

INVESTIGATION OF IMPACTS ON THE REQUIRED PRESS FORCE

R. Struck^①, S. Kulp^①, B.-A. Behrens^② and R. Krimm^②

^① VOLKSWAGEN AG, Group Research
Berliner Ring 2, 38436 Wolfsburg, Germany
e-mail: robert.struck@volkswagen.de, web page: <http://www.volkswagen.de>

^② Institute of Metal Forming and Metal-Forming Machines
Leibniz Universität Hannover
An der Universität 2, 30823 Garbsen, Germany
e-mail: krimm@ifum.uni-hannover.de, web page: <http://www.ifum.uni-hannover.de>

Keywords: press force/ tonnage, tool/ press deformation, bottom dead centre

ABSTRACT. *A decisive criterion for the selection of the optimal press line within the press shop's layout plan is the required press force. The press force necessary to form the component is defined significantly by the stroke range and the corresponding bottom dead centre. The latter finalises the embossing process commonly used for reinforced structures on body components. The high forces required hereby strongly impact the deformation behaviour of the tool and the press and result in force requirements specific to individual presses. This paper examines the significant influences on the maximum force requirements. Examinations of the force requirements using parameter studies on bending, bulge test as well as embossing tests will be presented. The impact of the presses and tools rigidity was determined by way of extensive measurements performed on a mechanical and on a hydraulic press. The decisive criterion here is the bottom dead centre, which can be reproducibly determined using a simple and reliable measurement technique.*

1. INTRODUCTION

Increasing efficiency in the product development process is achieved by standardisation and the synchronisation of the development and planning processes as well as by shifting of workloads to the early phases of the product development process (frontloading). The objective is to allow the product to be influenced as early as possible with regard to production technology and economic aspects. Such influence is realised through digital factory techniques (e.g. simulation of production processes) and utilisation of experiences gained in previous projects.

Options for influencing individual body parts with regard to economic aspects and production technology – and thus options for reducing costs – are, for instance, increasing the material utilisation, elimination of process stages and the correct layout of suitable press lines. For example, assigning the optimal product spectrum to the press lines has a substantial impact on the line's productivity.

A decisive criterion for the selection of the optimal press line within the press shop layout plan is the press tonnage.

The continually increasing use of high- and higher-strength steels results in significantly higher required forces and demands a more precise calculation of the required press forces.

The previously used values are based on an embossing force calculation using CAD software [5], the determination of the maximum force in the forming simulation or a depth of experience with similar components. However, examinations have discovered substantial deviations between the calculated and the real values, which are based on insufficient criteria for bottom dead centre, on the use of shell elements during the embossing phase as well as on the fact that tool- and press-specific characteristics were not given consideration. These deviations can lead to substantial costs for changes/replanning where force requirements are underestimated and to high collateral costs where force requirements are overestimated.

To increase precision, it is therefore necessary to perform extensive examinations of the relevant factors influencing the required press forces.

2. MATERIALS

For the examinations, only steels were used, although these were of varying strength classification. Steel grades used include DX53D+Z, HX260LAD+Z, HX340LAD+Z, HXT600T+Z, HXT700D+Z, HXT1000D+Z as well as manganese steels. The examinations focused on a side member of grade H260 2 millimetres thick as well as on a roof frame reinforcement made of TRIP700 at a material thickness of 1.2 millimetres. The materials' characteristics were recorded accordingly for use in the forming simulation.

3. EXPERIMENTAL PROCEDURE

The press force required for optimal press allocation cannot be correctly calculated by current forming simulations due to the restrictions inherent in model creation. On principle, the required forces should always be defined as the press force, tool force and stamping force as depicted in Figure 1.

Here, the stamping force is that force which current forming simulations are able to calculate without considering flexible boundary conditions and which comprises bending, friction and ideal forming force. The accuracy of the simulation was examined in extensive laboratory tests in order to decouple the individual force proportions from one another.

