influencing factors and specifically parameters. The main phenomenon that affects the precisions of the draw parts is springback. The effect of springback is contrary to the forming load and it modifies the values of the angles, the curvature of the part walls and the part dimensions. Generally, the springback angles decrease as the punch profile radius decreases at sufficiently large values of blank holder force and this fact is explained by the higher straining of the material and the sidewall radius decreases to the increase of die profile radius for high values of blank holder force.

The mathematical models for springback calculation are based on different simplifying hypotheses relative to different factors of influence. These models lead to important differences compared with the experimental values. The technical methods applied for the reduction of springback are mainly: the correction of tools geometry with the value of springback angle; the supplemental deformation of the material; the utilization of stiffeners; the utilization of the punches with coining strips; the utilization of an arched counterpunch that induces supplemental deformations compensating for the springback; the utilization of variable blank holder force. These methods have positive effects but on the other side increase the tools complexity and costs. Based on these conclusions, it is necessary the development of a method for the reduction or the elimination of the springback effects from the designing stage of forming tools and process. [5]

The present paper analyses the conditions and steps needed in the application of the LMecA/Taguchi's/Fuzzy Logic methods for the optimization of the drawing tools and processes. The optimization system based on the above mentioned methods, had as main purpose the optimization of the drawing process parameters by reducing or eliminating springback effects.

2. APPLICATION OF THE LMecA - TAGUCHI METHOD

2.1. Description of optimization method

The optimization method of the forming process using LMecA-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. [1] The above presented method and steps were applied in the case of a hemisp450 herical part (Figure 1) made from steel sheets.

The initial configuration of the tools (Figure 2) used to obtain the part did not consider springback.

The part obtained using this tool is shown in Figure 3 and significant deviations from the theoretical shape are visible.

The geometric parameters of the part that must be considered in optimization and the field of their variation are shown in Figure 4 and Table 1, respectively.

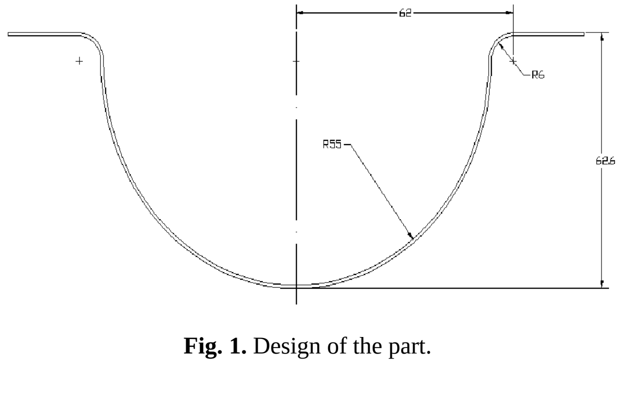


Fig. 1. Design of the part.

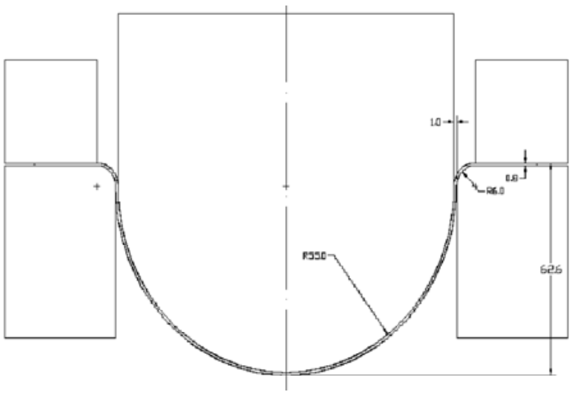


Fig. 2. Initial tools.

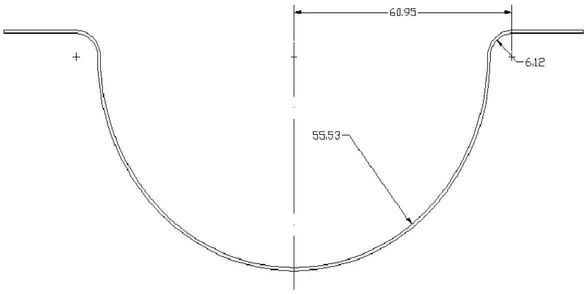


Fig. 3. Shape of the part obtained from simulation using the initial tools.

