Spring back Compensation in Reconfigurable Multipoint Forming

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Abstract: - Multipoint forming (MPF - multi-point forming) is a flexible manufacturing technology which assures the production of a high sheet metals parts variety with low costs in comparison with monolithic dies. The main characteristic of the deformation method is given by the active surface discrete design of the forming elements which is composed from a number of pins, vertically aligned, according with the geometry of the part. Conceptual models for multipoint forming dies are presented. The concept of reconfigurable MPF is analysed through a set of simulations, using the finite element analysis. The numerical experiments showed the dependence between the part radius, pins radius and material thickness toward the spring back and dimpling phenomenon. A method for spring back compensation was developed. From technologic point of view the major impact of applying this method will be the development of a new class of forming tool with superior performances.

Key-Words: - reconfigurable system, multipoint deformation, flexible manufacturing, spring back, spring forward

1 Introduction
Reconfigurable Manufacturing Systems (RMS) is a concept designed for the system configuration rapid change, in terms of their machines and controls. In this way RMS offer a developed approach of adjusting production capacity and functionality quickly to the new products as well as in response to market changes [2]. From economical point of view, RMS goes beyond the objectives of mass, lean, and flexible manufacturing and allows flexibility not only in producing a variety of parts, but also in changing the system itself [3].

In the field of metal forming processes, the application of reconfigurability 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. In the last decades important efforts were made to increase the flexibility in metal forming processes. This led today to could identify some reconfigurable systems for this technology.

According with figure 1, the first step in considering the concept of reconfigurability in sheet metal forming was the software programs developments applied in the forming trajectory generation, in the deformation steps calculus (spinning), and in the force and pressure control toward the blank.

Of course this thing was correlated with the progress in press design – use of PLC-s, hydraulics systems, etc.

The second level refers to the possibility to change the geometry of the active elements of the die, in short time,
outside the press space, according to the new part geometry. If we are referring to the MPF, the major advantage of this level is that the reworking by machining of the traditional monoblock dies is replaced with reconfigurability.

The third level refers to the possibility to change the geometry of the die in process, according to an optimum path of deformation. This advantage could be exploited especially in MPF.

In the paper some aspects of material deformation in reconfigurable MPF - RMPF are analysed based on the FEM study of the rigid/elastic-plastic media assembly behaviour.

2 Reconfigurable Multipoint Forming

The surface tooling in reconfigurable multipoint forming (RMF) is based on the concept of a die continuous surface discrete approximation (Figure 2). It consists of a number of closely spaced multiple rigid surface tool elements, known as pins, each of which is vertically aligned, according with the geometry of the part [4].

![Fig. 2. Reconfigurable surface tooling](image)

The principles of tooling for flexible fabrication in sheet metal forming were introduced by Hardt (RTFF – Rapid Tooling for Flexible Fabrication) [4]. Boyce and Walczky [11], [6] developed numerical control algorithms for vertical displacement of the pins in order to generate the working surface of active elements. Li and coworkers [20] developed the concept of Multipoint Forming for sheet metal (MPF). Derived from MPF technology they developed another concept of deformation, Digitized Die Forming (DDF). The principle of DDF consists in obtaining the part, section by section, which gives a more flexibility in comparison with MPF. The Closed-loop forming process technics which consists in integration the DDF system with a shape feedback system is used in the field of deformation with multipoint dies deformation. Li, Cai and Liu [21], propose a new technology for obtaining complex parts with multipoint dies, so called VP-DDF (Varying path DDF) technics. In this case the final shape of the digitized-die is described by a series of intermediate shape at a series of specific time t₀, t₁, …, tᵣ, … tₖ. The calculus of each pin position at the moment is realized based on a geometrical criterion, on a-priori calculated height, not on a material response reaction during the deformation. Multi-step DDF approximate VP-DDF technics and consists in obtaining the part by successive small deformation steps. This method is more easily to implement in practice than VP-DDF technics maintaining the majority of its advantages [22].

3 Simulation of Reconfigurable Multipoint Forming

The quality of the parts obtained by using the reconfigurable MPF - RMPF process is affected by two factors: dimpling and spring back.

Both factors could be analysed using the power of finite element method.

In figure 2 is presented the model of deformation using the FEM program Dynaform. Only a half of model is presented. The tool geomet ry without interpolator is configured for obtaining a single curvature plate with different radii (see table 1). No blankholder was used so the ends of the blank are free to deform.

![Fig. 2. Tools in modeling the RMPF](image)

The FE mesh consists of 4-node Belytschko-Tsay shell elements, with five integration points through the thickness of the sheet. The Belytschko-Lin-Tsay shell element are based on a combined co-rotational and velocity-strain formulation.

