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To cite this article: J Pilthammar *et al* 2023 *IOP Conf. Ser.: Mater. Sci. Eng.* **1284** 012055

IOP Conf. Series: Materials Science and Engineering 1284 (2023) 012055 doi:10.1088/1757-899X/1284/1/012055

Three Industrial Cases of Sheet Metal Forming Simulations with Elastic Dies

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Abstract. Previous research and experience points to many advantages if sheet metal forming is simulated with elastic dies. Some areas that are enabled by simulations with elastic dies are virtual spotting, improved digital twins, and improved production support. A promising method was selected from the literature, and after important modifications it is deemed to be fast and robust for simulating industrial sized dies. The method consists of meshing die solids with a coarse mesh to represent the structural behaviour of the die. The forming surfaces are then represented by a fine shell mesh connected to the solid mesh by tied contacts with an offset. With additional modifications to reduce solver time this yields a robust and flexible way of modelling sheet metal forming with elastic dies. There is an increase in preprocessing and simulation time compared to using rigid tools, but industrial dies can now be modeled within an hour and solved within a working day. It is also easy to update the model by replacing separate parts such as die solids or forming surfaces. One of the main criteria in favor of the selected approach is the realistic modeling of blankholder and cushion systems. In this paper simulations of three industrial cases are demonstrated: one case of virtual die spotting and two cases of production support. The three cases demonstrate the importance and potential of using elastic dies during virtual die tryout, production support, and for cases like digital twins and production control.

1. Introduction

Previous research and experience points to many advantages if sheet metal forming is simulated with elastic dies [1-8]. Some areas that are enabled by simulations with elastic dies are virtual spotting, improved digital twins, and improved production support. However, simulations with elastic dies have previously been very demanding and computational costly. In [9] an overview is presented of simulation methods incorporating elastic dies. This paper presents three industrial cases simulated by the recommended, and further developed, method in [9]. The method consists of meshing die solids with a coarse mesh to represent the structural behaviour of the die. The forming surfaces are represented by a fine shell mesh connected to the solid mesh by tied contacts with an offset. The surface mesh is present just to represent the geometry of the forming surfaces, it consists of a NULL material without any mechanical properties. Apart from the meshing strategy the density of the die solids is artificially reduced to minimize dynamic effects, and the distribution of the model across solver cores is controlled to minimize the solver time. All of this generates a flexible and robust simulation method and also enables a realistic representation of blankholders and hydraulic cushions.

The first case in this paper demonstrates a virtual tryout of a blankholder. In the second case, chapter 2.2, the importance of blankholder deformations is demonstrated. Effects are found that cannot be seen with rigid or constrained blankholder models. The same is true in the example in chapter 2.3 where hydraulic cushions start to tilt during forming operations. There are no other existing methods available to represent these dynamics which can have a profound impact on the forming operation process control and die development process.

Models throughout this paper are created in LS-PrePost V4.6.0 and solved with the explicit FE software LS-Dyna R11.1.0 [16]. Keywords and setup of models throughout this paper are referencing this software.

2. Three Case Studies: Applications of SMF with Elastic Dies

2.1. Case 1: Virtual try-out of a double-action blankholder

In this first case, the focus is on a double-action blankholder. Double action blankholders are notoriously known for large deformations. This is because the forces are applied by an outer ram, then transduced by a plate to a forming area that can be quite far from the ram.

2.1.1. Step 1: Simulation with rigid tools. This case shows an outer rear door manufactured in a double-action press. Symmetry is utilized in the model, two doors are manufactured in each stroke. Once the blankholder is closed displacement control is turned off, instead, a blankholder force of 1300kN is applied.

