FE FORMING MODELS INCLUDING PRESS BEHAVIOR ALLOW FOR REALISTIC COMPUTATION OF BLANKHOLDER FORCES

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ABSTRACT: Modeling the elastic and dynamic influences on the drawing part was and is a major research object in many finished and ongoing research projects conducted by the authors. As a result, new simulation models are available which allow for implementing the machine's properties into the process simulation of deep drawing and help to increase its prediction accuracy. A more precisely computed tool surface allows for resource efficient manufacturing since material use, machine hours, work force, and even the number of production tools due to higher potential drawing ratios can be reduced. In particular, properties, advantages and disadvantages of the simulation methods are discussed and the modeling procedures are specified. The potential of the advance forming process models was demonstrated for practical issues from the die spotting stage. Those include predictions of part-specific cylinder forces, virtual die spotting and adjusting the local lubrication on the tool's surface.

KEYWORDS: FE process simulation, press behavior, holistic simulation

1 Introduction

Although the costly, manual die spotting is conducted on try-out presses which are designed to imitate the production press as close as possible, the tool set still requires additional spotting time on the actual production press to attain sound part quality. This suggests a significant influence of the individual press behavior on the deep drawing process. Reusing the tool sets on different presses due to machine damage or spare part production entails extra die spotting time.

In order to reduce spotting time, simulation models are utilized to predict the drawing results and show critical geometries upfront. The simulation models used in industrial applications employ rigid shell elements to represent to tool geometry and ideal force and velocity boundary conditions, hence, the elasto-static and dynamic behavior of the tool and the machine are ignored.

2 FE deep drawing simulation

Despite the fact that the FE process simulation is a standard tool in the process and tool design process, relevant elasto-static and dynamic interactions between process, tooling and machine are neglected in commercially available simulation tools [1]. This leads to inaccurate predictions of the tool's contact geometry which results in expensive manual die spotting. Neglecting dynamic interactions prevents the correct prediction of optimal part-specific number of press strokes and leads to conservative machine settings.

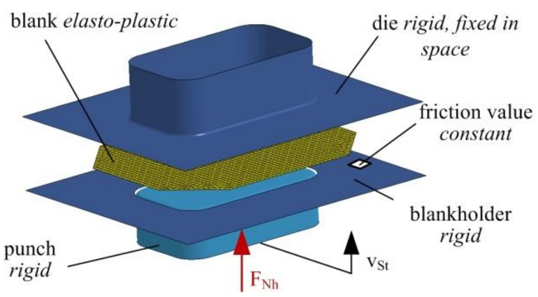

Fig. 1 Standard FE process model

3 Implementing machine properties into FE process simulations

Besides elasto-static machine properties the advanced FE process models allow for implementing dynamic machine properties and the machine's control systems. Depending on the required level of detail, the implementation of relevant machine properties into the FE process simulation can be done with different methods. The increasing level

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of detail significantly influences time and cost of modeling and computation.

3.1 Elasto-static machine properties

3.1.1 Model reduction

The model reduction is a simple method to implement relevant machine properties by means of non-linear discrete spring-damper elements and reduced FE element structure into FE process models. The principle stiffnesses of the machine can be modeled with spring-damper elements which can easily be parameterized based on standardized measurements of the machine's stiffness [2].

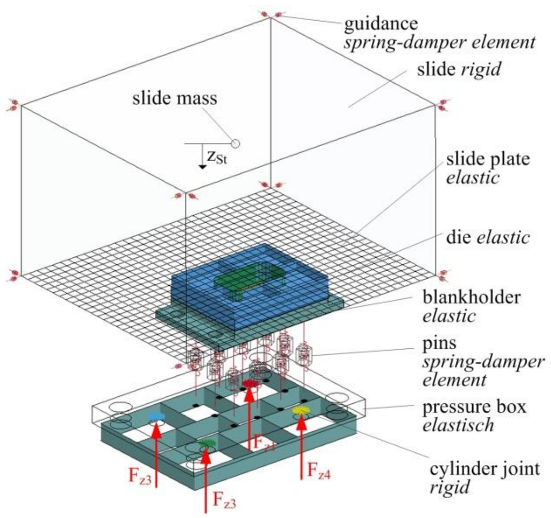

Fig. 2 *FE-process model with elasto-static machine properties*

The local and global elastic deformations of the die cushion's pressure box are a major influence on the distribution of the pin forces. Therefore, the pressure box was implemented as a 3D FE structure consisting of hexahedron and shell elements (see Fig. 2). Due to the very complex contact between sheet metal and tooling as a result of local sheet thickening and wrinkling, a good quality tool model must display global as well as local deformations.

