Substitutive models of press deflections for efficient numerical die cambering

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Abstract. Cost and time for stamping die tryouts are significant within the car industry. A major contributing factor is that elastic deflections of stamping dies and presses are usually not considered during the virtual die design and forming simulation phase. Active surfaces of stamping dies are only cambered based on previous experiences of tool types and stamping presses. However, almost all stamping dies and presses are unique, and available experiences are not valid for new sheet materials. This leads to component deviations and often several loops of tool adjustments are needed. Previously partners within the SMART Advanced Manufacturing research project CAMBER have developed advanced deflection measuring devices to quantify the elastic deformations of stamping presses. Using these measurements, cambering methodologies can be utilized in sheet metal forming simulations. In this paper numerical substitutive stamping press models are described which are capable of compensating for measured stamping press dynamics. The result show that a numerical compensated tool can improve the contact by over 80% compared to the corresponding contact without compensation.

1. Introduction

Cost and time for stamping die tryout are significant within the car industry, and elastic deflections of stamping dies and presses are most commonly not considered during the virtual die design and forming simulation phase. Because of this, stamping dies are only cambered based on previous experiences of tool types and stamping presses. However, almost all stamping dies and presses are unique, and available experiences are not valid for new sheet materials. This creates extensive problems when a toolmaker has optimised a tool through a spotting process. The toolmaker's stamping press has unique press dynamics and consequently problems arise when the tool is moved to a production unit with stamping presses with completely different characteristics. This means that a new adjustment process must conducted and sometimes with delays of several weeks. The same problem could also arise when tools need to be shifted between different lines within a production unit.

Several efforts have been carried out in order to reduce the number of try-out loops and time of the spotting processes. Numerical method for automatic contact pressure detection based on the blue pattern have been developed [1]. The objective is automation of the stamping die spotting process and stamping optimising contact patterns for the forming surfaces. Research efforts have also been aimed at developing measurement technology to detect stamping press deflections, both portable solutions and imbedded sensors in the presses [7]. The deflection strain has been measured by optical fibers with Fiber Bragg Gratings (FBG). Research have also been focusing on cambering strategies and methods. Important breakthroughs in recent years enabling the cambering methodology consists of efficient simulation strategies for full scale simulations with elastic stamping dies [2-4]. The different simulation methods have in common that they, apart from blank and elastic die, need to include numerical representations of the elastic stamping press structure, e.g. [5-6]. The disadvantage is that they can be very computationally expensive when large sections of the stamping press are modeled. They are also often based on CAD data, which can create an idealized representation of reality. Consequently, the objective of this research work has been to generate a substitutive stamping press model which is computationally efficient and that the substitutive model can be calibrated with measurement data from real stamping presses.

2. Method

The activities to achieve numerical stamping die cambering is outlined below. Purpose of the implemented die compensation algorithm has up to now mainly been aimed at spring back compensation of sheet metal parts whereas here the objective is to reduces stamping die rework effort during try-out and ultimately to account for differences between try-out and production facilities.

2.1. Stamping press deflection measurements

Stamping press deflection measurements needs to be undertaken for the press at hand under loading conditions relevant to some generic forming situation in a sufficiently simplified manor. As described in [7] slender beams equipped with either fiber sensors, conventional strain sensors or linear displacement sensors can be used to obtain the deflections under well-defined loads measured by calibrated load cells.