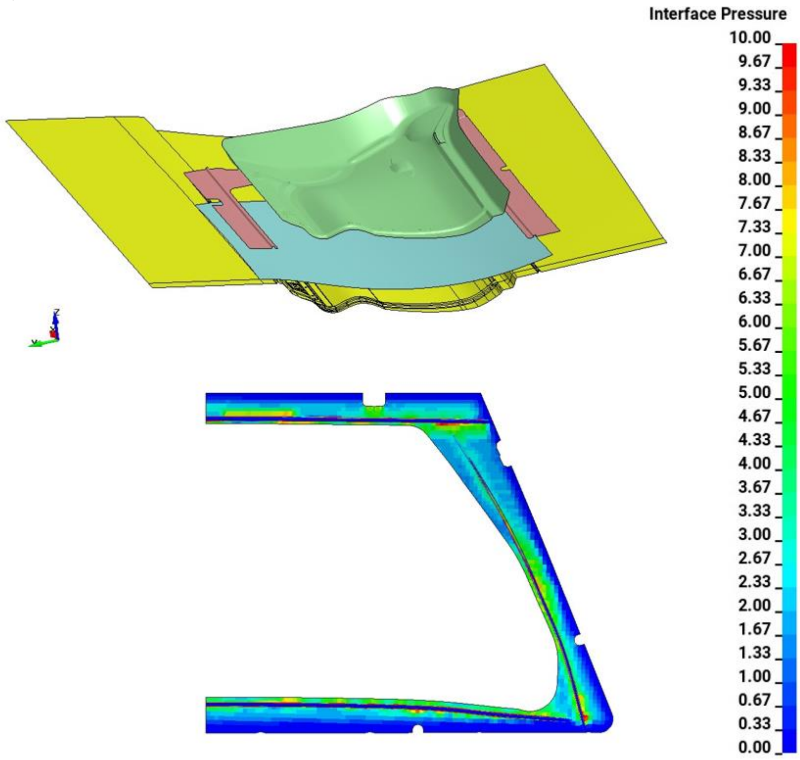

Figure 1. Blankholder pressure at blankholder closing

The initial step in the virtual die try-out is to run a standard simulation with rigid tools. The user then selects which point in time to use as a reference for the tool deformation. Here a point is selected just at the beginning of the stroke when the punch reaches the blank, this will give the tool deformation at a point that is called blankholder closing. The pressure at this point is what we later would like to achieve when the die is compensated. It can be discussed what point in time that should be chosen, currently this point was selected because the tool shop starts with blankholder spotting at this point of the stroke.

The simulation with rigid tools is a standard forming simulation in LS-Dyna. The blank material is a CR210BH simulated with *MAT_BARLAT_YLD2000. The blank has a thickness of 0.7mm. Tool velocity of the moving parts is 2000 mm/s, with a timestep for the mass scaled solution of 1.2e-6 seconds. Contact between sheet and tool is facilitated by *CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE. The initial element size of the sheet is 10mm, consisting of Belytschko-Tsay elements (mainly square 4-node elements, with some triangle elements). Adaptivity with three refinement levels is included in the model. The tools are meshed with a maximum elements size of 15mm, the minimum element size is 1mm, and a max deviation of 0.1mm.

2.1.2. Step 2: Deforming the blankholder and blankholder plate. The resulting pressure is converted to a pressure load, which is easily done by exporting results from LS-PrePost and changing the format in software such as Excel or MATLAB. A simulation is then conducted with just the NULL surfaces, the solid blankholder, the blankholder plate, and the ram which is held fixed. This gives a deformation that corresponds to the amount of compensation that is needed in the virtual die try-out. The blankholder is modeled as nodular iron with Young´s modulus of 173 GPa and a Poisson´s ratio of 0.25.

Presented simulations with elastic blankholder consist of the same shell meshes for the forming surfaces as previous. The outer ram in the double-action press is modeled as a rigid surface. The solid blankholder is meshed with tetrahedron elements in Catia V5 and transferred to LS-PrePost. The minimum element size is 10mm, with maximum element sizes of around 50mm. The maximum allowed deviation from geometric surfaces (sag in Catia), is set to 0.1mm. The blankholder is in contact with the ram and can separate except around the attachment slots where the blankholder is fastened to the ram, there groups of nodes on the blankholder are rigidly connected to the ram. The ram is driving the blankholder at 2000 mm/s.

