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SPRINGBACK ANALYSIS IN RECONFIGURABLE MULTIPOINT FORMING OF THICK PLATES

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ABSTRACT

Reconfigurable multipoint forming (RMPF) is a flexible manufacturing technology which assures the production of different sheet metals parts with low costs. The main characteristic of the deformation method is given by the surface discrete design of the forming elements which materialize the continuous 3-D surface of the punch and die active working surfaces. The paper presents some conceptual models for multipoint forming dies, possible to could be used in ship industry. For some die-punch models, the dependence between the multipont forming die configuration toward the springback are then discussed using FEM analysis. For this, the characteristic profiles coordinates of working surfaces are calculated. Based on the obtained results, it results that reconfigurable multipoint forming could be applied in practice for manufacturing large parts with complex geometry.

KEYWORDS: multipoint die, multipoint forming, CAD, sheet metal forming, ship body manufacturing

1. INTRODUCTION

In the field of metal forming processes, the application of flexibility is limited due to the production characteristics: a great variety of shapes and dimensions; a great quantity of parts; each part demands a specific tool, each change in part design demands a new tool; less flexibility in comparison with machining, where the same set of cutting tools can be used to produce a wide variety of finished shapes. On the other hand the development of a new sheet metal part is a very expensive process, which implies costs associated mainly with the presence of a try-out press, a try-out die or dies and a lot of experimental tests for correcting the active geometry in each stage of deformation.

The ship body is a combination of surfaces (figure1) which could be classified in plane surfaces, simple curvature surfaces and double curvature surfaces. The double curvature surfaces in turn are classified in double curvature surfaces with or without torsion. So, in the central zone of the ship are used plane and cylindrical (simple curvature) thick plates and in bow and stern zones the plates will have double curvature.

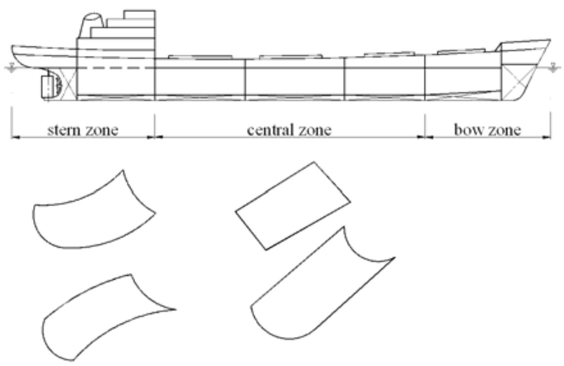


Fig. 1. Types of thick plates which compose a ship body

The manufacturing process of such types of plates, in ship industry, is based on bending using rolling, in using flame bending or in using both method. In all cases the desired shape is difficult to achieve due to springback. As a result the experience of the workers is still important in obtained such components and compensate for springback.

In the last decades important efforts were made to increase the quality of body parts in ship industry by using new methods of manufacturing by metal forming. Among them, multipoint deformation using reconfigurable dies is an advanced manufacturing technique for obtaining three-dimensional sheet-metal parts.

Multipoint forming is an engineering concept which means that the working surface of the die and/or punch is made up of hemispherical ends of individual active elements (called pins), where each pin can be independently, vertically displaced (figure 2).

Fig. 2. Multipoint forming die subassembly

Using a geometrically reconfigurable die, precious production time is saved because several different products can be made without changing tools. Also a lot of expenses are saved because the manufacturing of very expensive rigid dies is reduced. But the most important aspects of using such types of equipments is the flexibility of the tooling which could be easily used in adjusting for springback reduction or compensation.

In the paper is presented the application of multipoint forming process in ship industry by simulating the influence of tool configuration toward the springback phenomenon. Three tool models are considered: model 1 – tooling with die-punch pins placed out of face; model 2 – tooling with die-punch pins placed face to face and next to each other; model 3 – monolith die-punch tooling. Both simple and double-curved cases are analysed.

