DRAW BEAD GEOMETRY OPTIMIZATION ON SPRINGBACK OF SHEET FORMING

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Abstract

The effect of springback during forming is the main concern. Although it was studied and found that the variable blankholder force reduces this effect for some operations it was not enough due to part complexity. In such cases the draw bead is used to control the redundancy and the spring back. In addition to this many studies performed on this topic showed that there is no standard method to determine the blankholder force trajectory. In this study the parameters of draw bead were optimised together with an orthogonal experiment design for a complex part by using FEM software. The parameters investigated are the three important radius of draw bead. The effects of these parameters are optimised by using Annova and response surface regression methods. The optimised parameters were used in the final model and then the punch and die are manufactured. Finally experiments were done to prove the accuracy of optimisation.

1. Introduction

The geometry o the part to be formed in sheet metal processes effects the control of process. For simple geometries there were many studies related to control of blankholder forces and punch velocities etc. However, in practice when the punch velocity and variable blank holder forces in intermediate straining method was not enough to ovecome the undesired redundancy and cause uncontrolled thinning, or splitting, the draw bead is used. The geometries of draw bead are the control parameters to solve these type of problems. It is possible to see their application in many auto-body parts.

The main problem in the metal forming is the springback. This type of defects affects the subsequent assembly. Current trends of using aluminium alloy and high strength steel to reduce weight and enhance safety make the problem more critical.

Sidewall curl results from complicated bending, unbending and stretching deformations. The effect of low and high blankholder forces were studied [1] . The die side of blank has tensile stress whereas the punch side of blank has compressive stress. Therefore the residual bending stress occurred cause in sidewall curl. In the forming operation intermediate restraining method was proposed by Liu. In this method the forming process was divided into two cycles. in the first one relatively low blankholder force was applied to ease the material flow. After a relatively long period, a high blank holder force is applied to introduce plastic strain. The forming parameters are these blankholder magnitudes and the their application time intervals. They must be optimised with respect to material used and the geometry of the part also.

In this study the effects of the parameters related to geometry of drawbead were investigated for complex shaped automotive panel part. Optimum parameters obtained and the punch and dies are manufactured and then production was performed.

This paper proposes an optimisation design that combines orthogonal experiment design with FEM software. Better forming quality with greater efficiency in the optimisation and the obvious effects in springback were obtained.

2. Materials and Methods

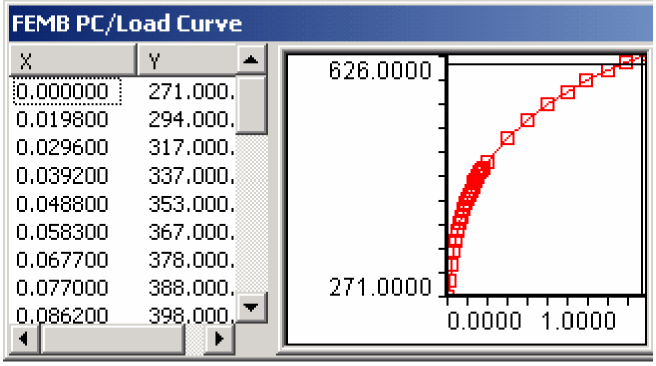
Geometry of front panel of Mercedes car body is shown in figure 1. The blank has 800x400x1mm dimensions and following mechanical properties; Elastic modulus is 207 GPa density is 7830 kg/m3 and poisson’s ratio is 0.28. The blank has transverse _anisotropic _plastic material model. The stress strain data is given in figure 2.

The study Ls-Dyna 970 software and FEMB preprocessor were used. The analyses were performed for forming explicitly. The **BelytschkoTsay** element with seven integration points through sheet thickness describes the blank. Springback is simulated implicitly. The materials modelled by means of piecewise elastic plastic with planar anisotropic material model. The simulation was performed first of all for a uniform steel plate with 1 mm thickness at a constant blank holder force 2 kN. The FEM model created in Ls-dyna is shown in figure 3.

Complete finite element model was created due to unsymmetrical geometry of model. The complete simulation cycle comprises forming simulation and spring back simulation also. In
The simulation was repeated for intermediate straining method. The starting and final blankholder forces and time intervals are chosen as BHF1 (starting blank holder) 2 kN, BHF2 (main blank holder force) 30 kN and t1/t (the ratio of BHF2 application time to total time) 0.6.

Figure 1 The geometry of part

These parameters were studied and it was found that BHF1 has no significant effect on redundancy and springback whereas the lower t1/t the higher redundancy and the higher BHF2 the higher redundancy for studied intervals. The values chosen for this study fall in this interval.



X	Y
0.000000	271.000.
0.019800	294.000.
0.029600	317.000.
0.039200	337.000.
0.048800	353.000.
0.058300	367.000.
0.067700	378.000.
0.077000	388.000.
0.086200	398.000.