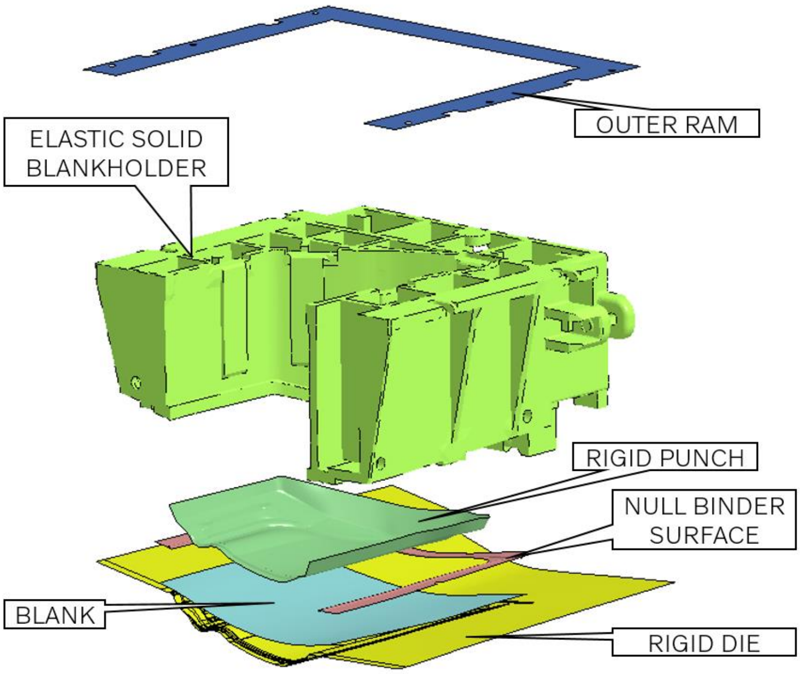

Figure 2. Exploded view of the model with elastic blankholder.

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2.1.3. Step 3: Compensating the blankholder surface. The resulting deformation in Step 2 is exported and used to compensate the NULL shell elements. Each node on the NULL surfaces is moved the calculated distance in Figure 3, in the opposite direction. The resulting pressure distribution at blankholder closing with uncompensated surfaces is visualized in the top part of Figure 4. Contact is lost in the middle of the blankholder when no compensation is made. Using the compensated forming surfaces, depicted in Figure 4, shows that pressure in the middle of the tool increases again. The distribution doesn´t fully return to the one in Figure 1, this can be due to several reasons as slight non-linearities in the model and other elastic and dynamic effects. More compensation loops can probably achieve a converging solution towards the pressure in Figure 1. However, the compensation has a significant impact on the blankholder pressure distribution. There is a large difference in pressure in the corners of the blankholder, areas where a lot of grinding traditionally is applied. It is estimated in the tool shop at Volvo Cars that this type of virtual try-out cuts the spotting time by at least 50%, sometimes much more.