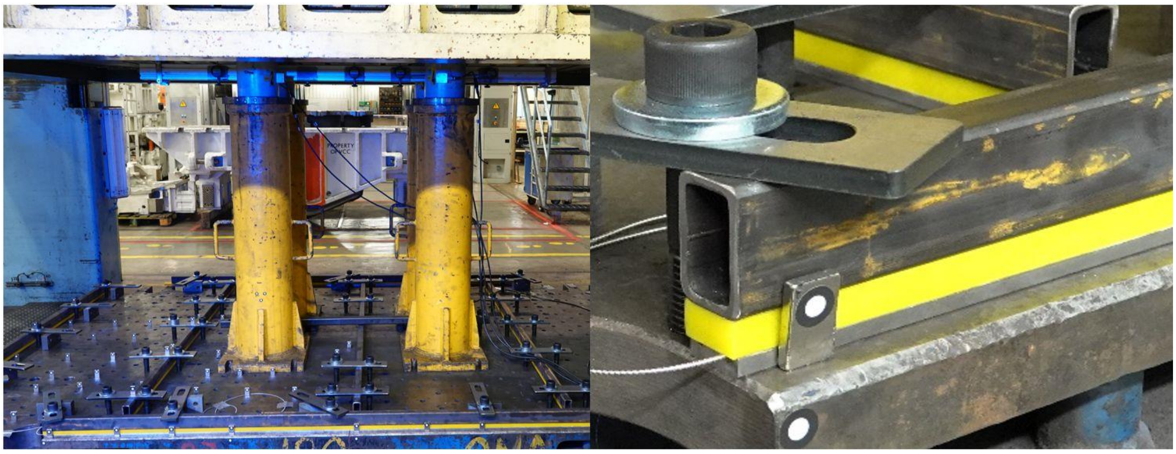

Figure 1. The figure to the left show sensor beams temporarily mounted on a stamping press table [7]. The figure to the right shows the details of a sensor beam mounted on the press table optical fibers with Fiber Bragg Gratings (FBG).

Rotational stiffness associated with tilt was measured according to DIN55189-1 and DIN55189-2. Additionally input for calibration of substitutive models measurement data from fiber sensors and dial gauges have been used.

2.2. Substitutive model

To take stamping press deformations into account in FE modelling of sheet metal forming processes the influence from the press needs to be modelled somehow. Modelling the entire stamping press structure based on e.g., CAD models is one way to do this but with the drawback of creating large models that requires significant computational resources.

Another way to go about this is to use substitutive models that focuses on modelling the major influencing contributions in a simplified manor as compared to using full models of the stamping press. This approach also has the benefit over using nominal CAD models that they can account for deviations in stamping press performance from age, damage, material, and manufacturing deviations from the intended and ideal situation as present in a simulation model based on CAD-data.

Here the substitutive stamping press model is intended to mimic the most important features in the press as seen from the tooling perspective, namely the ability of the press table and ram to bend, deform and tilt, all of which influence the tooling via contact interfaces. To account for this, both table and ram is made of shell elements of various thicknesses in a framework resembling actual press tables. To the left in Figure 2 this substitutive press model is shown where the press table with underlying shell element framework is visible for both press table and ram. Both ram and cushion can tilt, a function that is provided by additional sets of shell element supporting the ram and blank holder. The tilt itself comes from use of joints (*CONSTRAINED_JOINT_STIFFNESS_GENERALIZED in LS-Dyna) in the finite element model that enables angular deviation simultaneously in two directions. The amount of tilt is determined by a non-linear resisting moment as function of the rotation angle and at the same time the degree of freedom in the forming direction is unconstrained. Surfaces of shell elements that supports the tilt function is shown in Figure 2 as yellow surfaces. A complete tool set for process simulation using the substitutive press model is shown in the right part of Figure 2.

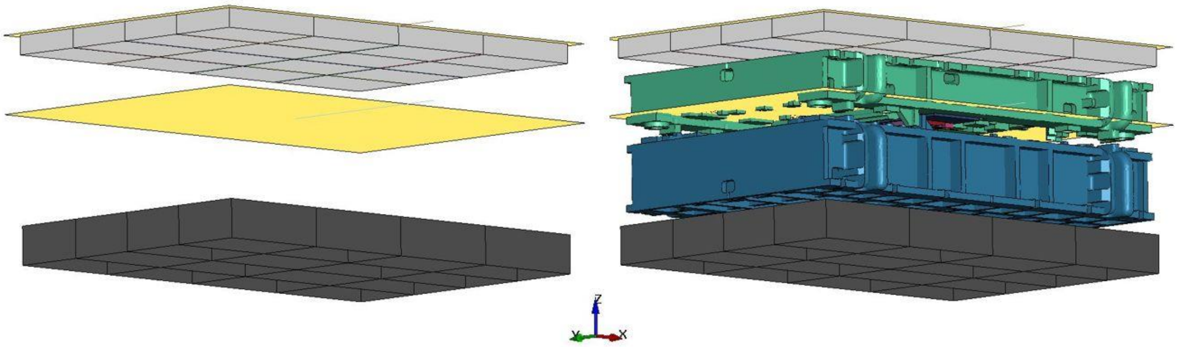

Figure 2. Substitutive press model (left) with ram (light grey), bolster (dark grey) and built in tilt function (yellow). Complete tool set model for process simulation using the substitutive press model (right).