Figure 2 Stress _Strain data is given as Load Curve

Table 1 Parameters and their levels

Parameter	**R1**	**R2**	**R3**
Levels	**A**	**B**	**C**
1	6	1	1
2	5	2	2
3	4	3	3
4	3	4	4

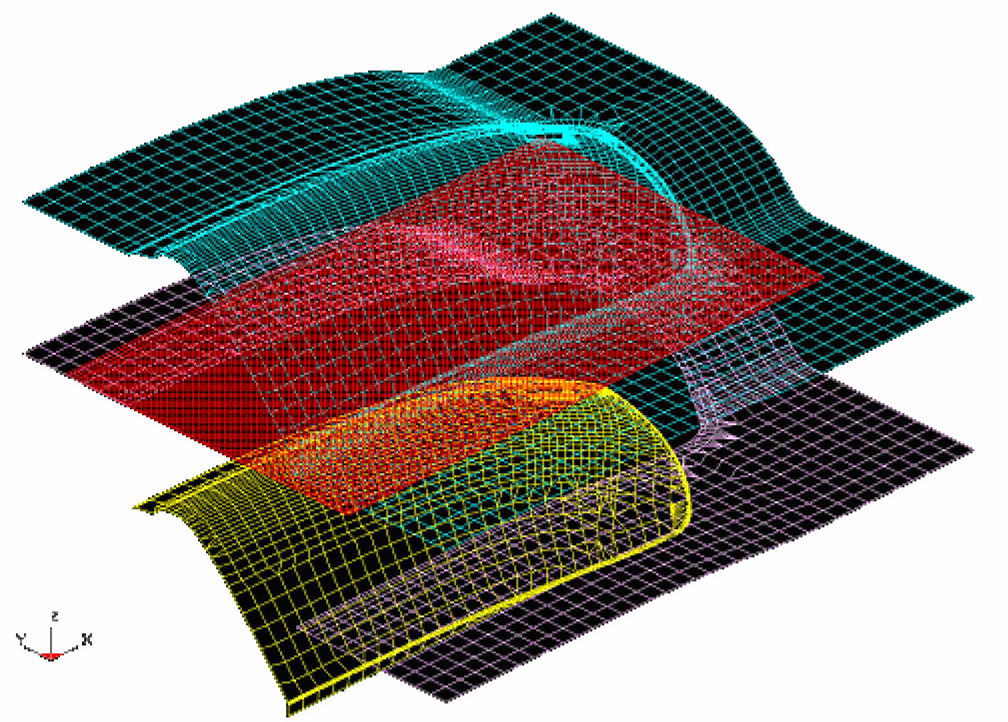


Figure 3 FEM model of Part, Die and Punch

3. Optimisation

The objective of optimisation is the minimizing spring back length. The orthogonal experiment design algorithm was chosen for the optimisation method.

In the study the geometry of draw bead was studied. There are three important radius which are shown in following figure 4. It was well known that changing these radius will result important changes in forming redundancy and springback. The geometry investigated in this study needs 10% redundancy at least and 1 mm spring back at most. So they are the main constraints

The variables R1, R2 and R3 are denoted A, B, C and D respectively For each design variables there are four levels of input as indicated in table 1.

Among orthogonal tables, appropriate one for four parameters with three levels for each is $L_9(3)^4$. The parameters are assumed independent from each other.

The results of the orthogonal table selection were obtained by carrying on Linux Cluster Super Computer IBM x series 330 with RAM 576 Mbyte. The orthogonal experiment plan is shown in Table 2.

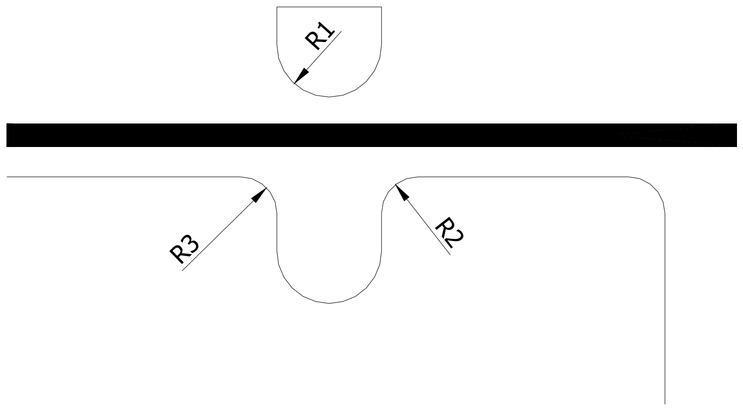


Figure 4 The parameters studied.

Table 2. Orthogonal Plan for Experiments

Number	Parameters		
	A(mm)	B(mm)	C(mm)
1	1	2	3
2	3	4	1
3	2	4	3
4	4	2	1
5	1	3	1
6	3	1	3
7	2	1	1
8	4	3	3
9	1	1	4
10	3	3	2
11	2	3	4
12	4	1	2
13	1	4	2
14	3	2	4
15	2	2	2
16	4	4	4

4 Results

The model was simulated by using following parameters values. For these values forming redundancy obtained is given in figure 5. As it is seen from figure 5 the lack of forming redundancy is localized in the central zone of the part. This is unexpected distribution. Therefore it must be improved by means of changing parameters explained above.