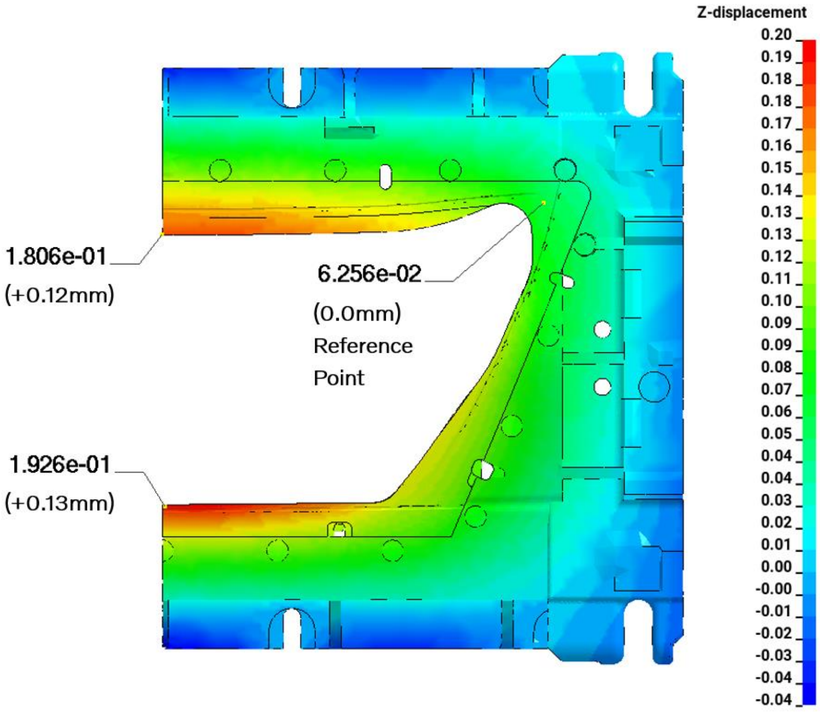

Figure 3. Simulated deformations

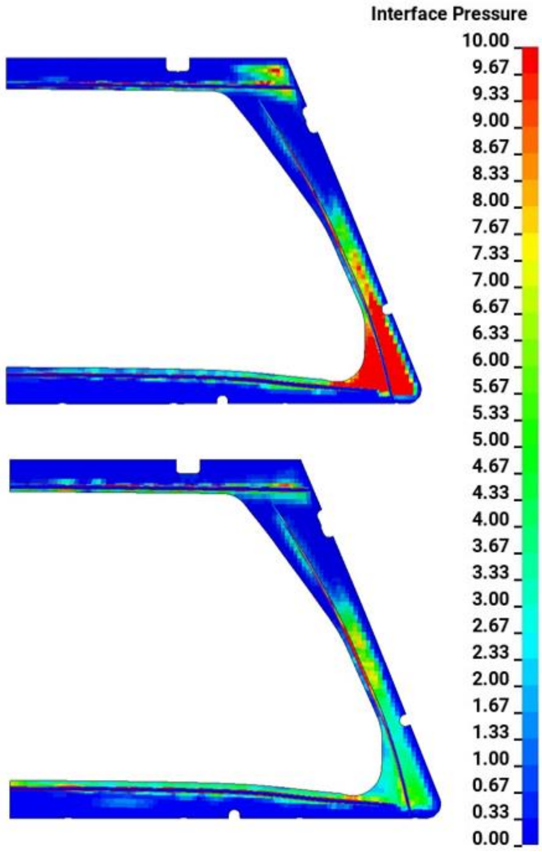

Figure 4. Pressures with elastic blankholder. Before and after compensation.

2.2. Case 2: Production support through simulations for a part non-responsive to changes in blankholder force

Issues were reported for an inner structural car part manufactured from 0.7mm thick CR4 steel. Different types of issues were present from time to time in the circled areas in Figure 5, wrinkles, cracks, etc. However, these issues shouldn´t be impossible to solve by adjusting the blankholder force. In this specific case, it was found that it was near impossible to get any response in these areas by adjusting the blankholder force. Standard SMF simulations predicted that an increased blankholder force would yield a relatively evenly distributed linear response: higher strains and less draw-in around the whole part. This was not observed in the real die.