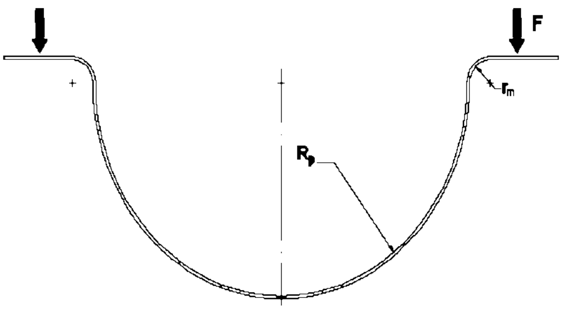


Fig. 4. Geometrical parameters that must be considered in optimization.

Table 1

Field of variation of the parameters used in optimization

	R_p (mm)	r_m (mm)	F (kN)
Min	54	5	20
Max	56	7	50

In a first step it was applied a linear model. By comparing the values resulted from simulation with that obtained using the above presented model a great difference was obtained especially in the case of the distance between centres. Hence, we can conclude that the geometrical parameters considered in the linear model do not present a linear variation with the geometrical parameters of the tools. In this case it is needed to apply the optimization based on the quadratic model. The following polynomial function of second degree was used in the quadratic model:

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

where Y represents the value that must be optimized (R, r or ρ) and $X_1 ... X_n$ represent the values of the input parameters that must be varied (R_p, r_m, F). In order to determine the coefficients of the model, a number of 7 additional simulations were used by comparing with the linear model. The results of simulations are given in Table 2. The following models were obtained from calculation:

$$R = 55.527 + 0.7214 R'_p + 0.0676 r'_m + 0.0167 F' + 0.0575 R'_p r'_m + 0.065 R'_p F' + 0.07 r'_m F' + 0.0271 R'^2_p - 0.0422 r'^2_m + 0.0452 F',$$

$$r = 6.0844 - 0.0236 R'_p + 0.9496 r'_m + 0.0032 F' - 0.0325 R'_p r'_m + 0.08 R'_p F' - 0.1025 r'_m F' + 0.0344 R'^2_p + 0.0875 r'^2_m + 0.0344 F'^2,$$

$$\rho = 61.194 + 0.6803 R'_p + 1.0167 r'_m + 0.0487 F' + 0.0287 R'_p r'_m + 0.1188 R'_p F' - 0.0288 r'_m F' + 0.2868 R'^2_p + 0.3472 r'^2_m + 0.2838 F'^2.$$

In order to test the obtained model, a simulation was performed for the case when: R_p = 55 mm, r_m = 6 mm, F = 35 kN. The obtained results are presented in Table 3.

Table 2

Results of simulation

	R_p (mm)	r_m (mm)	F (kN)	R (mm)	R (mm)	ρ (mm)
9	0	0	0	55.53	6.12	60.95
9'	0	0	0	55.53	6.12	60.95
10	61.33	0	0	54.21	6.18	60.62
11	63.49	0	0	56.93	6.05	63.08
12	0	0	0	55.57	5.01	60.71
13	0	0	0	55.62	7.39	63.19
14	0	0	0	55.62	6.14	61.86
15	0	0	0	55.58	6.09	61.83

Table 3

Results of the model testing

	R_p (mm)	r_m (mm)	F (kN)	calculation	simulation
R	0	0	0	55.53	55.53
r	0	0	0	6.0844	6.12
ρ	0	0	0	61.194	60.95

By comparing the values resulted from simulation with that obtained using the above presented model, it was observed a diminution of the differences between the values obtained by applying the both methods. Also, if we compare the values obtained by applying the linear and quadratic models we can observe that in the case of quadratic model the differences are smaller than in the case of the linear model.