BHF1=2 kN
BHF2=30 kN
t1/t=9.6
R1=R2=R3=5 mm

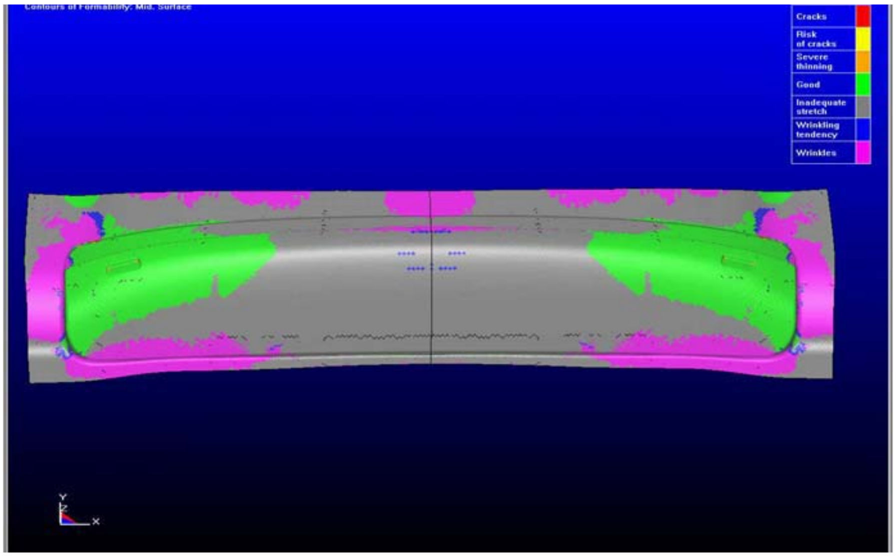


Figure 5 The distribution of forming redundancy on the part surface.

From figure 6 the thickness distribution is seen. The change in thickness si 1.5 % approximately. This value must be 5%. So the results will also be checked for the thickness distribution. The values obtained are very poor and not acceptable. In ordr to improve these values with minimum cost an optimisation design was encountered.

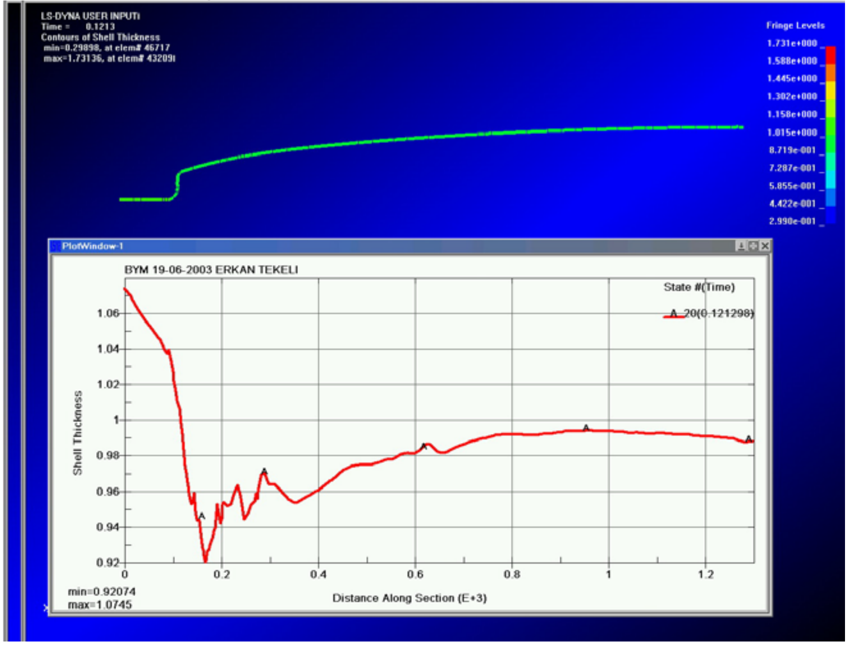

LS-DYNA USER INPUTI
Time = 0.1213
Contours of Shell Thickness
min=0.29898, at elem# 46717
max=1.73136, at elem# 43209I

Figure 6 The thickness distribution obtained on part.

4.1 The result for forming redundancy

Optimization method needs a design ef experiment. This design of experiment was performed with orthogonal array (taguchi method) From this design following rsults were obtained for redundancy and springback.

Table 3 Results of Orthogonal Plan

Number	Constraint	
	$\Delta\varepsilon_{mm}$(%) >10%	Springback(mm) <1 mm
1	25.12	0.37
2	18.01	0.84
3	14.20	1.10
4	12.03	1.40

5	15.02	0.78
6	14.50	0.63
7	11.02	1.40
8	8.00	1.30
9	9.12	1.23
10	6.01	1.50
11	6.80	0.85
12	5.03	1.30
13	7.22	0.98
14	2.00	1.56
15	2.92	1.60
16	0.10	1.80

Tha variance analyses of the results predicts that all of the factors strongly effects these constraints. The factors A,and are very effective at 99% but C is effective at 95%.
The results of variance analyses are given in table 4.