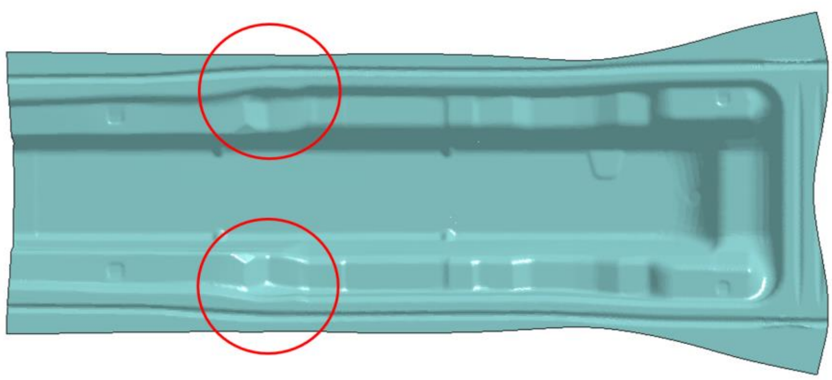

Figure 5. Areas with issues in the car part.

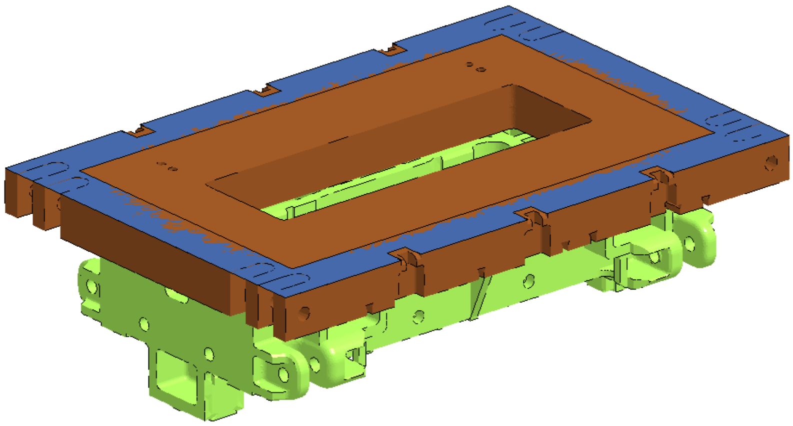

Figure 6. SMF model with elastic blankholder and blankholder plate.

For a deeper analysis of the problem, SMF simulations with elastic tool parts were utilized. A double-action die was used for producing this part, from experience it was known that the blankholder deformations can have quite a large impact on the produced part. The blankholder forces are bending the blankholder, thereby reducing contact pressure in the middle of the blankholder. Blankholder and blankholder plate were therefore modeled as elastic structures in these simulations. The setup of the model is the same as in the previous case 1, just different tool geometries and an added blankholder plate in steel (brown in Figure 6). Figure 7 depicts the difference in blankholder pressure distribution when an elastic blankholder is used in the simulation. Nominal force is simulated as well as a simulation where the force is increased by 20%. Increasing the blankholder force distorts the blankholder pressure by moving it outwards towards the short edges of the blank. In Figure 8, the difference in major strain between the two simulations with different force levels is visualized. On average the strains are increasing throughout the part. However, the simulation with an elastic blankholder shows a very minor influence on the problematic area. This confirms what was observed in the stamping plant, that it is almost impossible to influence this area of the part by adjusting blankholder force. This happens because a deforming blankholder increases the pressure at blank edges when the blankholder force is increased. It is also lowering the pressure in the middle of the blank. Right around the problematic area barely anything happens, this is a neutral area with neither increase nor decrease in the blankholder pressure. Shimming or adjusting the blankholder geometry is thereby the only options available to influence the part here. These options are both more time-consuming and expensive than just adjusting the blankholder force.