2.2 Optimization of the manufacturing parameters

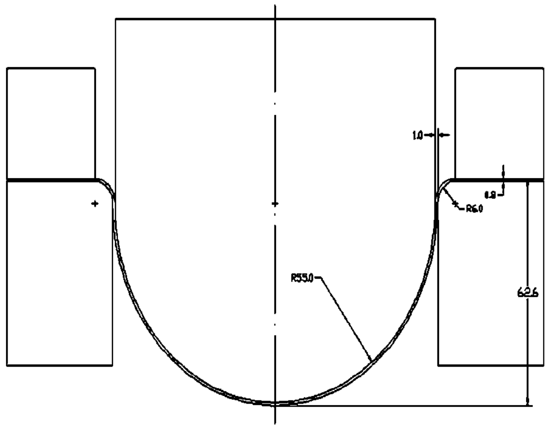
In order to optimize the process parameters, in other words to obtain simultaneously the three wished values for the part parameters (R = 55 mm, r = 6 mm, ρ = 61.8 mm), the following function was applied:

Table 4

Optimal set of values for the process parameters

	R_p (mm)	R_m (mm)	F (kN)
Quadratic method	55.444	6.2935	50
Simulation	55.444	6.2935	50

	r_p [mm]	r_m [mm]	ρ [mm]
Quadratic method	55.195	6.3762	61.486
Simulation	55.00	6.40	61.58



a **b**

Fig. 5. Geometry of the optimized tool:
a - initial tool; *b* - optimized tool.

$$F = (R - 55)^2 + (r - 5)^2 + (\rho - 61.8)^2. \qquad (2)$$

In the field of variation of the process parameters defined by the values -1 and +1, the function (5) has some minima, but any of the minima is not equal to zero. The function $F = 0$ for $R = 55$ mm, $r = 6$ mm, $\rho = 61.8$ mm. Hence we can choose in this field the lowest minimum for the function F that must present the optimum value for which will be better and simultaneously satisfied the above presented three conditions of optimization. The values of the process parameters for which the function F will present the minimum value are given in Table 4.

From the analysis of the results we can observe a very good concordance between the estimated values by minimizing the function *F* and that obtained from simulation. The geometry of the optimized tool obtained by applying the above described optimization method is shown in Fig. 5.

3. APPLICATION OF THE FUZZY LOGIC METHOD

3.1. The phases of the optimization method

Using Fuzzy logic in order to optimise the drawing process involves the setting of the input and output variables used to establish the influence of different factors on springback and on the geometrical parameters of the tool. The optimisation module searches for a combination of the factor levels, so that the requirements imposed equally to influence factors and to geometrical parameters of the tool to be simultaneous satisfied. Its application will allow also the optimisation of the tools geometry and the changing of several technological parameters of the drawing process.

The precision of optimization can be increased by enlarging the number of the process influence factors that can be considered. The phases of the optimisation method are as follows:

- the setting of geometrical parameters of the part (R_p, R_f, A);
- setting of parameters which influence the drawing process (F_r = blankholder force);
- setting of the input variables (R_{pn}, R_m, F_r);
- setting of the output variables (R_p, R_f, A);
- setting of two levels of variation for each parameter: minimum and maximum;
- simulation of the process using Fuzzy logic ;
- comparison between the resulted parameters and the nominal ones [2, 3, 4].

In Fig. 2, the theoretical profile of the hemispherical draw part is presented. The nominal parameters of the part are as follows: part radius R_p= 55 mm, connection flange radius R_f = 6 mm, flange angle with the horizontal axis A = 0 and piece height h = 62.6 mm.

The geometrical parameters of the part, which recorded considerable errors from the theoretical profile, are as follows: the piece radius, flange connection radius, and flange angle with the horizontal axis (Fig. 1).

The setting the of the process parameters is one of the most important phase in the attempt to control the springback phenomenon. The original configuration of the tools used in the hemispherical drawing process is shown in Fig. 2. From the experimental tests it resulted that the blankholder force F_r has a significant effect on springback intensity and therefore it will be marked as the *input variable.* The tool radius R_{pn} (the punch radius) and the die radius R_m affects the springback intensity and therefore its will be marked as the *input variables.* So, the 3 input variables which affects the springback phenomenon are as follows: punch radius R_{pn}, die radius R_m and blankholder force F_r. These three parameters will directly influence the following parameters considered to be the *output variables:* the piece radius R_p, the connection flange radius R_f and the springback angle of the flange A.