Table 4 Analysis of Variance for REDUNDANCY, using Adjusted SS for Tests

```
Source      DF      Seq SS      Adj SS      Adj MS        F       P
A            3     468.525     397.225     132.408    76.47   0.000
B            3     129.057      80.914      26.971    15.58   0.003
C            3      28.387      28.387       9.462     5.47   0.038
Error        6      10.389      10.389       1.731
Total       15     636.357
```

The values obtained are plotted for Ls Means, Normal probability distribution of residuals and Histogram of residuals at figures 7,8 and 9 respectively. As it is seen from figure 7 the higher factor A the lower redundancy. This is also valid for the other two factors B and C . However the effect of B and C are not so strong with respect to the effect of A.

The normal probabilty distribution of residuals and histogram of distributions are also given in figure 8 and 9 to show as an providence for the distribution of data.

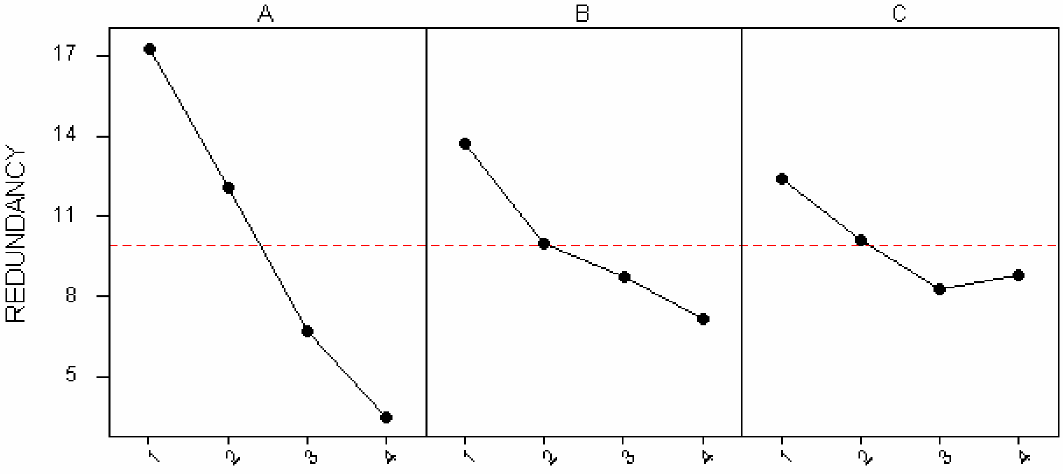


Figure 7 Ls Means for Redundancy

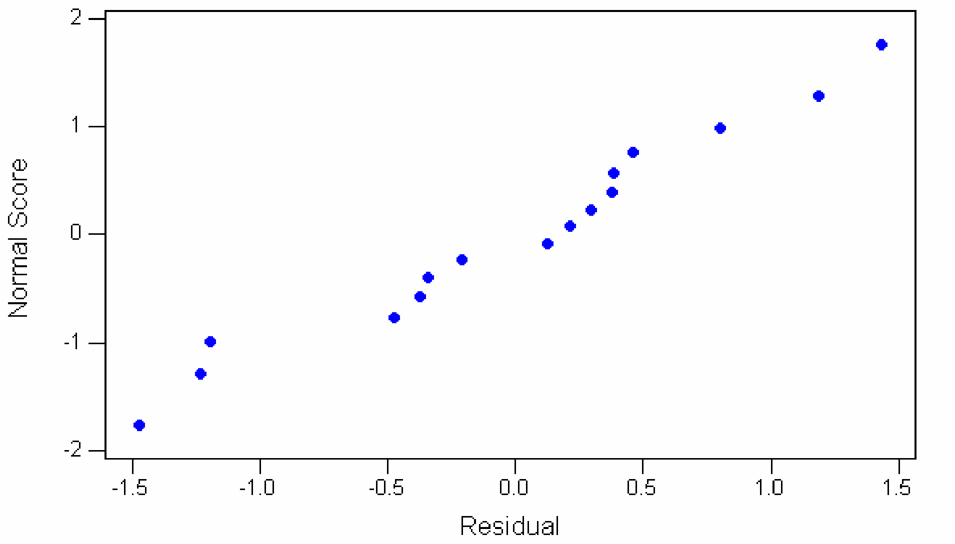


Figure 8 Normal probability distribution of Residual for redundancy

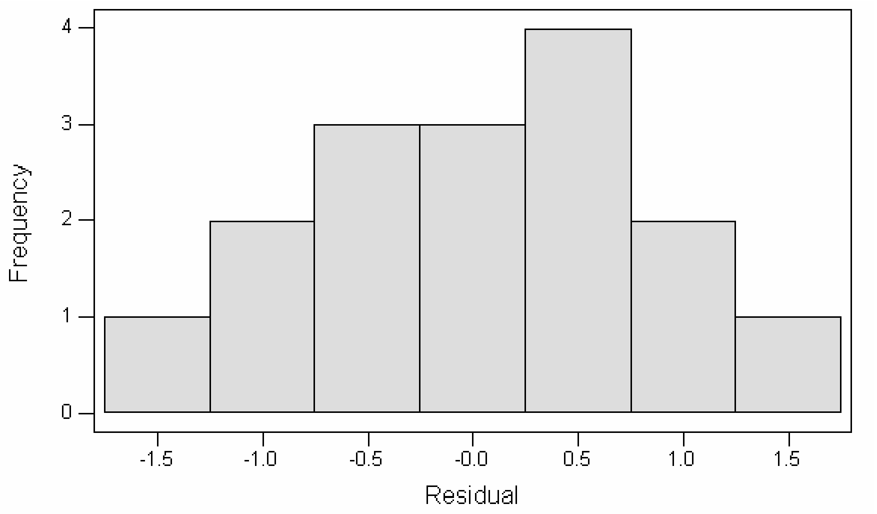


Figure 9 Histogram of residuals.

4.2 The results for springback displacement

The same procedure was repeated fro the second constraint , springback of sheet. The results obtained for the variance analyses are given in table 5.

Table 5 Analysis of Variance for SPRINGBACK, using Adjusted SS for Tests

```
Source      DF     Seq SS     Adj SS     Adj MS       F      P
A            3    0.72295    0.38788    0.12929   10.30  0.009
B            3    0.77265    0.27640    0.09213    7.34  0.020
C            3    0.75067    0.75067    0.25022   19.93  0.002
Error        6    0.07533    0.07533    0.01255
Total       15    2.32160
```

For the constraint springback, the factors A, B and C are found very important again. But as it is seen from figure 10 the relation is reversed. The normal probablity distribution of residuals and histogram of residuals are given in figure 11 and 12 respectively for this constraint also.