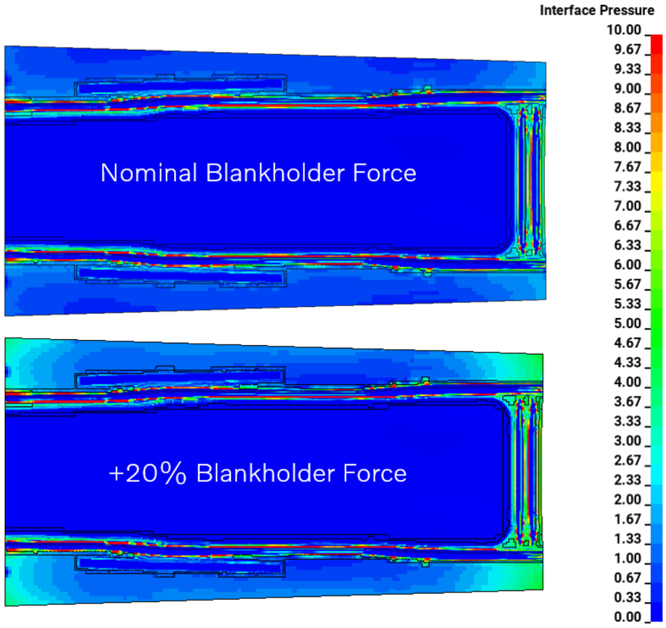

Figure 7. Predicted blankholder pressures with elastic blankholder and blankholder plate.

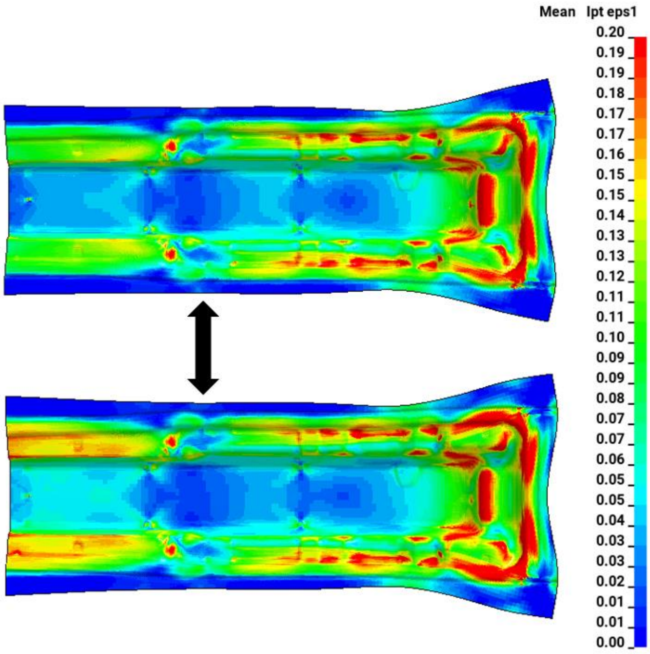

Figure 8. Differences in major strain between nominal and increased blankholder force.

2.3. Case 3: A single die in a dual cushion press

Single action press lines can have more than one hydraulic cushion in the forming press. Two cushions could be used for producing two parts in one press with one press stroke. By using two cushions the blankholder pressure can be controlled individually for the two parts. There is also the possibility to place a single larger die in the press. However, a die that isn´t large enough risks tilting the hydraulic cushions inwards towards the center of the press. This will severely distort the blankholder pressure and risk damaging the cushion guiding rails.

With the method selected and presented in this paper for SMF simulations with elastic dies, it is possible to simulate these kinds of cases. The different parts in the model will hold each other in place with this method, preventing rigid body motions when deformations are calculated. It is a major strength of this approach compared to others presented in the literature survey. The case here with two cushions and one die might not be very common in real life, but similar issues like finding an evenly distributed blankholder pressure are critical in any forming die. Asymmetric part shapes in SMF are very common causing challenges in die design and predicting cushion settings. These kinds of simulations can help set individual cushion cylinder pressures, optimize die design, optimum placement of the die on the press table, etc.