2. MULTIPOINT FORMING PROCESS CLASIFICATION

Multipoint forming was developed more than fifty years ago, designed for sheet metal forming, including thick plates. Hardt and Walczky [1-6] developed the principles of *reconfigurable tooling for flexible fabrication (RTFF)*, used a numerical control algorithms for vertical displacement of the pins in order to generate the working surface of active elements. Cai and coworkers [7] have made a series of progress in the filed of multipoint forming for sheet metal (*MPF*). Derived from *MPF* technology one developed the newer concept of deformation with digitized die forming *(DDF – Digitized-die forming)* which assures the obtaining of large parts with small active elements sets. The principle of *DDF* consists in obtaining the part, section by section, which gives a more flexibilty in comparison with *MPF*. During the process of deformation three regions coexists: the deformed region, the undeformed region and the transition region. The transition regions are the superimposing area between the deformed regions in previous forming steps and the forming region in the curent step and play an important role in the quality of the final part. Cai, Li and Liu [26], developing the research in this field, propose a new technology for obtaing complex parts with multipoint dies, so called *VP-DDF (Varying path DDF)* technics. In this case the shape of the digitized-die varies continuously during the process which is numerical controlled. The variation mode of this shape is described by a series of intermediare shape at a series of specific time t_0, t_1, …, t_i, … t_f. The calculus of each pin position at the moment is realized based on the principle of the contact assurement between the pin and the material. *Multi-step DDF* approximate *VP-DDF* technics and consists in obtaining the part by succesive small deformation in steps. This method is more easily to implement in practice than *VP-DDF* technics maintaining the majority of its advantages. The researches evolution in the field of deformation with multipoint dies deformation lead to the development of the *closed-loop forming process* technics which consists in integration the *DDF* system with a shape feedback system. Its function consists of a rapid 3-D shape measurement and the associated software of control algorithm of shape errors. *DDF*, *VP-DDF*, *Multi-step DDF* and *Closed-loop forming* tehnics have been developed and they have been applied to large parts, of medium complexity, having the same section along a generatrix of complex form.

Depending on the type of application, multipoint forming could be classified according to the data presented in table1. The examples from the table 1 are presented in different scientific papers, [1, 4, 10, 11, 12, 13, 19], and are actually used in industry.

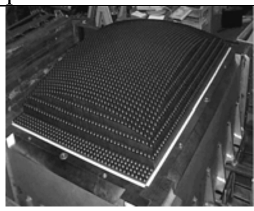
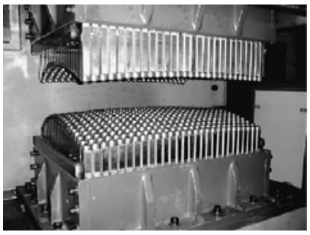
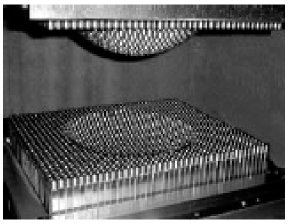
Depending of the type of configuration, the geometry of the dies could be fixed or active.

The system with fixed configuration was first developed. The geometry adjustment of the die is made at the beginig of the process, using mechanical, hydraulical or electrical devices and the die configuration is the same from the begining to the end of the process. For increasing the number of contact points between the die and the blank and from technological reasons, it is used a square network of pins, irrespective of type of configurations.

In active configuration, the pins are vertically moved during the process of deformation, according to a forming path, to finally obtain the desired geometry of the part. The forming path depends on the degree of stresses and strains in material.

Electrical, hydraulical or electro-mechanical devices are used to control the pins positions during the deformations. An adaptive control of the process is used.

Table1. Multipoint process clasiffication

No.	Type of process	Type of configuration	Configurations examples	Main charactersitics
1.	For stretch forming	Fixed		The geometry configuration is fixed from the begining to end of the process
		Active		The geometry configuration is changeable according to a path-forming
2.	For bending	Fixed		The geometry configuration is fixed from the begining to end of the process
		Active		The geometry configuration is changeable according to a path-forming
3.	For deep-drawing with or without blank-holder	Fixed		The geometry configuration is fixed from the begining to end of the process
		Active		The geometry configuration is changeable according to a path-forming

3. MATERIAL CHARACTERIZATION OF SHIP'S HULL STEEL PLATES

Plate forming and beam bending is obtained by deformation in elasto-plastic range. The most concluding test for the materials behaviour study in the elastic and plastic deformations range is the tensile test. This test is done according with the standard conditions, such as European standard SR-EN 10002-1. The results of this test are the relation between the engineering strain $\varepsilon = \Delta l_o / l_o$ and nominal stress $\sigma = F/A_o$, respectively.