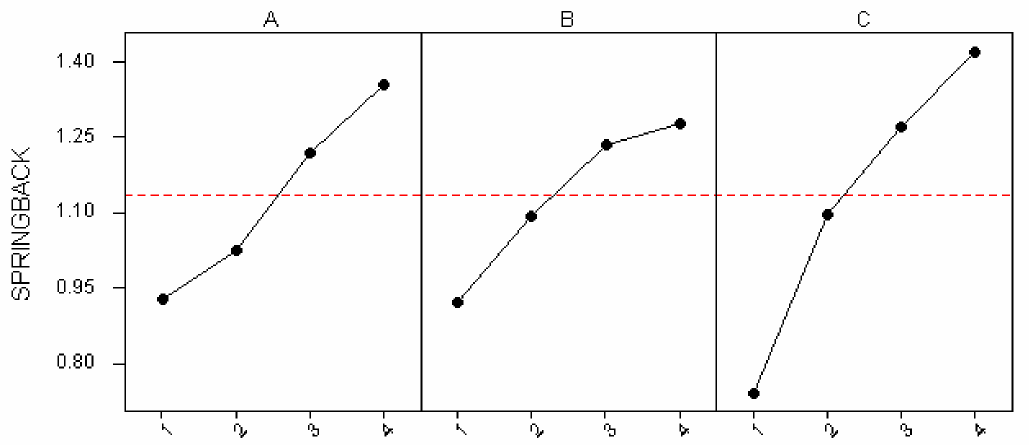


Figure 10 Ls Means for Springback

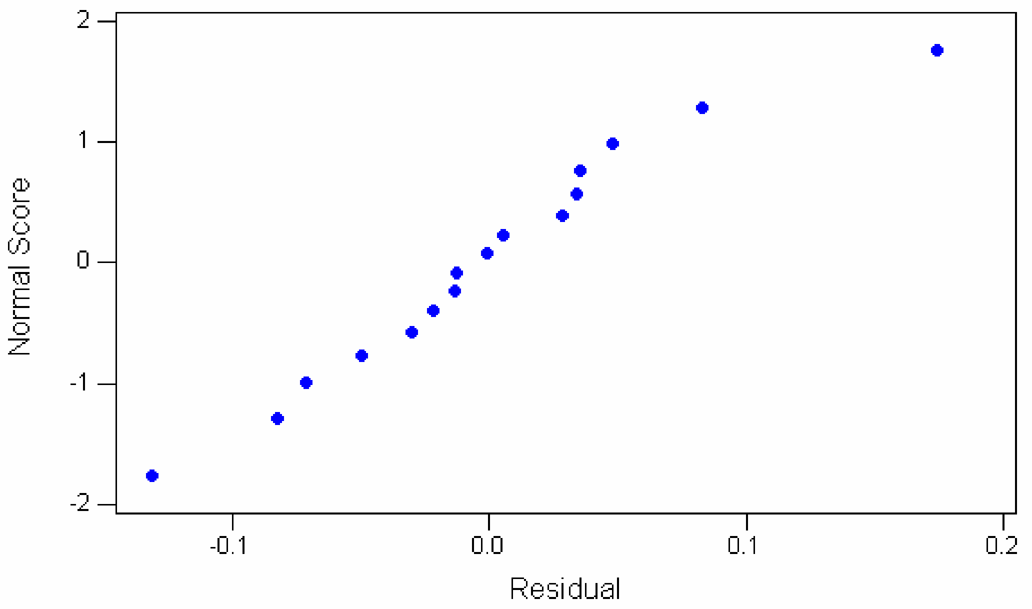


Figure 11 Normal probability distribution of Residual for Springback

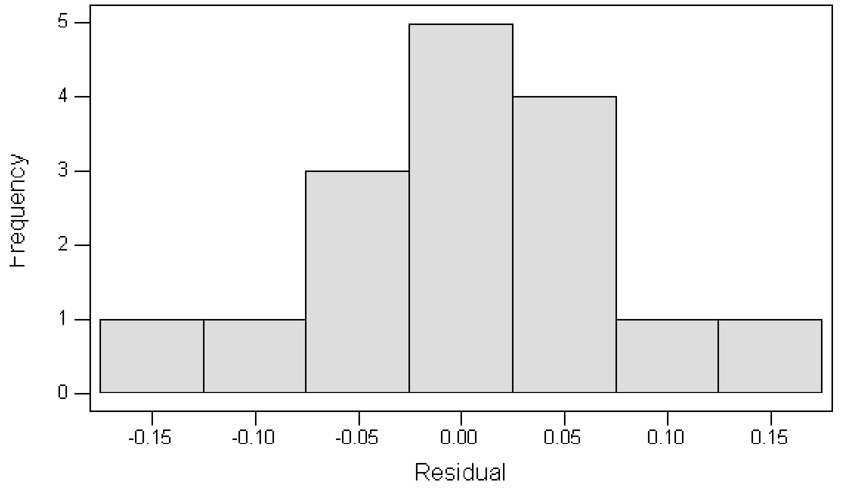


Figure 12 Histogram of Residuals for Springback

4.3 Correlation between springback and redundancy

Since all of the factors are found as effective on both of the constrains the correlation tes was desired to perform the corrleation between them . The correlation test predicts that there is a strong and negative correlation betwenn springback and redundancy for this case.

```
Pearson correlation of REDUNDANCY and SPRINGBACK = -0.829
P-Value = 0.000
```

4.4 Surface Response Regression Test

In order to optimize the factors for desired output a surface response regression test ws designed. For this test a new design for experiments was created. This design is given in table 6 . Then the simulations were run 20 times and the results for redundancy and springback were evaluated. These results were also given in table 6.

Table 6 New design of experiment and the results obtained for this design

	A	B	C	A	B	C	REDUNDANCY	SPRINGBACK
1	1	1	1	-1.00000	-1.00000	-1.00000	7.10	0.864