2.3. Optimisation of stamping press table layout

Stamping press measurements can be accounted in a substitutive model by an optimization of the model with respect to e.g., the measured deflections that gives a response in the substitutive model which in a global sense resembles the physical press behavior in a FE simulation. It is then also possible to use process simulations with substitutive models to camber the forming tools to account for occurring deformations during forming in a certain stamping press.

Optimization of the substitutive model is done with the software LS-OPT using the measured deflection in the ram and bolster as described above. The response is evaluated with the composite function for curve matching implemented therein as responses in a D-Optimal sampling for a quadratic polynomial meta-model. The optimization objective is the minimization of the mean squared error of deflections with respect to the responses. An example of results from an optimisation based on stamping press measurements can be seen in Figure 3 where one iteration varying the associated design variables in terms of shell element thicknesses is shown. Each line in the diagram represents one design iteration and the data to match is represented by the crosses, hence it can be seen that among the selected designs there is an optimal solution for this design variable. It is obviously possible to also vary other influencing factors such as Young’s modulus to achieve a desired behaviour corresponding to measurements. In Figure 4 the optimized press table with underlying shell element framework is visible. Here the colour scale indicates the deformations in z-direction when the press table is subjected to the calibration load however the deformations are exaggerated.

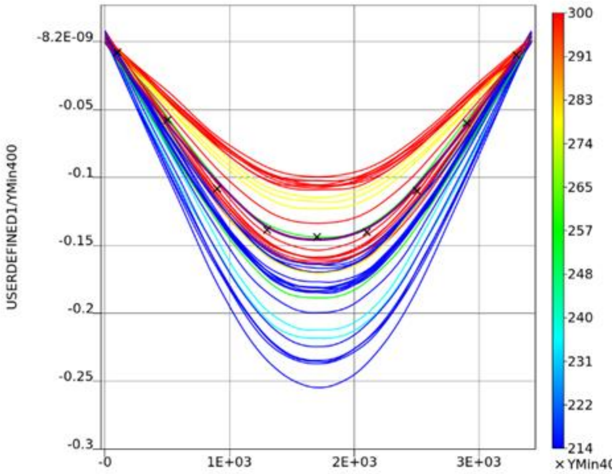

Figure 3. Output from one iteration of the optimisation of table stiffness. Cross symbols indicate response function from discretized press measurements, republished from [7].

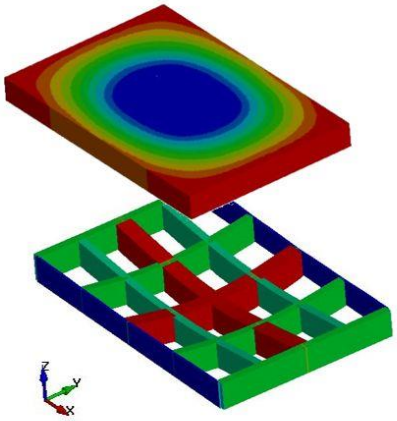

Figure 4. Exploded view of bolster with various thicknesses for the supporting framework. Deformations are exaggerated. Colour scale indicates the deformations in z-direction, republished from [7].

2.4. Stamping press tool modelling for stamping die cambering

The stamping press tooling needs to be modelled with enough detail to capture its fundamental deformation behaviour. A complex forming tool includes hundreds of components. To limit the time for simulation of the forming process it is necessary simplify press tooling taking main active features into account. At the same time, special care not to omit guiding pins and other features devised to control the tooling motions and that might influence the outcome in terms of contact surface deformations.