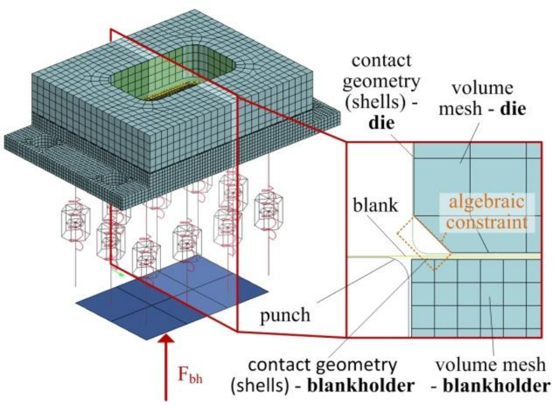

Fig. 3 *Hybrid mesh for reducing modeling and computation time*

The so-called hybrid method has proven as a very efficient method to model large scale FE structures with good accuracy regarding local deformations [3]. The tool body is meshed with large volume elements. A fine shell mesh on the tool model's surface guaranties an accurate representation of the tool's contact geometry. The two meshes are connected by means of TIED contacts, as shown in Fig. 3. The method significantly reduces time for both modeling and computation.

The tool guidance is an important connector between upper and lower tooling and the blankholder. Depending on the type, the tool guidance has a substantial influence on the tilting stiffness of the press [4]. The fact was confirmed for the experimental set-up by means of photogrammetric measurements [5]. Furthermore, the tool guidance defines the boundary conditions of the elastic blankholder model and has, therefore, a considerable impact on the pressure distribution on the blankholder surface. The models account for effects of the tool guidance by adjusting the tilting stiffness of the slide depending on the slide position and by linking the blankholder to the slide and press table with elastic joints. The process model was systematically advanced with all relevant elasto-static press properties. As a result the prediction accuracy of the model was considerably improved. Fig. 2 shows those advancements on the example of a demonstrator tooling by BMW mounted on a hydraulic press with 4-point cushion.

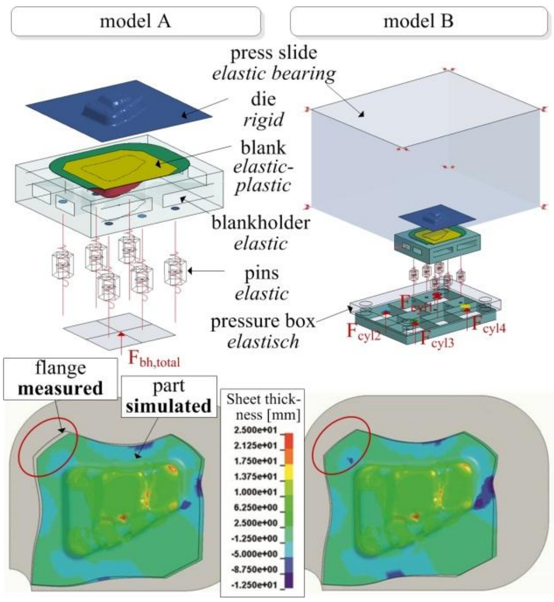

Fig. 4 *Verification of the simulation model on the example of the BMW demonstrator tooling*

Comparing the flange outlines of experiment and the computer models shows the best results for the process model including elastic die cushion properties and the tilting stiffness of the press slide (model B).

3.2 Dynamic properties in the process model

In addition to the elasto-static effects of the press, the following implementations allow for analyzing the effect of dynamic machine properties on the drawn part. By means of those models the drive systems (to the level of their controls systems) can be implemented and their interactions with the process can be investigated. In this paper the methods of model-code migration (MCM) and co-simulation (CS) are explained. The process models need to be modified in order to react sensitive to the dynamic boundary conditions based on the dynamic machine behavior.