For each of these parameters the following so - called *linguistic variables* which contain 3 “fuzzy sets” have

Table 5

Input variables	**minimum value**	**maximum value**
Die radius (R_m)	5 mm	7 mm
Punch radius (R_{pn})	55 mm	56 mm
Blankholder force (F_r)	20 kN	70 kN

Output variables	**minimum value**	**maximum value**
Piece radius (R_p)	55 mm	57 mm
Flange connection radius (R_f)	5 mm	7 mm
Springback angle (A)	0 mm	1 mm

been defined: “small” - it describes the minimum value of the input and output variables; “medium”- it describes the medium value of the input and output variables; “big”- it describes the maximum value of the input and output variables. Each of the above presented variables has a field of variation between a minimum and a maximum limit, as it is shown in the Tables 1 and 2.

3.2. The simulation of the drawing process using Fuzzy logic

The manipulated variables of the proposed algorithm are the following: punch radius, die radius and blankholder force. For each of them a so called linguistic variable must be defined. For example the linguistic variable “die radius” which consists of three fuzzy sets: small: it describes the *small* radius; medium: it describes a *medium* radius: big: it describes a *big* radius. The set small is trapezoidal, having the big base of 1 and the small base of 0.5. The set big is also trapezoidal but using the big base of 1 and small base between 0.5. The set medium is triangular with the base of 1. The linguistic variable “punch radius” is very similar to the linguistic variable “die radius”. The output variables are as follows: part radius, flange radius and the springback angle. All of them have the following characteristics: three fuzzy sets: small, medium and big; the small and big sets are trapezoidal and the medium set is triangular. The results of simulations are presented bellow.

Simulation no 1

Input variables: punch radius (Fig. 6,*a*), die radius (Fig. 6,*b*). Output variables: piece radius (Fig. 7,*a*), flange radius (Fig. 7,*b*), springback angle (Fig. 7,*c*).

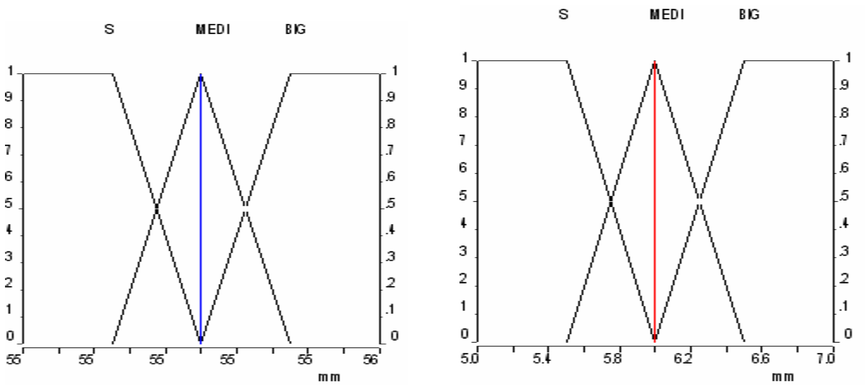
Simulation no 2

Input variables: punch radius (Fig. 8,*a*), blankholder force (Fig. 8,*b*). Output variables: piece radius (Fig. 9,*a*), flange radius (Fig. 9,*b*), springback angle (Fig. 9,*c*).

Simulation no 3

Input variables: die radius (Fig. 10,*a*), blankholder force (Fig. 10,*b*). Output variables: piece radius (Fig. 11,*a*), flange radius (Fig. 11,*b*), springback angle (Fig. 11,*c*).

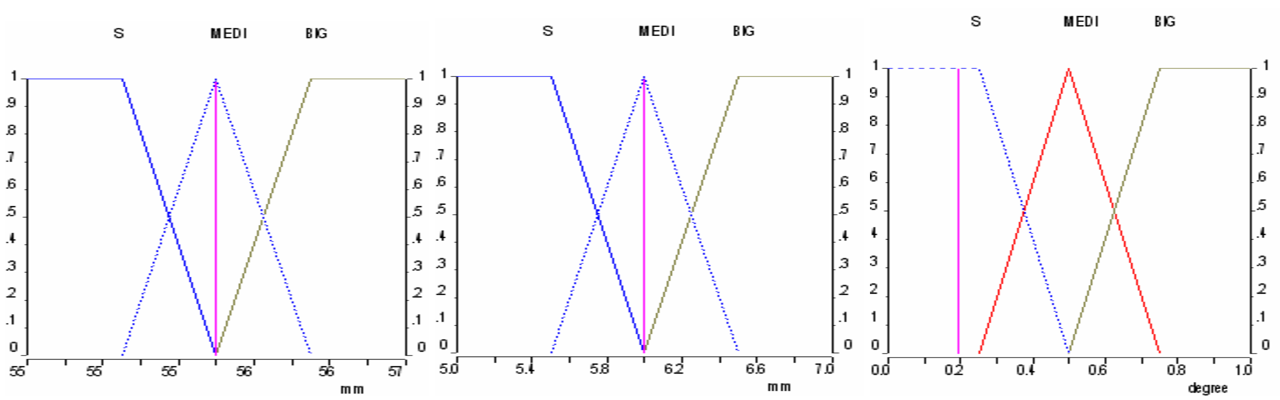
Input variable	**Resulted value**
Die radius	6 mm
Punch radius	55,5mm