In this study a tool set to be used for forming of a physical part in the press characterised by press deflection measurements has been selected. One forming station in this tool is in focus, hence other stations in the tool has been omitted to being able to focus the computational resources on the major forming step which constitutes the challenge with stamping die spotting. In Figure 5 a cross section of the elastic tool model is displayed. To the left in Figure 5 the entire tools is seen together with the substitutive model of the press table the ram and the cushion for the blank holder and to the right a close up of the forming station is shown.

Tetrahedron elements are used to discretize the deformable tool body with a mesh resolution optimised for numerical speed rather than high resolution of local stresses. This means that small geometrical features not relevant to the major deformations can be meshed with low resolution.

The tooling interface with the substitutive press model corresponding to the press table and ram surfaces respectively is managed by means of numerical tied contacts. A simplified way of setting this up is to use tied contact of the tooling attachment to the substitutive press model. If more detail is required a regular contact definition between tool and press model can be used in combination with constrained nodal rigid bodies to model discrete clamping points between tool and press model.

The stamping die surface needs to have a resolution sufficient to shape the part geometry. That includes radii and other local features such as embossments. This causes mesh size gradients causing challenges in terms of mesh qualities for the deformable tool model. As long as deformations are small enough not to cause major element distortions these shortcomings are manageable.

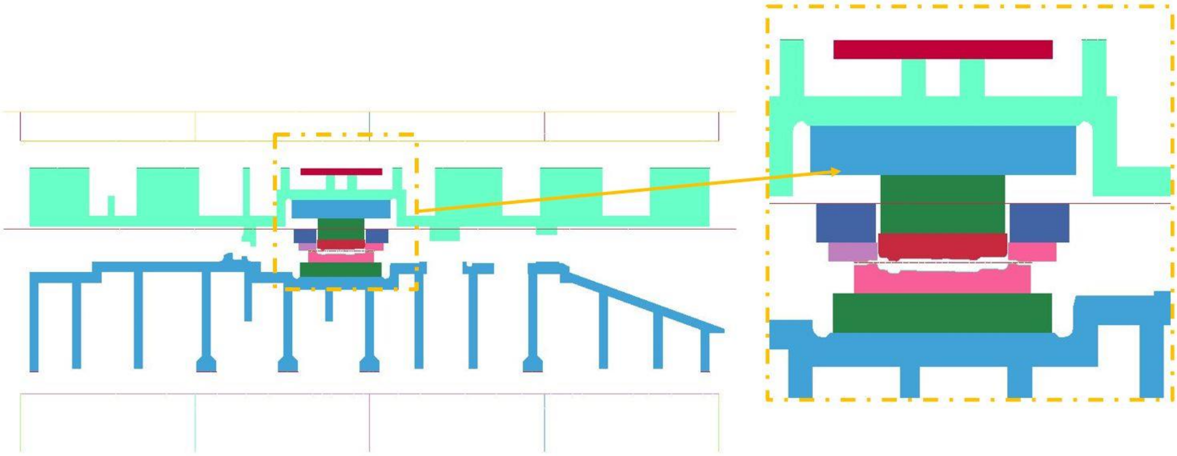

Figure 5. Cross section of elastic model of simplified tool set together with the substitutive press model with a close-up on the forming station at hand.

2.5. Numerical forming simulation of stamping press operation

The input for cambering stamping press tooling is a numerical simulation of the forming process at hand in combination with a substitutive press model based on press deflection measurements as described above that enables the capture of elastic deflections of stamping dies and presses. Forming simulation and corresponding elastic deformation in the tool and substitutive press model are integrated into one simulation eliminating the need for coupling of separate models. A benefit from using deformable tool surfaces also in the forming stage is that it enables the tooling surface to deform according to local thinning of the blank in the forming as well.

To keep simulation time reasonable the tool model needs to be simplified apart from the features most relevant for the deflection during forming operation. Simplifications needs to be undertaken without compromising the tool surface that is relevant for the geometry of the formed part. In addition to this the simulation is set up using mass scaling to enforce a larger explicit timestep than determined by the element size. The validity of this with respect to the dynamics is justified by review of the kinetic energy in relation to the total energy since the former is a minute fraction of the total energy.