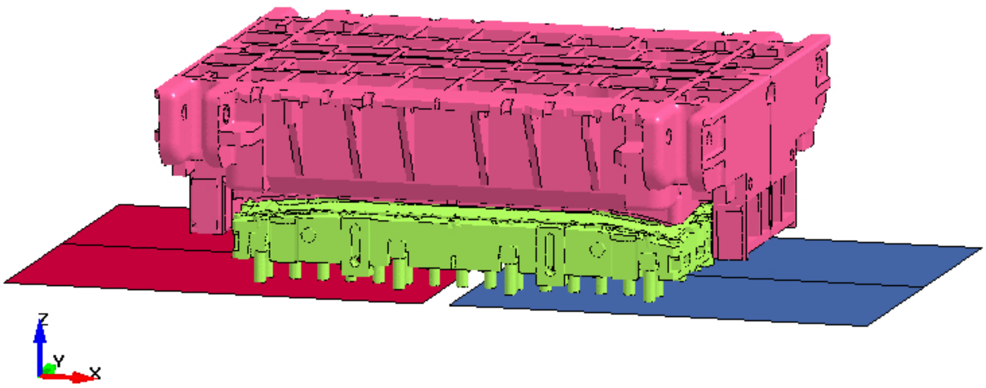

Figure 9. Simulation model of a single die in a press with two hydraulic cushions.

With the selected method for simulating SMF with elastic dies, it is possible to simulate e.g., the model presented in Figure 9. Here the tool parts are modeled as nodular iron. The ram is assumed to be rigid. The two cushions are modeled as two rigid surfaces, but they are free to move in the z-direction and rotate around the x- and y-axes. This is not possible with the method where two models are coupled, presented in chapter 2.4. With the method presented in chapter 2.4, it is possible to realistically simulate the deformations of matrix and punch because these parts are constrained in space in each coupling step. However, the boundary conditions needed for the cushion system make it impossible to realistically calculate the displacements and deformations of the blankholder and cushions. When the approach of coupled models is used the forming forces are extracted from an SMF model and then applied to a structural FE model to calculate and update the shape of the forming surfaces before forming continues. The cushions will in this case be loaded by a hydraulic force from underneath and by the contact pressure between the blank and blankholder from the top. There are no possibilities to realistically constrain this structure in space, both rigid body moments and rotations will cause the model to diverge and thereby making it impossible to solve. See the example of realistic boundary conditions in Figure 10. An example of how the pressure on the blank becomes distorted is seen in Figure 11, here a very slight tilting of the hydraulic cushions places all the cushion forces on the outermost row of blankholder pins, marked as red in the schematic Figure 10.

In conclusion, with coupled models, the blankholder needs to be artificially constrained. For example, by locking all the bottom nodes of the blankholder pins. This prevents both internal blankholder deformations and realistic cushion tilting. Using the method suggested in this paper realistic boundary conditions can be utilized, the blank with support of the matrix will hold the blankholder in a correct position.

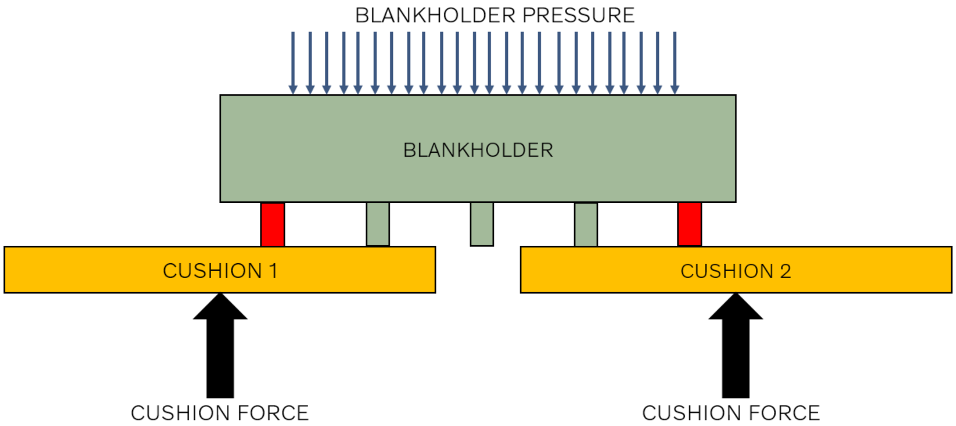

Figure 10. Blankholder and cushion system with realistic boundary conditions.