2	2	2	1	1.00000	-1.00000	-1.00000	25.12	0.370
3	3	3	1	-1.00000	1.00000	-1.00000	3.12	0.850
4	4	4	1	1.00000	1.00000	-1.00000	17.13	0.678
5	5	5	1	-1.00000	-1.00000	1.00000	7.20	0.980
6	6	6	1	1.00000	-1.00000	1.00000	18.45	0.721
7	7	7	1	-1.00000	1.00000	1.00000	0.10	1.800
8	8	8	1	1.00000	1.00000	1.00000	12.00	1.400
9	9	9	1	-1.68179	0.00000	0.00000	7.12	1.680
10	10	10	1	1.68179	0.00000	0.00000	28.12	0.150
11	11	11	1	0.00000	-1.68179	0.00000	10.10	0.890
12	12	12	1	0.00000	1.68179	0.00000	14.35	0.897
13	13	13	1	0.00000	0.00000	-1.68179	8.45	1.460
14	14	14	1	0.00000	0.00000	1.68179	14.25	0.940
15	15	15	1	0.00000	0.00000	0.00000	11.24	1.350
16	16	16	1	0.00000	0.00000	0.00000	11.24	1.350
17	17	17	1	0.00000	0.00000	0.00000	11.24	1.350
18	18	18	1	0.00000	0.00000	0.00000	11.24	1.350
19	19	19	1	0.00000	0.00000	0.00000	11.24	1.350
20	20	20	1	0.00000	0.00000	0.00000	11.24	1.350

The values of A, B and C are given in table 6 as Coded values.

4.4.1 Response Surface Regression: REDUNDANCY versus A; B; C

The analysis was done using coded units. Estimated coefficents for redundancy are given in table 7. The values obtained are analysed by variance mehods. The analyses of variance for these coefficients are given in table 8.