The obtained strain-stress curve is conventional due to modifying of the initial length and cross-section area, respectively, during test. The obtained characteristics are necessary to evaluate the plastic deformation phenomenon and elastic springback, respectively, but these are not enough. It is necessary to introduce the concept of true tensile curve $\sigma_{real} - \varepsilon_{real}$. The engineering strain supposes a linear accumulation of strain in aspect to initial length l_o.

In fact, the true strain increment for a tensile force ($F + \delta F$), in aspect to accordingly force F, is d ε_{real} = d l/l, where l is the current length to force F.

The total true strain accumulated from the test start is $\varepsilon_{real} = \ln(1 + \varepsilon)$, while the true stress is $\sigma_{real} = F/A = \sigma\, A_o/A$, where A is the current area of sample cross-section accordingly to force F. The relationship between the real and initial area $A = A_o/(1 + \varepsilon)$ and $\sigma_{real} = \sigma\,(1 + \varepsilon)$ are obtained to base on volume constancy hypothesis.

In the theoretical treatment of plasticity problems, it is generally convenient to represent the true strain-stress curve by an empirical equation. However, it must to approximate as well as possible the experimental curve. There are many empirical equations in the literature. One of these is the power law proposed by Ludwik (1909), $\sigma = K\,\varepsilon^n$, where K is a constant stress and n is the strain hardening exponent, which value is generally less than 0.5 [1].

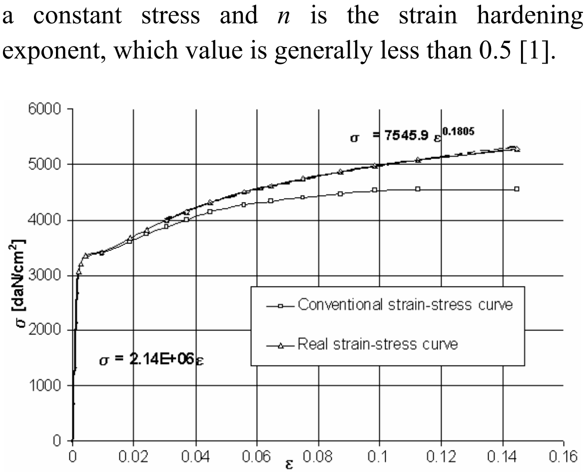


Fig. 3. The conventional and true stress-strain curves

This real strain-stress curve shown in Figure 3 gives the expression $\sigma = 754\ \varepsilon^{0.1805}$, i.e. the strain hardening exponent *n* equals 0.18, whereas the strain hardening coefficient is $k = 754\ MPa$.

4. PROCESS SIMULATION

The manufacturing error caused by springback may be attributed to inconsistent material properties or material thickness.

Springback in sheet metalforming leads to unacceptable dimensions and problems with fitting, thereby adversely affecting the quality of the product [1]. For thin sheet, the springback is the main component of the manufacturing error. Moreover, inconsistency in springback leads to the difficulties in obtaining consistent product quality. The magnitude of springback is determined by the material properties, the thickness and the tool geometry. For thick plates the springback is also present and a simulation analysis will be made as follow.

4.1. Geometrical modeling of contact points

The geometrical modeling of the die-punch tool requests calculations for the characteristic profiles coordinates of working surfaces (see A_i, B_i, C_i, D_i points from Figure 4). Because of semispherical shape of the pin ends that materialize the working surfaces, it is necessary to apply corrections that will count for the displacement of contact points between pins and curved plate.

To obtain the data, a program for cylindrical plates was developed, where the input data are *R* - desired radius, *s* - plate thickness, r_1 - top pins radius, r_2 - connection radius between pins and base planes, *n* - gap numbers, *i* - pin number, *i* = 0... *n*. The output data are *B* - distance between extreme pins, B_n - plate width, *p* - punch stroke, A_i, B_i, C_i and D_i - characteristic profiles points coordinates of working surfaces for *i* pin with the following expressions: $B_n = \pi\,(R + s/2)/2$, $B = R\sqrt{2}$, $p = R - B/2$.