The material used in experiments was mild steel. The yielding of the material was modelled using a power law:

\[ \sigma = K \varepsilon^n \]

where: \( K \) is the material characteristic; \( n \) – hardening
exponent. In simulation the \( n \)-value = 0.22 and \( K = 648 \) MPa. The \( R \)-values were set to: \( R_{00} = 1.87; R_{45} = 1.27; R_{90} = 2.17 \). The Coulomb friction law was used considering a friction coefficient of 0.125. The punch speed was 100 mm/second.

The tooling was modelled as rigid surfaces. The geometrical model of die-punch tool was composed from two working networks with 100 pins for each network. The pins are disposed face to face, both on x-direction and y-direction.

The values of material thickness and radii of parts are presented in table 1.

<table>
<thead>
<tr>
<th>Material thickness, ( g ), [mm]</th>
<th>Part radius, ( R ), [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
</tr>
</tbody>
</table>

The springback was calculated, considering the width variation, with the relation:

\[
\Delta L = \left( \frac{L_f - L_i}{L_f} \right) \times 100
\]

where: \( L_i \) and \( L_f \) are the part width before and after the spring back.

In figures 3 and 4 are presented the geometry of the parts obtained by simulation the RMPF process.

In figure 3 ones could observe variations along the part surface. If we look after the thickness variation, we can observe from figure that the difference between the maximum and minimum value is 0.08 mm. This difference appears as a result of the local effect of the pins radius. From point of view of thickness deviation this is an acceptable value, the normal deviation being at the level of tenth of millimeter.

But if we consider the strain and stress state, the local effect of pins radius is very important, the regions of high stress are intercalated with regions of small stress, even more the stresses of compression are intercalated with tension stresses.

In figure 4 are presented an optimum case, ones could observe the same variation of the thickness along the part surface as in the case of deformation with continuous surface of die and punch. This means that between punch radius, part radius and blank thickness the local effect of pins radii is null.

![Fig. 3. Geometry and thickness variation of simulated part in RMPF](image)

![Fig. 4. Optimum geometry and thickness variation of simulated part in RMPF](image)

In table 2 are presented the values of widths before and after spring back measured on simulated parts.

<table>
<thead>
<tr>
<th>( g-R ) parameters combination</th>
<th>Width ( L_i ) before springback, [mm]</th>
<th>Width ( L_f ) after springback, [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-80</td>
<td>120.526</td>
<td>120.465</td>
</tr>
<tr>
<td>1-85</td>
<td>124.617</td>
<td>125.596</td>
</tr>
<tr>
<td>1-90</td>
<td>125.828</td>
<td>127.204</td>
</tr>
<tr>
<td>1-95</td>
<td>127.696</td>
<td>127.438</td>
</tr>
<tr>
<td>1-100</td>
<td>128.877</td>
<td>128.596</td>
</tr>
<tr>
<td>2-80</td>
<td>123.594</td>
<td>123.711</td>
</tr>
<tr>
<td>2-85</td>
<td>124.777</td>
<td>124.754</td>
</tr>
<tr>
<td>2-90</td>
<td>125.642</td>
<td>125.768</td>
</tr>
<tr>
<td>2-95</td>
<td>128.725</td>
<td>129.103</td>
</tr>
<tr>
<td>2-100</td>
<td>129.016</td>
<td>129.005</td>
</tr>
<tr>
<td>3-80</td>
<td>124.725</td>
<td>124.729</td>
</tr>
<tr>
<td>3-85</td>
<td>125.934</td>
<td>126.134</td>
</tr>
<tr>
<td>3-90</td>
<td>127.045</td>
<td>127.149</td>
</tr>
<tr>
<td>3-95</td>
<td>127.736</td>
<td>128.354</td>
</tr>
<tr>
<td>3-100</td>
<td>129.132</td>
<td>129.216</td>
</tr>
<tr>
<td>4-80</td>
<td>125.039</td>
<td>125.241</td>
</tr>
<tr>
<td>4-85</td>
<td>126.500</td>
<td>126.829</td>
</tr>
</tbody>
</table>
From table 2 we obtain the spring back variation presented in figure 5 and 6.

In figure 5 is presented the spring back variation considering the case of deformation with the same thickness and different bending radius according to table 1. As we could see there’s appear different types of behaviors.

For small thickness, in this case 1 mm, appears a phenomenon of spring forward. At part radius of 90 mm the value of spring back is maximum.