Table 7 Estimated Regression Coefficients for Redundancy

```
Term              Coef    SE Coef          T      P
Constant        11.324     1.4909      7.595  0.000
A                6.627     0.9892      6.699  0.000
B               -1.345     0.9892     -1.360  0.204
C               -0.364     0.9892     -0.368  0.721
A*A              1.706     0.9630      1.772  0.107
B*B             -0.202     0.9630     -0.209  0.838
C*C             -0.511     0.9630     -0.531  0.607
A*B             -0.420     1.2924     -0.325  0.752
A*C             -1.110     1.2924     -0.859  0.411
B*C             -0.198     1.2924     -0.153  0.882

S = 3.656       R-Sq = 83.7%     R-Sq(adj) = 69.1%
```

Table 8 Analysis of Variance for Redundancy

```
Source                   DF     Seq SS      Adj SS      Adj MS      F      P
```

```
Regression          9   687.866   687.866    76.430   5.72  0.006
  Linear            3   626.208   626.208   208.736  15.62  0.000
  Square            3    50.079    50.079    16.693   1.25  0.343
  Interaction       3    11.580    11.580     3.860   0.29  0.833
Residual Error     10   133.634   133.634    13.363
  Lack-of-Fit       5   133.634   133.634    26.727      *      *
  Pure Error        5     0.000     0.000     0.000
Total              19   821.500
```

The results of variance analyses predict that the only linear terms are significant at 955 for redundancy constraint.

4.4.2 Response Surface Regression: SPRINGBACKversus A; B; C

The analysis was done using coded units. The same procedure was repetead for springback constraint and the results are given in table 9.

Table 9 Estimated Regression Coefficients for Springback

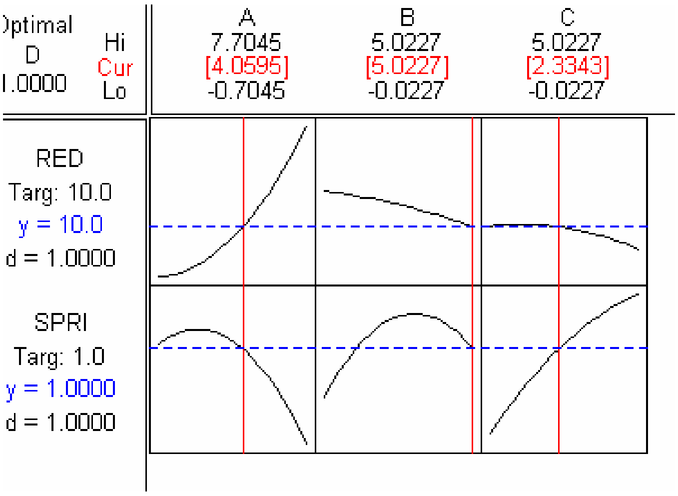
```
Term             Coef     SE Coef         T      P
Constant       1.3508     0.13274    10.176  0.000
A             -0.2854     0.08807    -3.241  0.009
B              0.1322     0.08807     1.501  0.164
C              0.0926     0.08807     1.051  0.318
A*A           -0.1588     0.08573    -1.853  0.094
B*B           -0.1664     0.08573    -1.941  0.081
C*C           -0.0581     0.08573    -0.677  0.514
A*B            0.0226     0.11507     0.197  0.848
A*C            0.0009     0.11507     0.008  0.994
B*C            0.1506     0.11507     1.309  0.220

S = 0.3255      R-Sq = 69.0%     R-Sq(adj) = 41.1%
```

The variance analyses of the results predicted for sprinback show that.again linear terms are significant at 95%. The results of variance analyses are shown in Table 10.

Table 10 Analysis of Variance for Springback

```
Source             DF    Seq SS    Adj SS     Adj MS      F      P
Regression          9   2.35994   2.35994   0.262215   2.48  0.087
  Linear            3   1.46824   1.46824   0.489415   4.62  0.028
  Square            3   0.70609   0.70609   0.235362   2.22  0.148
  Interaction       3   0.18560   0.18560   0.061868   0.58  0.639
Residual Error     10   1.05927   1.05927   0.105927
  Lack-of-Fit       5   1.05927   1.05927   0.211855      *      *
  Pure Error        5   0.00000   0.00000   0.000000
Total              19   3.41921
```

Surface optimiser method can give the optimum values for A,B and C simultaneously for selcted constraint. In this study the springback was tried to be minimized. Therefore the values for springback was chosen as 1 mm. The second contrained was choosen as 10% redundancy. The surface optimiser method predicts the optimal values for factors for this condition. In coded units.



For this optimal values madoel run again and the following distribution in redundancy was obtained.