a b

Fig. 6. Input variables.

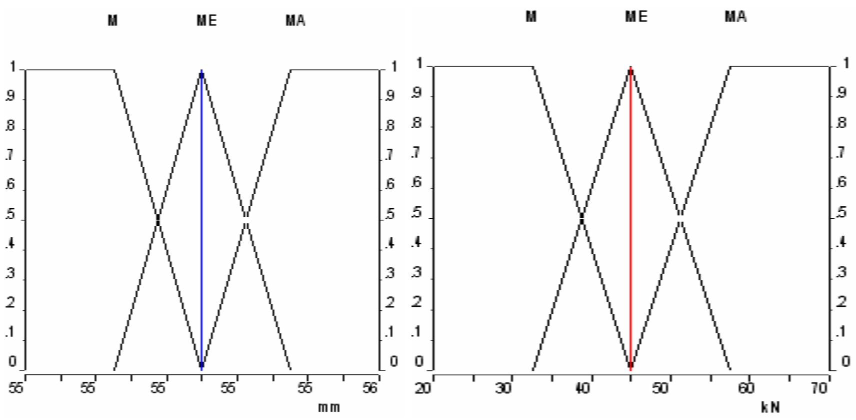
Output variables	**Resulted value**
Piece radius	55.75 mm
Flange connection radius	6 mm
Springback angle	0.2 deg



a b c

Fig. 7. Output variables.

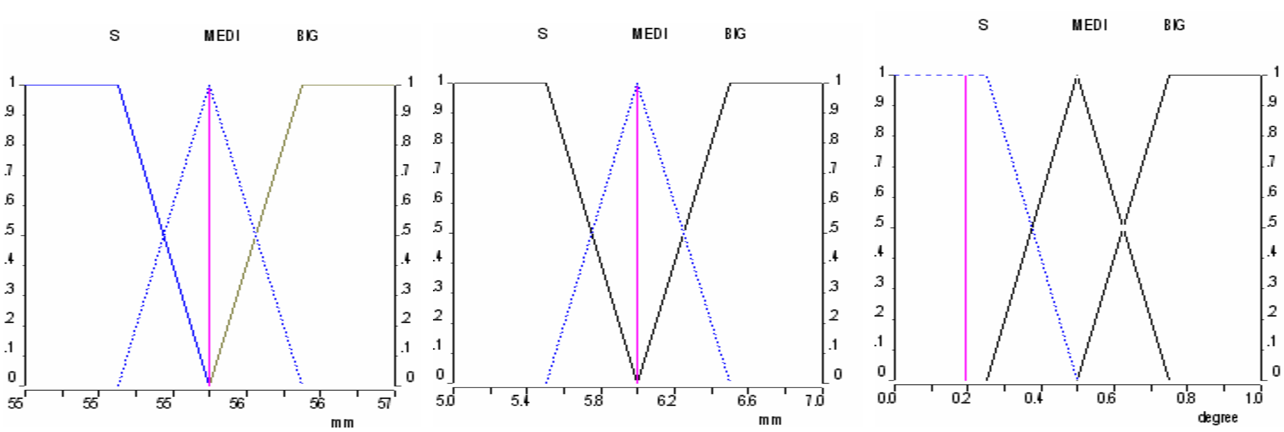
Input variables	Resulted values
Blankholder force	45 kN
Punch radius	55,5 mm



a b

Fig. 8. Input variables.