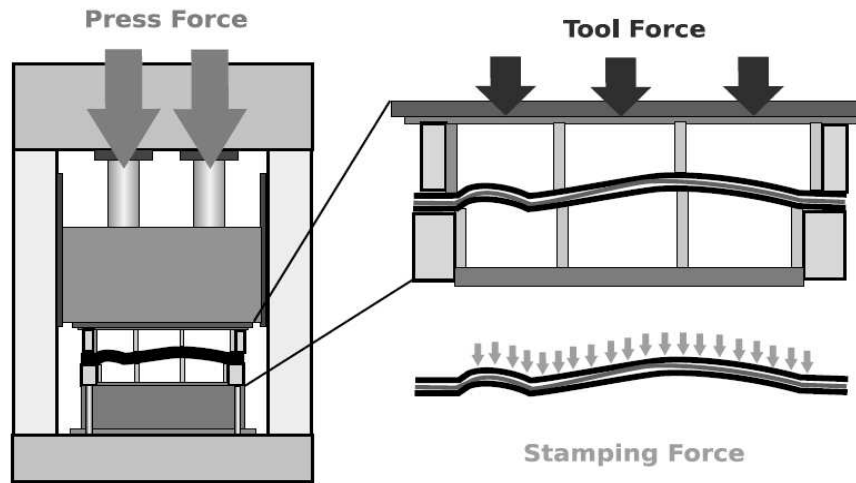


Figure 1. Definition of required forces to form stamping parts [9]

The tool force results from the elastic deformation work as well as the friction influences generated by the guidances and the draw-bead opening forces and can be determined using a force measuring clamping plate – consisting of two steel plates connected with load cells to each other. The tool influence was examined by setting up two tools with identical active surfaces but different base designs which facilitated the determination of the influence of the tool's rigidity on the force required and an assessment of the necessity to incorporate this factor in the forming simulation.

The press force also includes friction forces generated within the ram guides and additional deformation work particularly in the interaction between the ram and bolster plate rigidity. On mechanical presses, the press force can, for example, be determined through pressure measurements at the overload protection [3]. To determine the press's influence on the necessary press force, two presses were examined and force measurements were performed using identical tools.

In the following, Section 3.1 presents examinations of the factors influencing the required stamping force. Section 3.2 details examinations regarding the influence of tool and press deformation on the force requirements. Decisive in this respect is the precise and reproducible determination of bottom dead centre. A criterion suitable for this is described in Section 3.3.

3.1. STAMPING FORCE

The force required for the forming of a component – the overall total forming force F_T – consists partially of the bending force F_B , ideal forming force F_I and friction force F_F .

$$F_T = F_B + F_I + F_F \quad (1)$$

The bending force was determined by performing tests using a top-hat profile. With this type of die bending with blank holder, the process itself eliminates stretch-forming parts of the total force while the use of drawing film, drawing grease and displaced blank holder substantially reduces friction parts of the force. The die radius is 10 mm. In total, five different materials were tested at two material thicknesses of 1.2 and 2.0 mm. Figure 2 shows the influence of the material type on the bending force. The forces were measured at the die, the punch and the binder. All results are used for validation of the forming simulation and therefore were digitalised in addition to the material flow in the flange and the reduction of material thickness.