The curves present or two maxims or one minimum and one maximum with increasing the material thickness. It is interesting to note that at a part radius of 90 mm the values of spring back is almost the same, when the material thickness is higher then 2 mm.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Spring Back Value</th>
<th>Spring Back Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-90</td>
<td>127.821</td>
<td>127.946</td>
</tr>
<tr>
<td>4-95</td>
<td>128.645</td>
<td>128.816</td>
</tr>
<tr>
<td>4-100</td>
<td>129.462</td>
<td>129.607</td>
</tr>
<tr>
<td>5-80</td>
<td>125.094</td>
<td>125.289</td>
</tr>
<tr>
<td>5-85</td>
<td>126.889</td>
<td>126.885</td>
</tr>
<tr>
<td>5-90</td>
<td>127.975</td>
<td>128.117</td>
</tr>
<tr>
<td>5-95</td>
<td>129.147</td>
<td>129.321</td>
</tr>
<tr>
<td>5-100</td>
<td>130.148</td>
<td>130.205</td>
</tr>
</tbody>
</table>

In figure 6 is presented the spring back variation considering the case of deformation with the same bending radius and different thickness according to table 1.

The curves present different variations for different material thicknesses.

It results that using the simulation the dimpling and spring back could be studied. The phenomenon of spring back is important to be quantified and to develop methods for compensate it. The phenomenon of spring forward is also important and it is a result of stresses variation along the part surface.

### 4 Reconfigurability Model for Spring back Compensation

To compensate for spring back, a reconfigurability model based on the displacement adjustment (DA) method was proposed [12].

The idea is to measure the part, and to calculate the distance between the part after deformation and the desired shape of the part. The surfaces of the tools are then displaced with the same distance, but in the direction opposite to the springback deformation [13].

The general algorithm is presented in figure 7 and it is shown in figure 8.

The part is characterized by the reference surface (RS). The reference surface could be defined analytic or in discrete form. In RMF is important to find the contact points between the pins and the part, to could configure the tool. Some methods for this were developed in the Laboratory of Sheet Metal Forming from Dunarea de Jos University of Galati.

Virtually, using finite element method, the assembly, tools and blank, is configured using the coordinates of the contact points. After the forming operation, the forming reference surface (FRS) is obtained. The forming reference surface is characterized by the forming reference mesh (FRM). After the tools are removed, the part will springback resulting the springback mesh (SM0). The difference between the (FRM) and the (SM0) represents the value of spring back (VSB). If (VSB) is less or equal with an acceptable tolerance then the process of springback is finished. If not, using (VSB) the (FRS) is changed in the direction opposite to the spring back deformation.

The reference surface is modified obtaining the reference surface at the increment i (FRSI). The contact points are recalculated for this new (FRSI). The tool is modelled for increment i and the simulation is resumed. After the tools are removed, the part will spring back resulting the spring back mesh at the increment i (SMI).

The difference between the (FRM) and the (SMI) represents the value of spring back at the increment i (VSBI). If (VSBI) is less or equal with an acceptable
tolerance then the process of spring back is finished. If not, the process is resumed for the next increment.

The observation is that the (FRM) is affected by the dimpling phenomenon. That is why when considering the spring back an algorithm for surface reconstruction must be developed.

5 Results of Applying the Reconfigurability Model

The value of spring back becomes 1.081 after the first forming operation, 0.547 after the first die reconfigurability (first stage of deformation) and 0.214 after the second die reconfigurability (second stage of deformation). The simulation were made considering a part radius of 95 mm and a material thickness of 1 mm. As this value is less than one considered as acceptable tolerance of 0.25, it was concluded that the process of reconfigurability was finished. These values are measured in the parts corners as it is shown in figure 9 where the spring back has the maximum values.

Fig. 7. Algorithm for spring back compensation in RMPF

Fig. 8. Application of DA method

Fig. 9. Simulation results for spring back compensation

4 Conclusion

Using the simulation it could be studied both the effect the dimpling and spring back in the RMPF process.

The simulations showed that between the part radius, pins radius and material thickness a dependence relation exists. This must be developed in the future.

The dimpling phenomenon affects the material behaviour and as the result the size of spring back respectively of spring forward.

The method proposed for spring back compensation has the advantage of being applicable to any RMPF process.

The main disadvantage of the method is that is a time consuming procedure and in this case assume the development of some programs for surface reconstruction.

The implementation of the method implies the existence of an adequate informational system and also a robust control system of pins positions for developing a sound product with desired geometry.

Acknowledgement

The authors gratefully acknowledge the financial support of the Romanian Ministry of Education and Research through grant PN_II_ID_1761/2008
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