The part being formed in this study is made of 1.4 mm thick DP600 material modelled by Barlat 3 parameter material model in combination with Belytschko-Tsay shell elements with five integration points through thickness. Mesh adaptivity is not invoked, the element size in the blank is sufficiently refined from the beginning. Automatic surface to surface contact between tool and blank with a Coulomb friction of 0.125 is used.

2.6. Compensation of tool and stamping press deflections

Spring back compensation of tool surfaces has been available in LS-Dyna for some time, recently under the keyword *INTERFACE_COMPENSATION_3D. The compensation algorithm was initially devised for compensation of spring back to reduce or eliminate tooling rework to achieve accurate part shape within tolerances after forming operations. The part shape deviations after forming are compensated by the algorithm by modifying the rigid tooling and it usually takes a few iterations to converge to deviations within a reasonable tolerance.

Here however we are dealing with elastically deformable three-dimensional elements in the tooling. Thus, it is necessary to associate the tooling surfaces with corresponding shell elements that can be used in the numerical compensation process. These shells, corresponding to the contact surface are used for the compensation by mirroring the coordinates of the deformed shape in the corresponding coordinates of the undeformed shell. This works as long as the surface deformations are small enough not to violate element quality of the underlying tooling element. A difference with respect to regular spring back compensation is the input for the cambering, here we are looking at the maximum deformation occurring during the entire punch stroke and not the shape after elastic unloading as with usual spring back compensation.

Various options are available for the execution of compensation e.g., accelerator to speed up convergence, mesh smoothing and refinement, and scale factors to determine the amount of compensation which can contribute to reduce the need for iterations.

Several configurations for the cambering have been tested. Performing one iteration only, but with a scale factor of 1.5 turned out to be a good choice in this particular study. This is associated to both the simulation time and manual labour associated with a restart using updated geometry for the tooling surface after running the compensation algorithm. In the first iteration for compensation of the deformations it is necessary to determine a proper zero point for the deformed press and tool model as a pure offset of the tool surface is not of interest for the cambering. Here only the tool surface is compensated, i.e., the bulk tool material is left in its original shape.

3. Results

A substitutive press model was generated and calibrated as described above and simulation of the forming process using this setup has been undertaken. From this simulation a spotting image was generated which can be seen in **Figure 6**. Here a comparison with a spotting image from a manufactured sample using this very tooling and press is also displayed. The spotting image from the numerical simulation is based on the interface pressures from the simulation by setting the range to a maximum of 0.5 MPa, corresponding to what is denoted as “very soft contact” in [1].

A fairly good correlation, albeit not perfect can be seen in this comparison. For the physical sample approximately 60% of the blank has no or insufficient contact with the tool. For the corresponding simulation, the area without contact is even higher, 70%. Two major differences can be noted. On one hand for the embossments in the part better contact is achieved in the physical sample which might be attributed to sensitivity of the numerical contact in these narrow regions of the geometry. On the other hand, the blank holder pressure appears to be different in the simulation than in the physical sample since poor contact is indicated in this spotting image in these regions. Anyhow the correspondence between simulation and experiment is determined sufficient to proceed with the compensation algorithm.