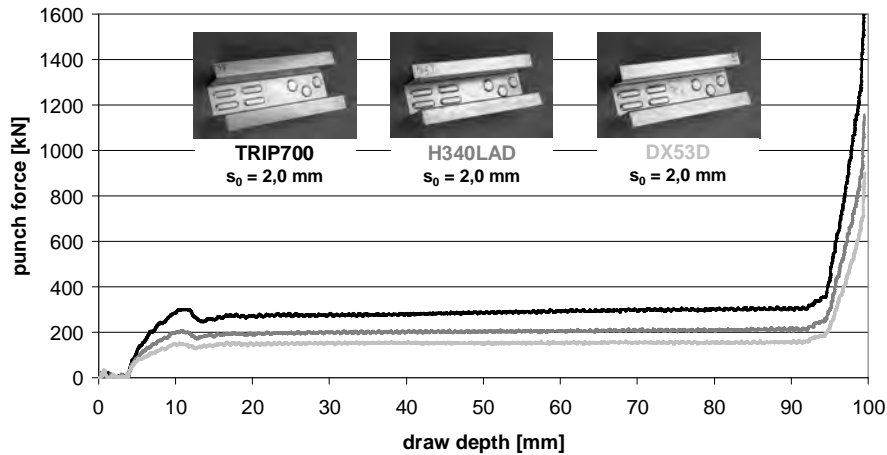


Figure 2. Comparison of the bending force of top-hat profile experiments

The ideal forming force was determined by conducting tests using hydraulic bulging at 200 mm diameter, which eliminates the friction parts of the total force and also facilitated as low a bending part of the total force as possible. Three different materials at two different material thicknesses were examined. To allow a comparison with the simulation, the forming degree was recorded via a matrix grid in addition to the forming depth. For the further comparison, flow curves were extrapolated using the collected data [2]. In addition, material thickness, geometry and main forming degree were incorporated in the investigation. Figure 3 shows the modification of the pressure compared to the draw depth for three different materials.

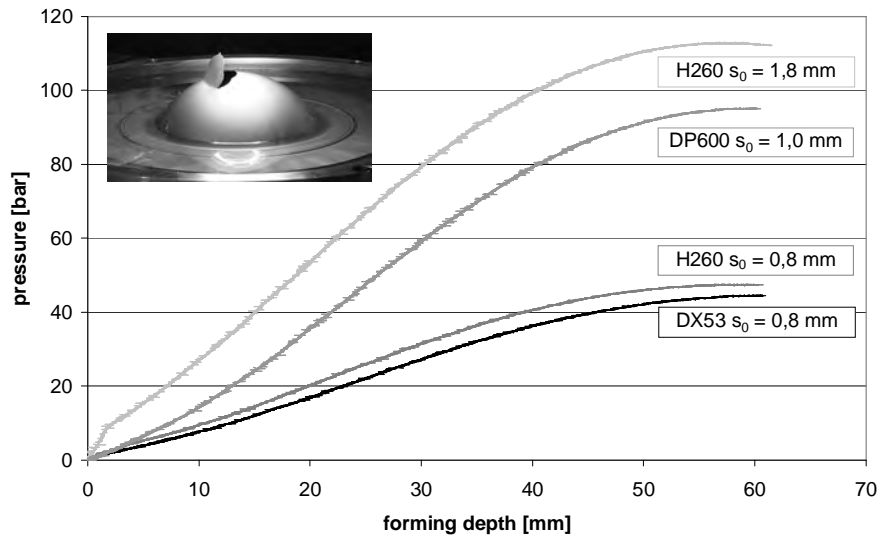


Figure 3. Comparison of bulge test experiments

The part of the process with the highest force-travel-gradient and force requirement is the embossing of the reinforcements. A multitude of tests were conducted for embossing using various numbers and shapes of reinforcements. Here also, five different materials at two material thicknesses were used. Figure 4 shows that the friction has a negligible influence on the required forces for the embossing of reinforcements. These experiments are also a basis for a specific validation of the forming simulation.