3.2.1 Adjusting the process model

Computing dynamic machine effects in the process model requires the material model of the sheet and the contact formulation between tooling and sheet metal to by velocity dependent. Strain rate effects were accounted for using the material model by Cowper-Symonds [6] which scales the flow stress curve according to the forming velocity.

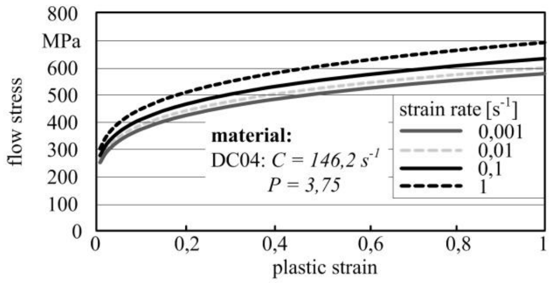

Fig. 5 *Strain rate dependent flow stress curve*

The contact definition between tool and sheet metal was upgraded according to Frontzek [7] by implementing velocity and normal pressure dependent friction values, as shown in Fig. 6.

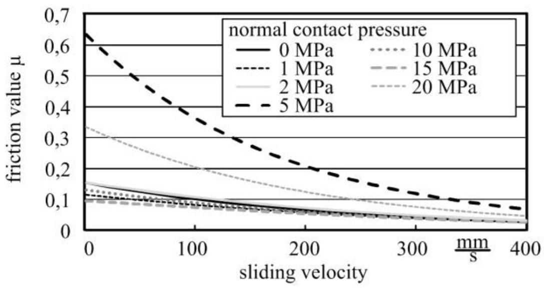

Fig. 6 *Velocity dependent friction values*

3.2.2 Model-Code-Migration

The Model-Code Migration offers the opportunity to implement model from other domains (here: system simulation) into the FE process simulation. (see Fig. 7). The machine is generated as a system simulation model; later it is reduced to the relevant components and tested against measurements. The final step is to transform the model code into a mathematic form which can by handled by the FE solver [8]. The advantage of this method is the computation of the entire model by one solver which leads to relatively short processing times and easy model handling when compared to the co-simulation which is introduced in the next chapter. The time step controller of the FE solver is optimized for the process simulation with a stable time step size calculation depending on characteristic element lengths. The lack of an additional time step control for the implemented machine model and its simplification lead to deviations in the computation of the machine behavior which is a major disadvantage. .

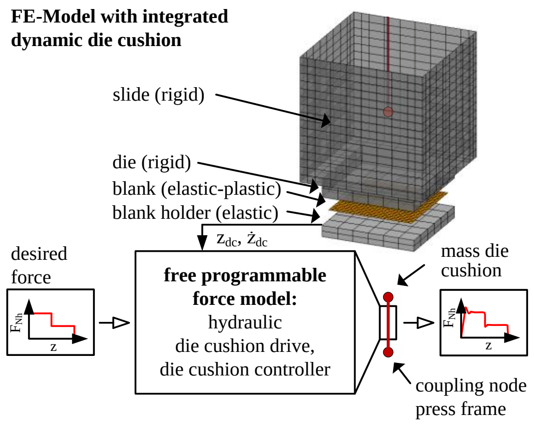

Fig. 7 *Scheme of model-code migration*

3.2.3 Application example

The MCM method was utilized for the analysis of the press stroke dependent quality of a rectangular cup. The model consists of the kinematics of a mechanical crank press and a hydraulic 1-point cushion structure. The die cushion model was exported from the system simulation as a difference model into the process simulation. A strain rate sensitive material model and a slide velocity dependent friction force allows for simulating the influence of the drawing velocity on the drawn part.

The impulse when the die establishes contact with the blankholder has a negative influence on the deep drawing part [9]. Additionally, sagging of blankholder force is observed for low slide velocities at the end of the drawing process [9]. In production there is a critical press stroke number which does not deliver sound quality parts. For simulating these effects, the die cushion drive and its control must be implemented in the FE process model. For the simple deep drawing geometry „rectangular cup“, the simulation shows an impact of the number of strokes on the sheet thickness distribution (Fig. 8).