Die pins coordinates are:

$$
\begin{aligned}
y_{A_i} &= \frac{B}{2}\cdot\frac{i}{n},\\
z_{A_i} &= (R + r_1 + s) - \sqrt{\left(R + r_1 + s\right)^2 - y_{A_i}^2},\\
y_{B_i} &= y_{A_i} + r_1,\ z_{B_i} = z_{A_i},\\
y_{C_i} &= y_{B_i},\ z_{C_i} = 0,\\
y_{D_i} &= y_{C_i} + r_2,\ z_{D_i} = 0.
\end{aligned}
\tag{1}
$$

Punch pins coordinates are:

$$
\begin{aligned}
y_{A_i} &= \frac{B}{2}\cdot\frac{i}{n},\\
z_{A_i} &= p + (R + r_1 + s) - \sqrt{\left(R - r_1\right)^2 - y_{A_i}^2},\\
y_{B_i} &= y_{A_i} + r_1,\ z_{B_i} = z_{A_i},\\
y_{C_i} &= y_{B_i},\ z_{C_i} = z_{A_{i=n}},\\
y_{D_i} &= y_{C_i} + r_2,\ z_{D_i} = z_{A_{i=n}}
\end{aligned}
\tag{2}
$$

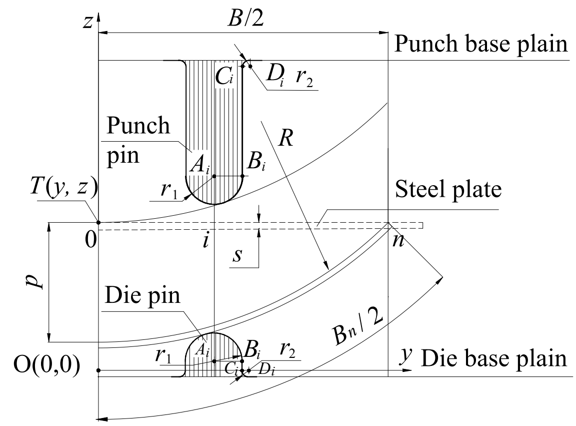


Fig. 4 Die-punch section for i pin

In the case of double-curved plates the input data are R_T - desired transverse radius, R_L - desired longitudinal radius, *s* - plate thickness, *r* - top pins radius, *u* - gap numbers on *x*-axis, *n* - gap numbers on *y*-axis, *i* - pin number on *x*-axis, *i* = 0... *u*, *j* - pin number on *y*-axis, *i* = 0... *n*. The output data are *B* - distance between extreme pins on *y*-axis, B_n – flat plate width, *L* - distance between extreme pins on *x*-axis, L_n – flat plate length, *p* - punch stroke, $A_{ijk}(x_{ijk}, y_{ikj}, z_{ijk})$ - semispherical surface center coordinates of characteristic profiles for *ikj* pin (Figure 5).

4.2. Simulation model

The simulation of the press forming process is carried out with the commercial program DYNAFORM. The Belytschko-Lin-Tsay shell element based on a combined co-rotational and velocity-strain formulation was chosen to analyze the elasto-plastic process with complex geometrical nonlinearity.

For simple curved geometry, the dimensions of flat plate model are 1120 x 2000 mm with 10 mm thickness. The desired plate radius is 707.1 mm. Due symmetry, the geometrical model is only for a quarter of real deformation case. Three cases were considered:

Case 1 - tooling with die-punch pins placed out of face - two working plates with 36 pins for die and 27 pins for punch. The die and punch meshing includes 83624 and 72392 finite elements, respectively, while the flat plate 100 finite elements. For simple-curved geometry, the geometrical model for the initial and final positions are shown in figure 6.