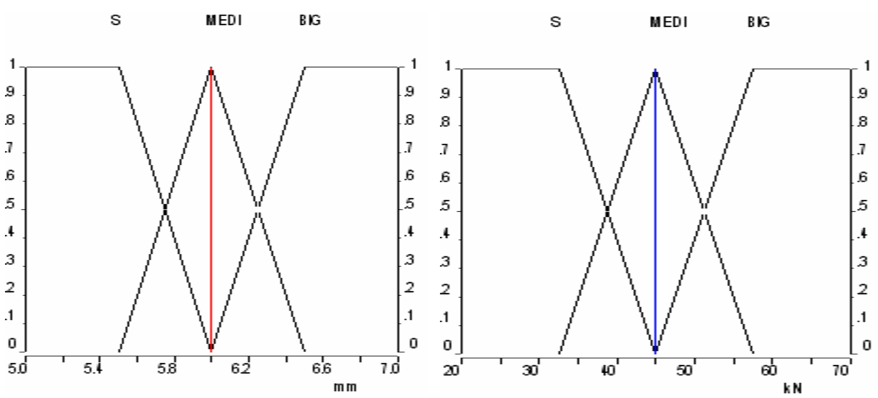
Output variables	Resulted values
Piece radius	55.75 mm
Flange connection radius	6 mm
Springback angle	0.2 degree



a b c

Fig. 9. Output variables.

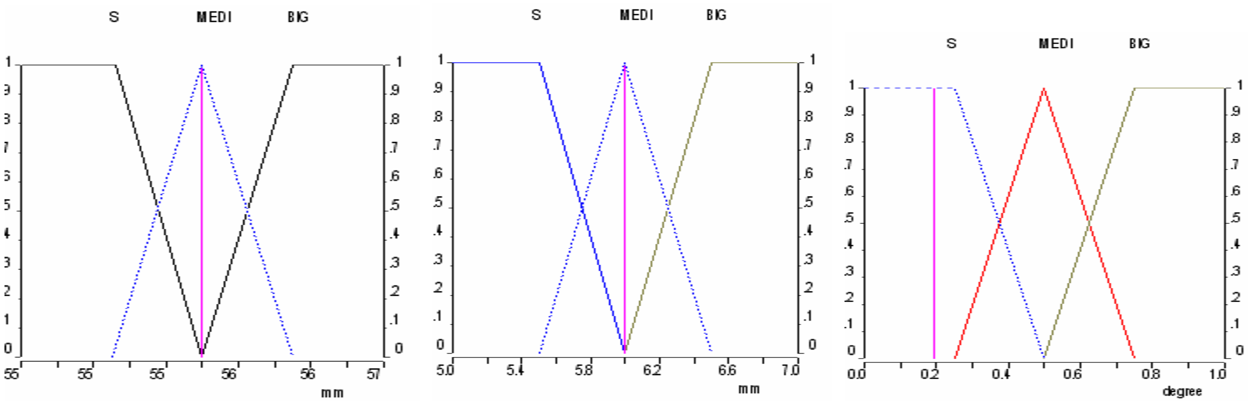
Input variables	Resulted values
Blankholder force	45 kN
Die radius	6 mm



a b

Fig. 10. Input variables.

Output variables	Resulted values
Piece radius	55.75 mm
Flange connection radius	6 mm
Springback angle	0.2 degree



a b c

Fig. 11. Output variables.

Table 6

Process parameters and geometry of the resulted part by using different models and methods

	Blank-holder force	Part radius	Flange connection radius	Springback angle
Theoretical	35 kN	55 mm	6 mm	0 deg
Experiment	35 kN	55.53 mm	6.12 mm	0.4 deg
LMecA	40 kN	54.922 mm	5.965 mm	0.2 deg
Fuzzy logic	45 kN	55.75 mm	6 mm	0.2 deg

4. CONCLUSIONS

By comparing the results obtained from the application of the above mentioned techniques of optimization it was concluded that both methods could be successfully used to control the springback phenomenon. Unsignificant differences could be observed, both as concern the optimum identified values of the process parameters and the geometry of the part resulted by their using (Table 6). However, a little bit advantageous seems to be the Fuzzy logic method because, once the adequate model was identified the determination of the optimum process parameters could be performed in a very short time and with a minimum effort of calculus.

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