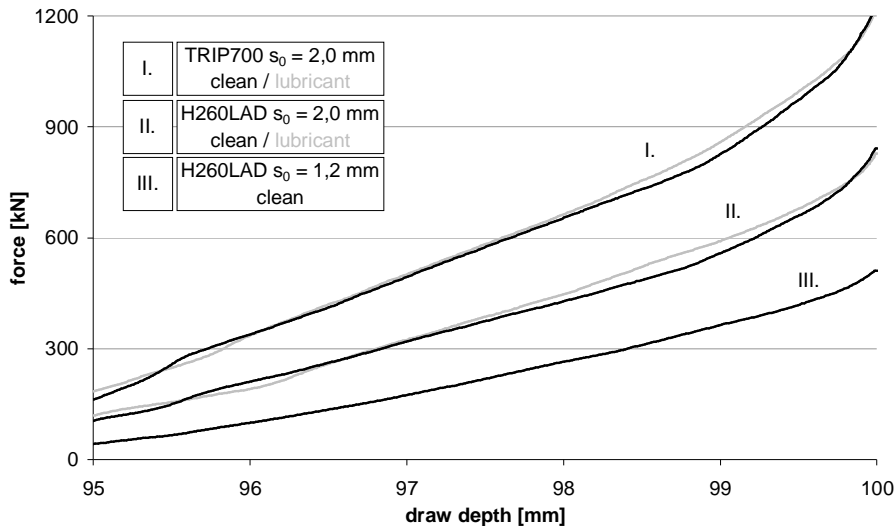


Figure 4. Force curves for embossing varying friction, material and sheet thickness

However, precise knowledge of the forming forces is not sufficient for the assignment planning of the press shop. Therefore, examinations of the force requirements specific to both the tool and the press were also necessary.

3.2. TOOL AND PRESS DEFORMATION

The impact of the tool and the press on the force requirement was examined through the extensive investigation of two presses. During the first stage, the tilting and resulting tilting resistance and displacement of the ram were measured according to DIN 55189 [7]. During the second stage, the deflection of the bolster plate and the ram were determined. This was done using central loading at 50% of the presses nominal force and using 20% off-centre loading at 30% of the presses nominal force. The deflections were recorded using incremental measuring sensors at 30 points on the bolster plate and 18 points on the ram (Figure 5).

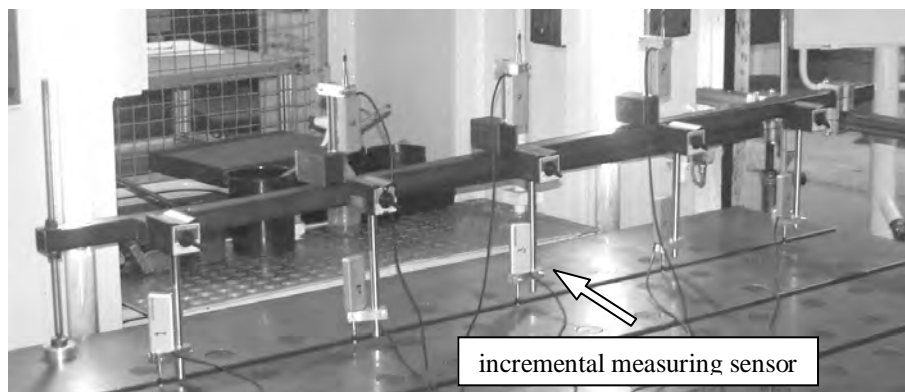


Figure 5 Measuring setup for bolster plate and ram deflection

During the third stage, the bending properties of the bolster plate with the tool mounted was measured. Here, the drawing operation of a side member was used. To measure the deformation under the tool, eddy-current sensors were used, which were mounted on a bar inserted into a T-slot of the bolster plate. A force measuring clamping plate with 36 load cells was used to measure the force between the ram and the die while the tool was mounted.