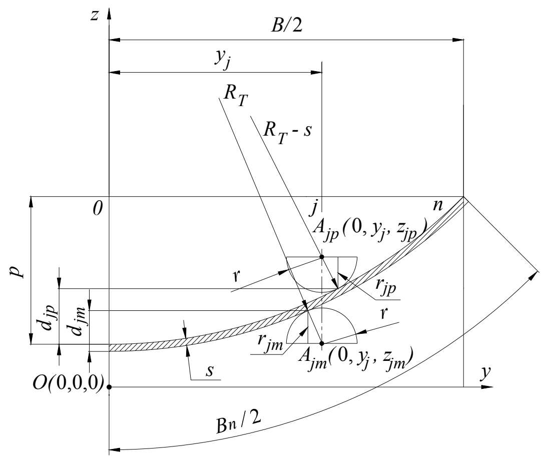


Fig. 5.a Die-punch transverse section

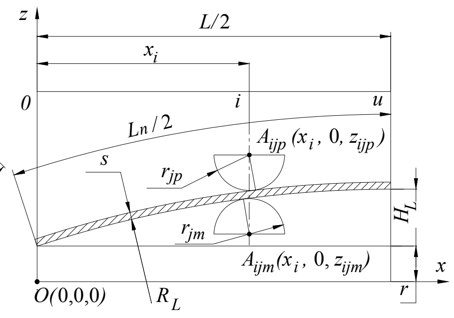


Fig. 5. b Die-punch longitudinal section

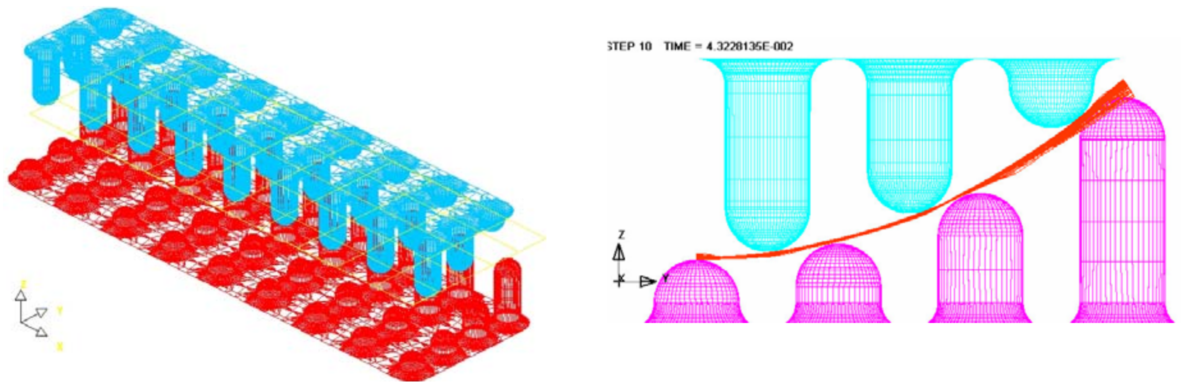


Fig. 6. Die-plate-punch assembly- case 1

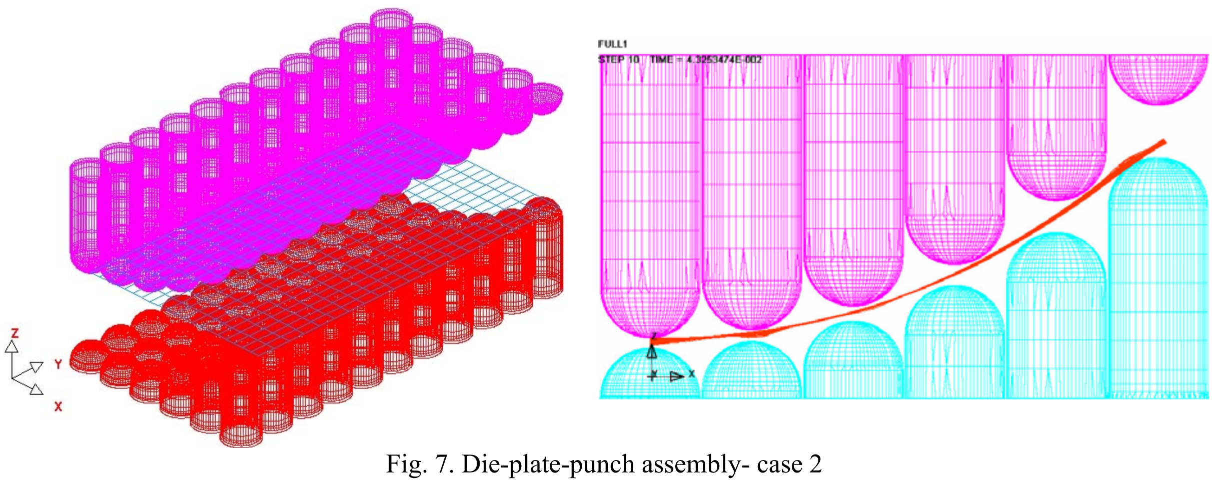


Fig. 7. Die-plate-punch assembly- case 2

Case 2 - tooling with die-punch pins placed face to face and next to each other - two working plates with 66 pins for each. The die and punch meshing includes 70582 and 82308 finite elements, respectively, while the flat plate 400 finite elements. For simple-curved geometry, the geometrical model for the initial and final positions are shown in Figure 7.