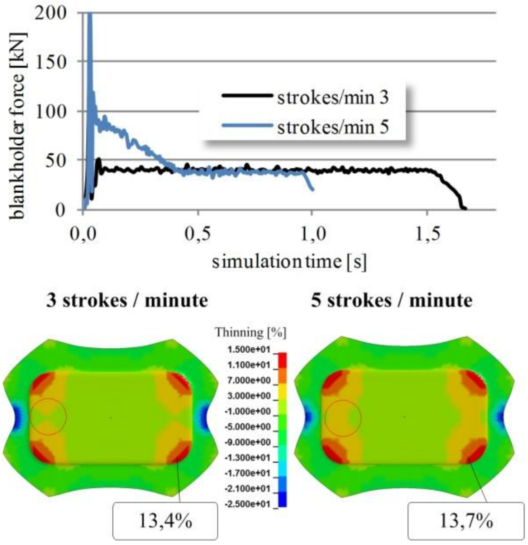

Fig. 8 *Press stroke dependent part quality*

3.2.4 Co Simulation

The highest possible level of detail, when computing the interactions between process and machine, can be achieved by means of coupling solvers. The models are processed with separate and specialized solvers and interact by exchanging forces and velocities, see Fig. 9. Thereby, the machine model is computed without any simplifications. Furthermore, the method offers the possibility to process both models with an optimal time step size, which increase the accuracy of the overall system model. This is a major advantage over the MCM method.

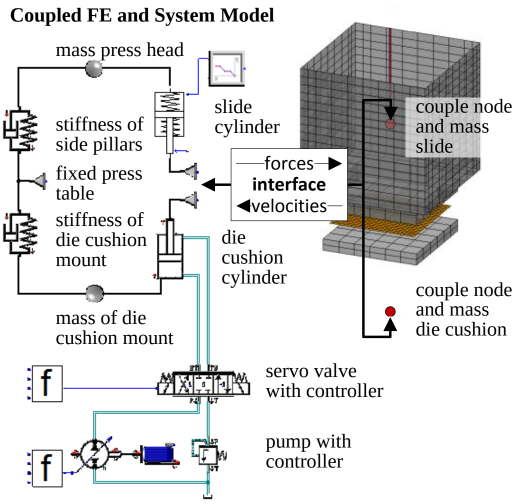

Fig. 9 *Scheme of co simulation*

There are two major challenges when using the method; first: achieving a stable overall system model since it tends to oscillations and second: to determine an appropriate coupling step size. In case of a too large coupling step size the computation is inaccurate; in case of a too small coupling step size the overall computation time increases disproportional.

3.2.5 Application of CS

The results of a computation with the CS method is displayed for the example of drawing a part with a cross die on a servo spindle press [10]. A uniaxial machine model which acts only in the vertical direction was used, which allows for applying a quarter model of the drawing process and a significant reduction of computation time. When comparing the sheet thickness distribution the coupled simulation shows less sheet thinning and a stronger tendency towards wrinkling than the quasi-static model, see Fig. 10. A fact which is caused by slightly fluctuating blankholder forces over the press stroke due to oscillation of the press slide and die cushion.

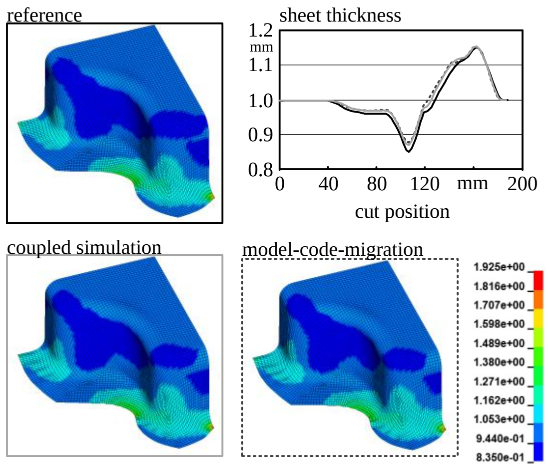

Fig. 10 *Blechausdünnung bei Simulation mit dynamischen Maschineneinflüssen*

Additionally the same deep drawing process was computed with the MCM method, which also shows less sheet thinning and a stronger wrinkling tendency than the quasi-static process simulation. By now, the authors cannot make a final conclusion regarding the general accuracy of both methods. The wide analysis with real parts is currently conducted.