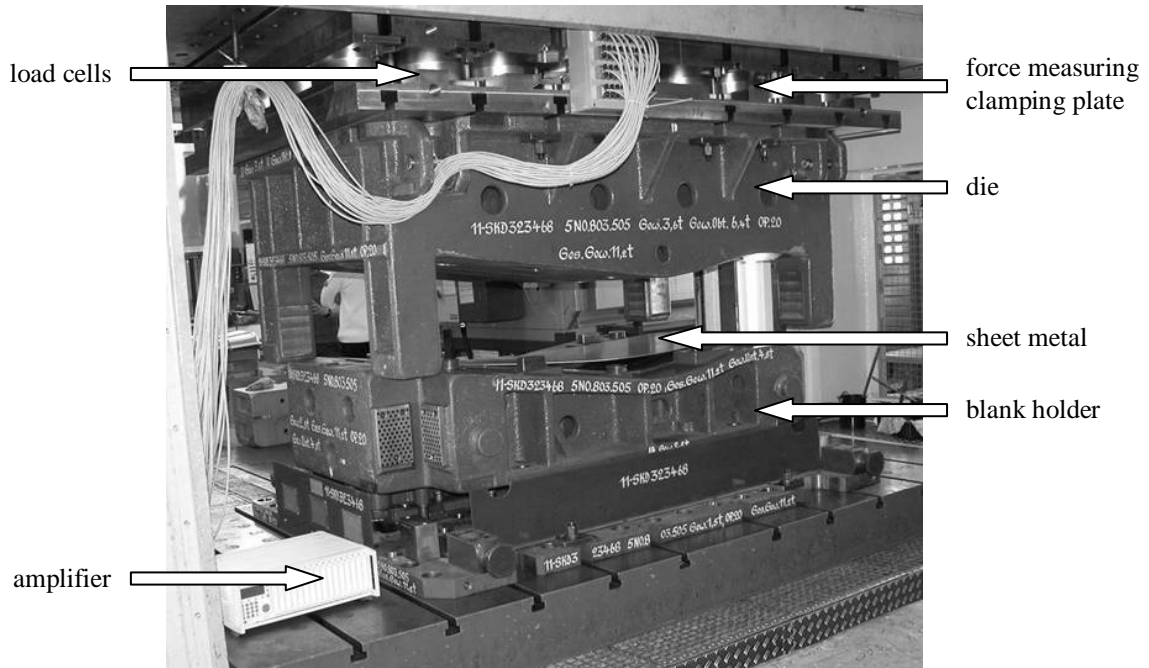


Figure 6 Installed force measuring clamping plate with side member tool

The measurements according to DIN 55189 showed a clearly asymmetrical displacement behaviour of the ram resulting from not optimally aligned ram guidances. However, this allowed the examination of the impact of a misaligned guidances as well as of the tilting resistance on the force requirements. The qualitative examination here showed that the tool performs significant guide work, thereby neutralising shift.

During the bending measurements with a load unit, a central load resulted in a maximum bending of $557 \mu\text{m}$ and an off-centre load resulted in a maximum bending of $301 \mu\text{m}$ (Figure 7). The ram's maximum bend was $10 \mu\text{m}$.

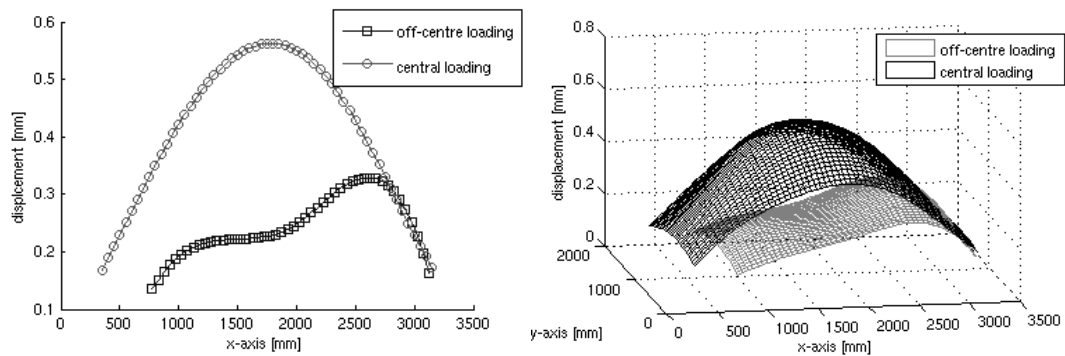


Figure 7 bolster deformations with central and off-centre loading

The bending behaviour observed using the load unit was subsequently also verified with the tool mounted. Measurement of the deflection of the tool and the bolster was performed using eddy-current sensors. This made it possible to verify that the tool fully adopts the deflection of the bolster plate. [8, 10] In summary, it can be stated that the interaction between a stiff ram and a softer bolster plate requires an increased press force to achieve a uniform contact surface at bottom dead centre.