Case 3 - for the monolith die-punch tool, the die and punch meshing includes 2816 finite elements, while the flat plate 100 finite elements (Figure 8).

For double-curved geometry the dimensions of flat plate model, are 1120 x 2030 mm with 10 mm thickness. The desired transverse plate radius is 707.1 mm, while the desired longitudinal radius is 5050 mm. Due symmetry, the geometrical model is only for a quarter of real deformation case. Two working plates with 66 pins for each materialize the geometrical model of die-punch tool, 11 rows on *x*-direction and 6 rows on *y*-direction. The pins are disposed face to face, both on *x*-direction and *y*-direction. The die and punch meshing includes 115150 and 121994 finite elements, respectively, while the flat plate 400 finite elements. For double-curved geometry, the full geometrical model of the die-plate-punch assembly in the initial position is shown in Figure 9.

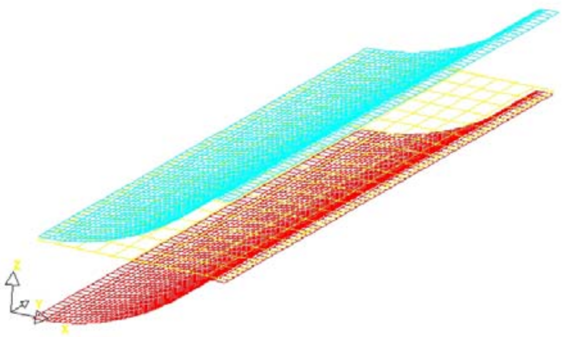


Fig. 8. Die-plate-punch assembly- case 3

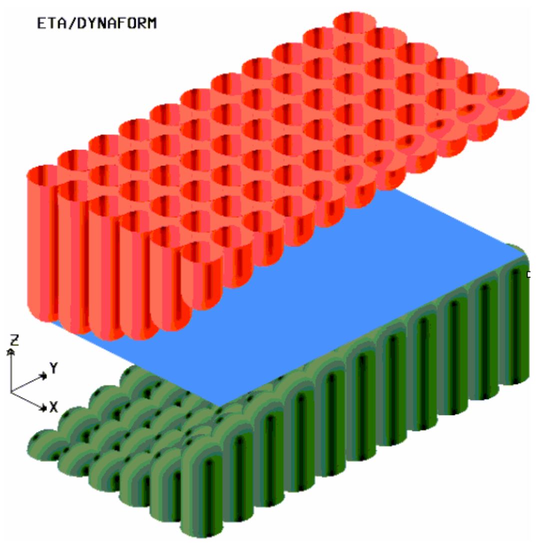


Fig. 9. Double-curved geometry simulation model

The following specific parameters were used into this simulation process: p = 207.11 mm - punch stroke, material properties for plastic deformation range according to Ludwik law $\sigma = K\,\varepsilon^n$, where K = 754 MPa and n = 0.18, input data for elastic material, density, Young’s modulus and Poisson’s ratio, according to implicit program values for steel, anisotropic coefficient equal to 1 and abrasion coefficient between plate and die-punch surfaces equal to 0.125.

4. NUMERICAL RESULTS

At the end of the simulation process, the postprocessor features enable various interpretation of output data, mainly the 3D-deformed shape and its sections for comparison to the desired shape, as well as other results such as stress components, von Mises equivalent stress for each element at its Gauss integration points, the magnitude of the springback, the time variation of the applied loading forces. As we are interested only in springback variation, we will discuu about this in what is follows.

On the basis to the coordinates of points series obtained for a certain cross section were plotted the plate shape before and after springback, comparatively to desired shape, for each case, respectively: case 1 – die-punch pins placed out of face; case 2 – die-punch pins placed face to face and next to each other; case 3 – monolith die-punch. In Figures 10-12 are presented the values of springback for the analysed cases.