4 Potential industrial applications

The potential of advanced forming process models was demonstrated for various applications during the tool ramp-up. Those are: evaluating a press switch, the prediction of part specific die cushion cylinder forces, virtual die spotting as well as local application of lubricants to manipulate material draw-in. In order to achieve a correct virtual die spotting a detailed model of the machine's and the tool's elasto-static behavior is necessary.

4.1 Switching machines

During the live cycle of a deep drawing tool of the automotive industry various machine switches (e.g. from tryout press to production press, to substitute press, to the post-serial manufacturer) might be necessary.

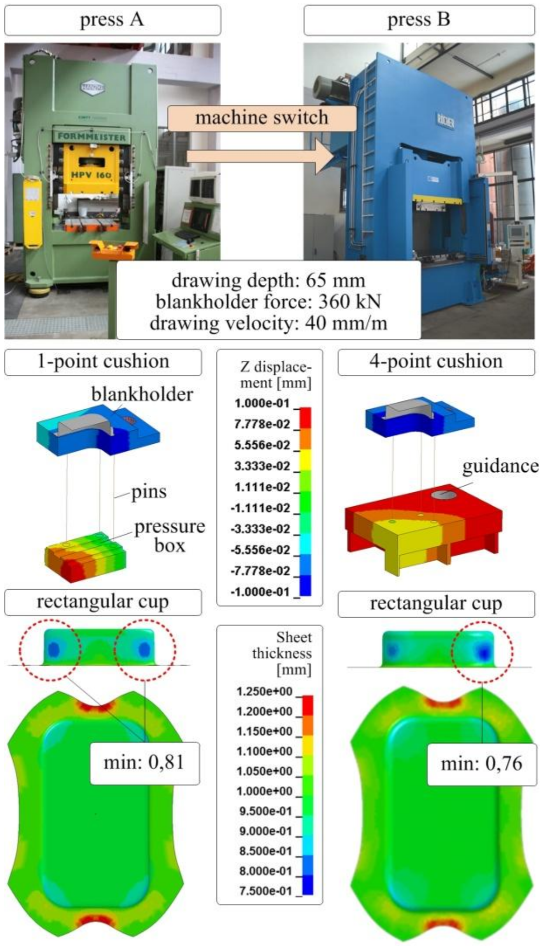

Fig. 11 Influence of machine properties on the quality of the drawn part

The individual properties of the presses affect the part quality. The scenario was demonstrated for the rectangular cup tooling mounted on two different hydraulic presses; one with a 1-point die cushion and the other with a 4-point die cushion (see Fig. 11). Due to dissimilar pin holes in the press tables, the tooling had to be eccentrically mounted in press B (a shift of 75 mm in Y direction). That leads to a tilting press slide and an asymmetric deformation of the die cushion pressure box and increases the normal pressure in the back area of the blankholder, see Fig. 12 top. A fact which causes larger maximum sheet thinning in the manufactured part when switch from machine A to B while working with the same machine settings (see Fig. 11).

4.2 Part specific cylinder forces

The most economic way to manipulate the material draw-in is to adjust the machine settings in particular the cylinder force of the die cushion. Due to the higher normal pressure in the back area of the blank due to the eccentric tool position in press B, the cylinder force F_{Z1} and F_{Z4} are reduced by 30 kN each. The measure leads to lower normal pressure in the critical area and the material flows easier into the die and causes less sheet thinning in the back corners of the part (see Fig. 12, bottom).