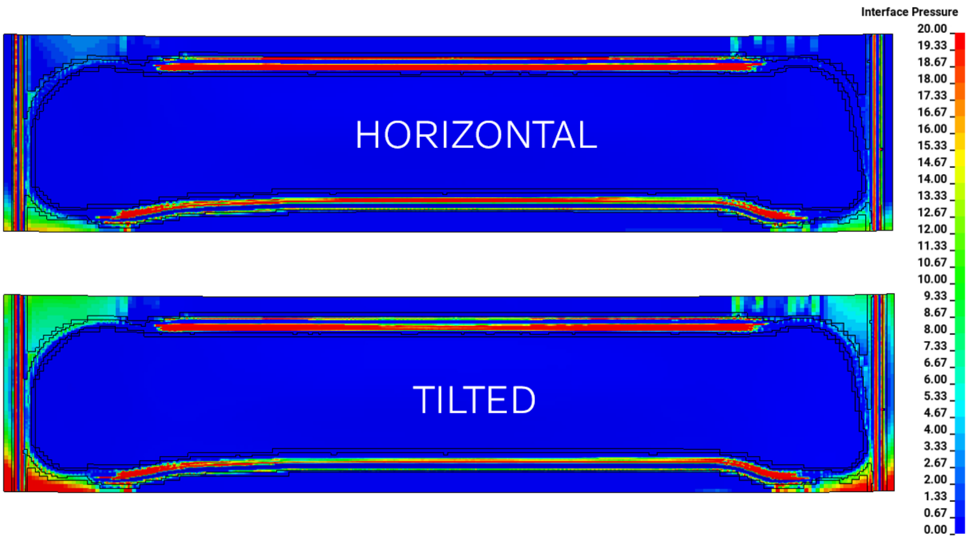

Figure 11. Distortion of blankholder pressure due to tilting of the two cushions.

3. Conclusion

A try-out was demonstrated for a double-action blankholder in chapter 2.1. The method is straightforward to set up and solve, and it yields reliable results. It is estimated in the tool shop at Volvo Cars that this type of virtual try-out cuts the spotting time by at least 50%, sometimes much more. Considering that hundreds of hours can be spent spotting each die this is a significant step forward. Some reflections on die spotting are that punch and die should be compensated at the bottom of the stroke since that is the position with maximum force and final geometry of the part. However, it will be important to gain practical experience for what position during the stroke that should be used for blankholder surface compensation. Here blankholder closing was used, other options could be considered such as blankholder closing or an average of the deformations during the stroke.

Apart from the die try-out the suggested method can be used for analyzing existing dies as in [10-12]. This has the potential to be very helpful during production support where scanned die surfaces can easily be included by the demonstrated method. The demonstrated cases of production support in chapters 2.2 and 2.3 of this paper demonstrate more benefits of being able to simulate sheet metal forming with elastic die parts and press dynamics. Apart from production support this will also be important creating digital twins for process analysis and control. Many of the behaviors seen in these simulations cannot be represented with rigid forming surfaces and will not be represented in these digital twins unless elastic dies are use.

Acknowledgements
This research received funding within the project "Reduced Lead Time through Advanced Die Structure Analysis" financed by the Swedish Innovation Agency Vinnova within the "Strategic Vehicle Research and Innovation (FFI) Programme". Grant number: 2016-03324.

This research received funding within the project "Advanced numerical solutions and experimental deflection measuring devices for an efficient stamping tool cambering (CAMBER)" financed by Vinnova within the SMART EUREKA Cluster program in Advanced Manufacturing. Grant number: Vinnova, 2018-03331.

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