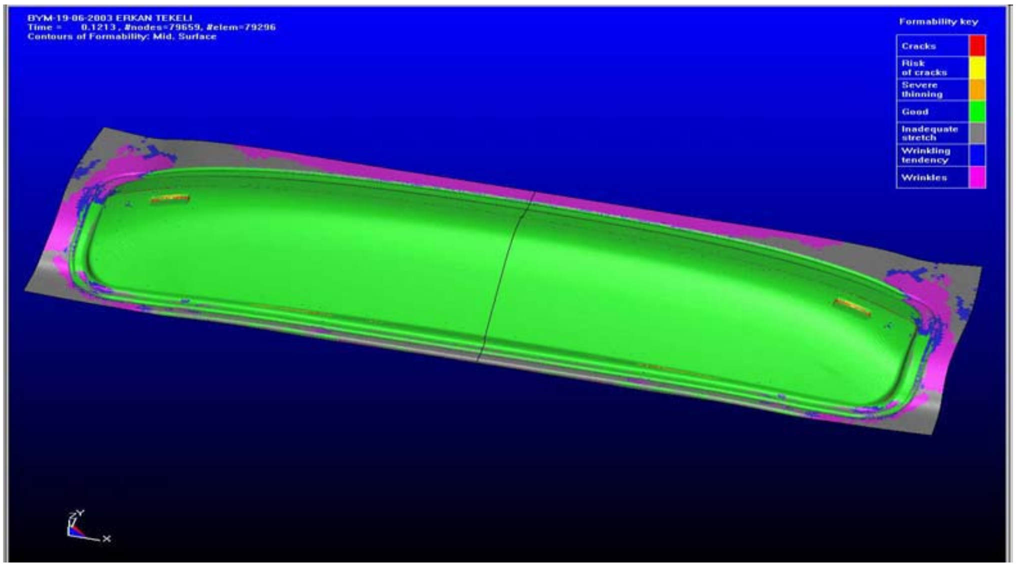


Figure 13 The redundancy distribution on the part

In additio to the desired distribution the thickness distribution was improved also. The figure 14 shows the thickness distribution on the part. The change in thickness is higher than 5% which is desired value.

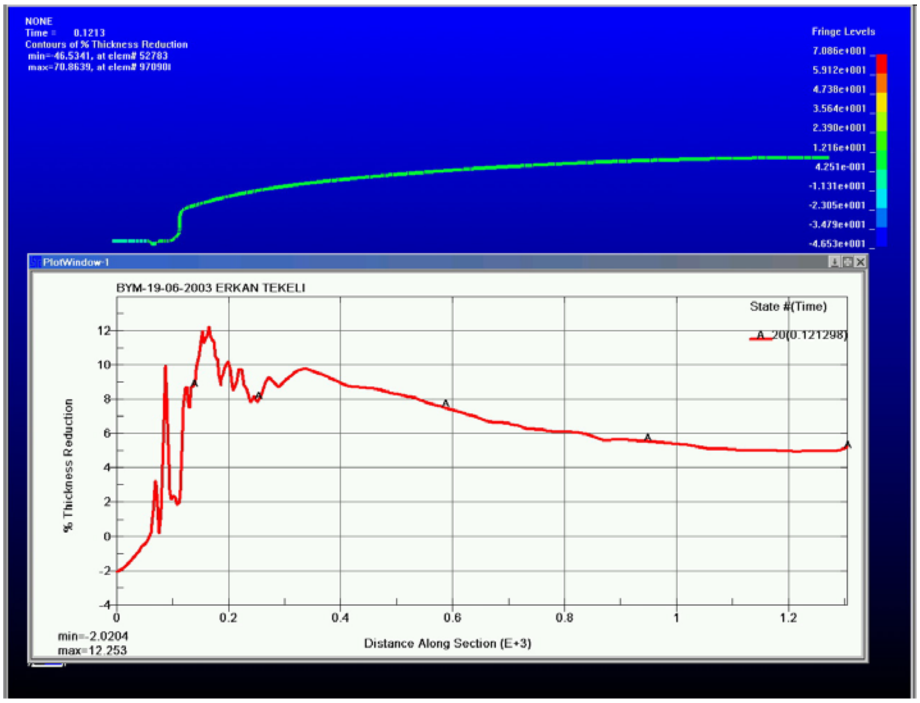


Figure 14 the thickness distribution on part after forming.

The optimal values are predicted and used in the production of Tooling for this part. The test product for this tooling configuration showed desired redundancy and springback behavior similar to the optimum simulation values. The optimization technique make the production of tooling faster and cheaper.

Figure 15 The Tooling Configuration Produced according to Optimal Values.

5. Conclusion

In order to prevent cracking deep drawing process draw beads are used. By means of the draw bead geometry it is possible to optimise spring back and redundancy. For this purpose an optimisation design for variable blankholder force was created by means of orthogonal experiment. From these simulations and following optimisation techniques it can be said that;

1. The increase in the factor A (R1) decreases the springback. The situation is reversed for the other factors B and C. the lower R2 and R3 the lower the springback.
2. For the seconf constraint(reundancy) situation is completely reversed. As it is explained in th correlation study. The existing correlation between springback and redundancy is found –0.829
3. For the product studied it was possible to form the model without cracking and higher than 8 % redundancy.
4. After performing these calculations response surface regression test was intended to find the optimum values for desired factors. For this reason a new design of experiment was created and simulated. Responses of each constraints were calculated separately and then by means of response optimiser calculations optimum values are reach for any conditions.
5. The values advised by response optimiser test are 4.0595 for A 5.0227 for B and 2.3343 for C (coded values) are selected for final simulations. These values are used in the final simulations and the results were compared with the ones obtained from response optimiser. They are in convenience with each other.
6. The optimes values were used in the production of tooling to see the springback value.

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