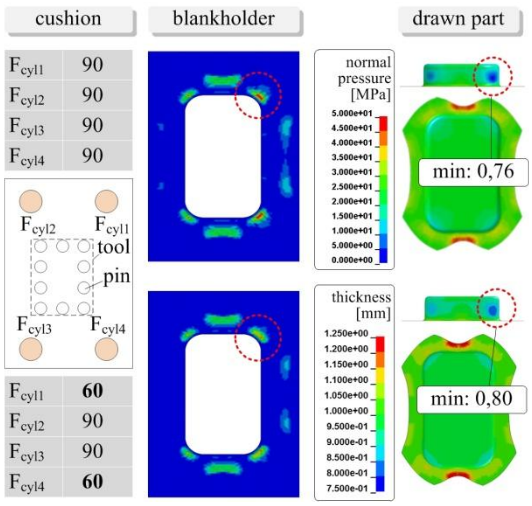

Fig. 12 Adjusting the cylinder forces in die cushion

4.3 Virtual die spotting

Another counter measure is to spot the die surfaces. The separate modeling of the die surface and the tool body allows for local changes of the tool surface mesh (including element number, size and node position) without affecting the volume mesh of the tool. The spotting of the tool surface was conducted by means of morphing tools in the FE pre-processor. The node positions are shifted according to the amount of removed material. Fig. 13 shows the virtual die spotting for the right back corner of the blankholder of the same rectangular cup tooling. By removing 100 µm material from the blankholder surface the normal pressure in this area was reduce which again leads to easier material draw-in and less sheet thinning.

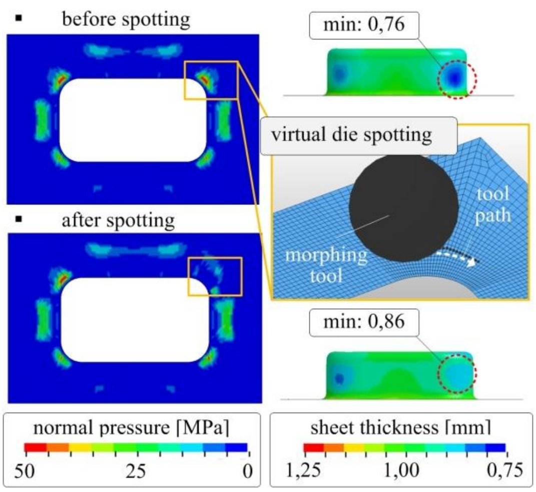

Fig. 13 Virtual die spotting by means of morphing tools in FE pre-processor

4.4 Local lubrication

The local application of lubrication is another way to impact the material draw flow during the deep drawing process. The friction value must be determined by expensive experiments and can then be locally applied in the model by means of contact segments. The reduction of the friction value in the corner areas of the blankholder reduces the material hold back while containing the same normal pressure. Again, the material flows easier into the die and the critical sheet thinning was reduced (Fig. 14).

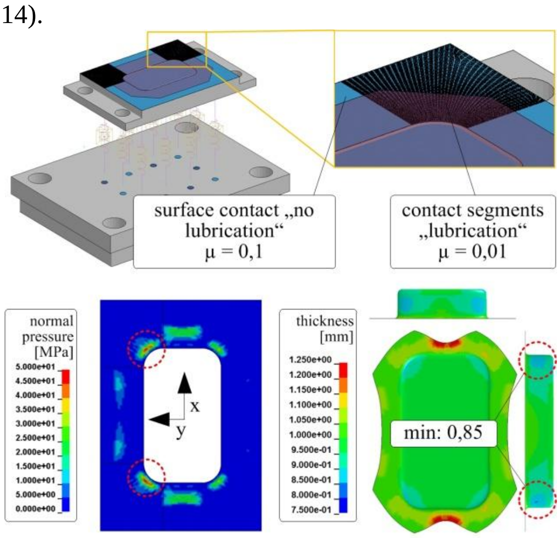

Fig. 14 *Local adjustment of lubrication*

5 CONCLUSIONS

The paper demonstrates the large potential of FE process models with elasto-static and dynamic machine properties. In the future, the advanced process simulations will allow for computing the optimal machine settings for a robust process with an optimal press utilization regarding energy efficiency and component wear at the same time.

6 ACKNOWLEDGEMENT

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