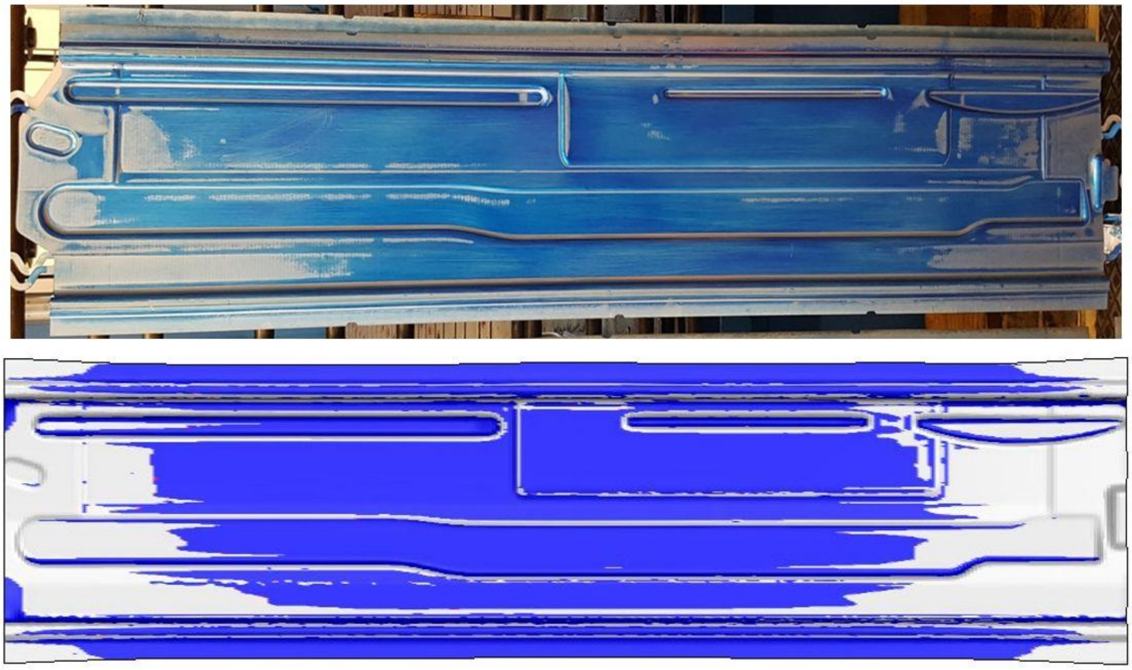

Figure 6. Spotting image of formed physical blank (top) regrettably the top picture is taken at an inclined angel with respect to the object. Corresponding numerical result (bottom) where colour range is set to 0.5 MPa corresponding to "very soft contact".

For the compensation, the deviations of the tooling surface from the original simulation are used as input, see Figure 7. By using the maximum deflections during the punch stroke in combination with the described compensation algorithm a cambered tool surface was generated and used for a subsequent simulation of the forming process to generate an updated spotting image as seen in Figure 8.

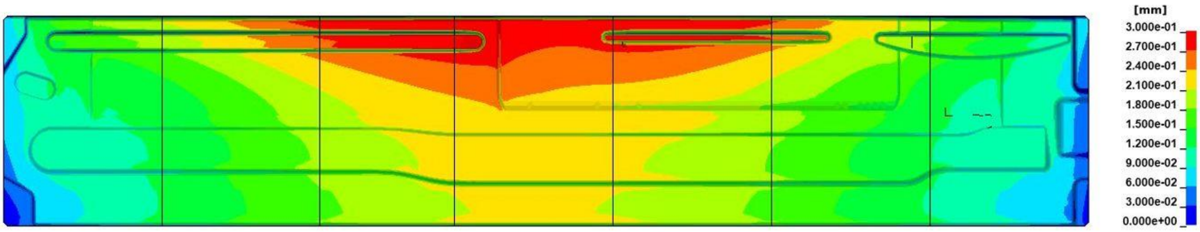

Figure 7. Maximum tool surface deflections in the forming process used for the cambering.

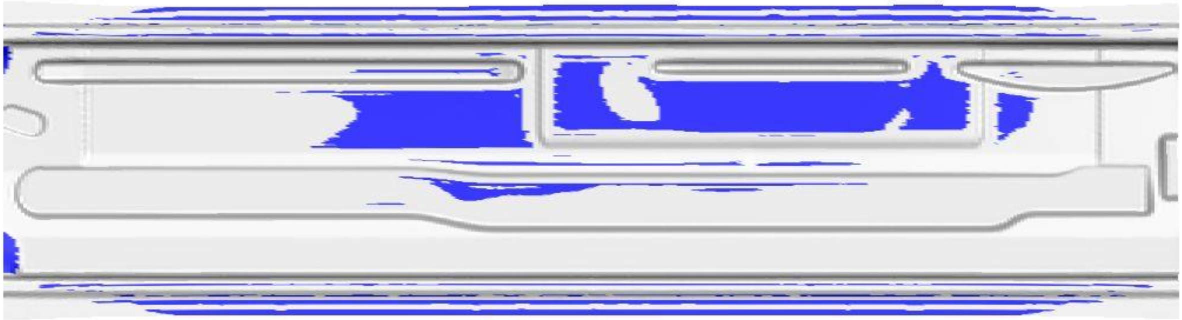

Figure 8. Spotting image after compensation of tool surface. Colour range is set to 0.5 MPa corresponding to “very soft contact”.