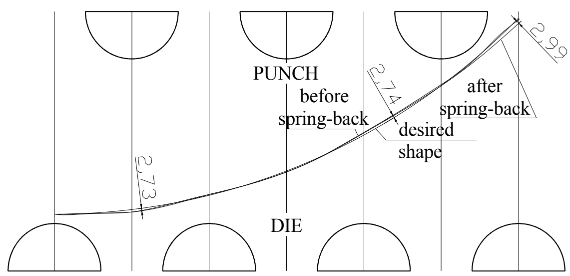


Fig. 10. The springback values in the first case

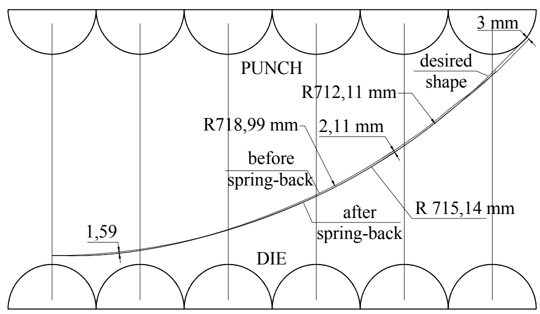


Fig. 11. The springback values in the second case

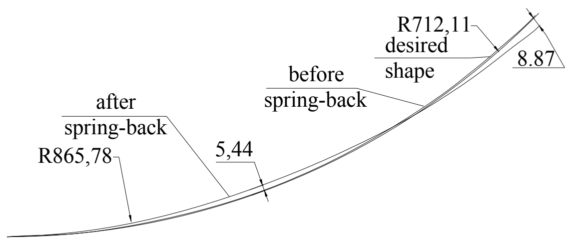


Fig. 12. The springback values in the third case

From figures, result that the level of springback in the case of the multipoint forming (figures 10 and 11), is smalll in comparison with the values of springback obtained using monolith dies (figure 12). The accuracy in relation with the part dimensions is good for all cases, but is much smaller isn the case of multipoint forming. Is the first case of multipoint deformation , the springback is almost uniform on all the profile. In the second case, the level of springback is not uniform, being higher at the end of the part. The same observation ia available in the case of deformation with monolith dies.

For the double-curved geometry the values of the springback are presented in the next Figures 13 and 14.

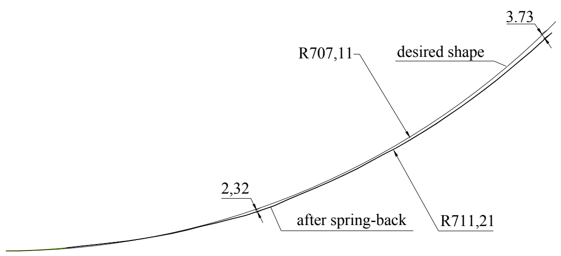


Fig. 13. Transverse shape after spring-back comparatively to desired shape

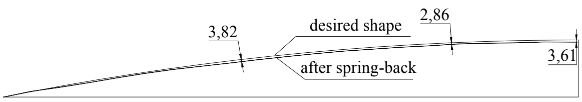


Fig. 14. Longitudinal shape after spring-back comparatively to desired shape

In this case the springback values are different for the two curvatures and also are small in comparison with the part dimension. On the concave curvature the springback is variable and is bigger at the end of the part. On the convex curvature the springback is almost constant.

5. CONCLUSIONS

From the simulation is result that the surface shape using monolith die-punch tool is better qualitative than those obtained with reconfigurable die-punch assembly with forming pins. The dimpling phenomenon is present in both cases of deformation with pins. The obtained surface shape using reconfigurable die-punch tool has a qualitative increase when the pins are disposed face to face to each other. The springback is greater when press forming is simulated with monolith die-punch tool. Also the springback is greater when the pins are disposed out of face. In both cases, it is possible to recalculate the initial tool radius in accordance with the springback value as to compensate for the springback.

Press forming simulation of the saddle-type thick steel plates with reconfigurable die-punch tool proved possibility to evaluate easily different series of surface configurations that leads to the desired double-curved shape. The obtained surface shape shows a small deviation of the obtained transverse and longitudinal shape from the desired shape.

The results of simulations of the thick plates with multipoint tooling based on the discrete die-punch concept proved possibility to evaluate easily different series of surface configurations that leads to the desired curved shape.

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