Instead of using several iterations a scale factor was applied for the compensation. After some attempts it was found that a scale factor of 1.5 was preferable in this specific case. The resulting spotting image of this setting is displayed in Figure 8 which can be compared with the photo on top in Figure 6. A significant improvement was achieved leaving minor part of the blank without full contact with the tool. The area of the part not in contact with the tool is reduced by 80% compared to the simulation before cambering of the tool surface and slightly more than 70% when compared to the physical sample top in Figure 6. However, during the subsequent forming simulation using the compensated tool surface it was observed that a slight loss of blank holding occurred causing an increase in draw in of the blank (3 mm). At the same time the punch force required to close the tool properly increased by 7%. Thus, process adjustments might have to accommodate the virtual cambering to yield an even better outcome. In the process of virtual cambering care must also be taken not to adversely affect the final part shape with respect to tolerance requirements.

4. Discussion and conclusions

The objective of this research work has been to generate a substitutive stamping press model which is computationally efficient that can be calibrated with measurement data from real stamping presses. The result show that the spring back compensation algorithm implemented in LS-Dyna can be used for adjusting tool surface to take stamping press and tool deformations into account to minimise the effort for rework of tool and stamping die during try-out for production. This however rests on thorough measurement of stamping press deformations and associated substitutive modelling to be used in the process simulation for the input to the compensation algorithm. At the same time virtual cambering has the benefit of reduce the amount of manual expertise judgement and possibly also the labour involved in try-out processes since 80% reduction of area of part not in full contact was achieved in this study. The described attempt to improve the spotting image by means of cambering the tool surface demonstrated the ability but was unfortunately not pursued until the spotting was perfect.

In this work the cambering was performed on the entire forming surface to come in contact with the blank. As described in [8] elastic tool deformations can be divided into local and global and significant effects on local deformations can be attributed to locally high pressures especially in forming situations where e.g., thickening effects come into play. This will set entirely different demands on the tool modelling in terms of discretisation, mesh quality and computational resources. The geometry in this case however is a quite shallow u-shape thus not a deep drawing process and hence can be expected to have a more limited effect from e.g., thickening on the stamping die radii. In cases when more local variations of compensation are desired, variants of compensation strategies for instance by using locally varying scale factors in the compensation can be worked out.

A scale factor was used for the compensation algorithm instead of several iterations as used in regular spring back compensation. This has the benefit of saving both computational and labor resources in updating and handling the consecutive simulations necessary when performing several iterations.

When the compensation algorithm is used to reduce spring back, convergence is fast and most often only a few iterations are required to reach tolerances. The reason behind the strategy to use scale factor is the fact that deviations for the cambering in general are smaller than in the case of spring back compensation. Compensation of small deviations has been seen to result in a kind of oscillation were results flip from one side to the other as a result of consecutive iterations, hence it was judged to be productive to start off with a scale factor that sets the compensation off sufficiently to give a clear effect.

A more difficult aspect to possibly consider is taking the dynamic loading into account such as not only using the maximum deflection throughout the stroke but also looking at different phases of the forming process to study if a compromise of different loading situations can by useful for cambering. In a real complex situation this might even involve some means of active cambering.

Here the punch was subjected to compensation whereas the die was left unchanged. This choice was based on the practice in the tooling workshop to perform adjustments on the punch only. But it could also be valuable to investigate variants of the strategy e.g., whether the punch, the die or both are preferable for the cambering once the physical try-out is significantly reduced by virtual cambering. Physical verification of this virtual cambering is also a desired result to complete this work.

Acknowledgement

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