However, the tool still has an influence on the bending behaviour through its load distribution on the bolster plate and the ram. Figure 8 shows this distribution between ram and die during blank holder contact (left) as well as at bottom dead centre (right) of the side

member tool – each vertical bar representing one load cell. Here, the differences in load application during the forming process on the ram are clearly visible.

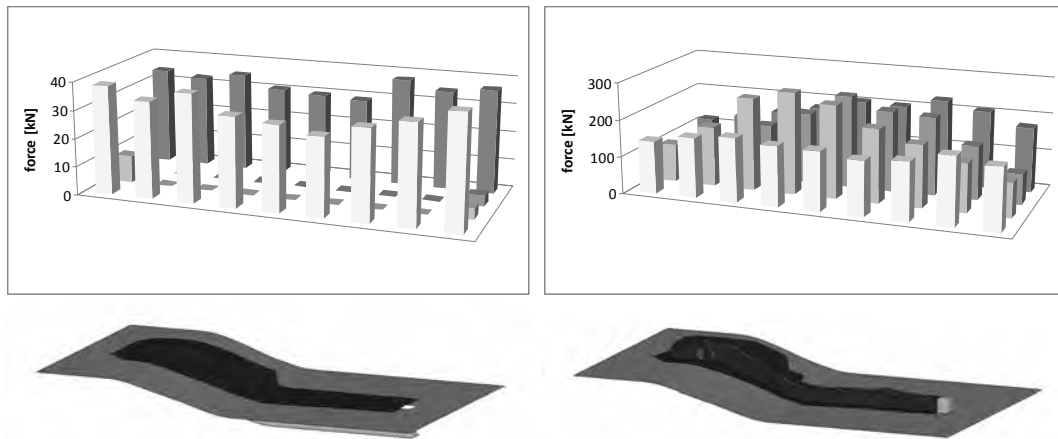


Figure 8 Load distribution for blank holder closure and bottom dead centre

All examinations have evidenced that the knowledge of a certain load and the resulting deflection properties of the tool and press are only applicable if the bottom dead centre (BDC) is defined precisely. Therefore in reverse the BDC is decisive for the determination of the necessary force requirement.

3.3. BOTTOM DEAD CENTRE

In practice, bottom dead centre is usually determined visually. Statements can be made regarding tool closure, for example by creating a blueing print, by comparing the target value and the actual status of selected radii, by measuring the remaining drawing gap using lead fragments and by stamping a bottoming marker on the component (Fig. 9).

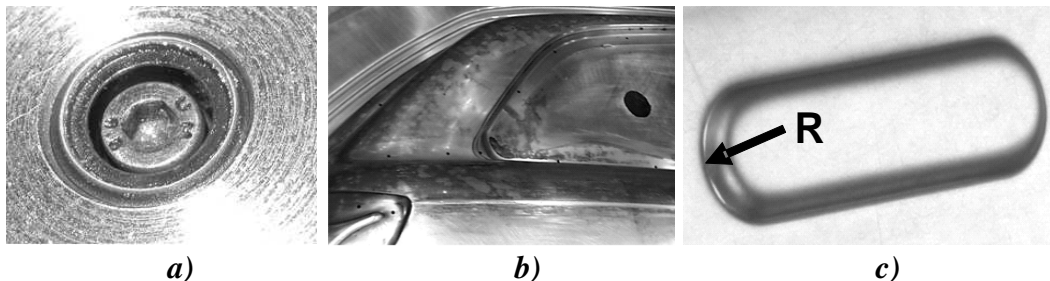


Figure 9 a) bottoming marker, b) blueing print, c) comparison of radii

All currently employed methods suffer from subjectivity and thus from a lack of reliability when determining bottom dead centre. Furthermore, statements regarding tool closure are merely qualitative – the discrete point of time cannot be determined. It is therefore necessary to define a criterion as precise as possible to determine the time of tool closure and the acting forces. The most commonly employed method is the use of a bottoming marker (BM). Due to the durability and the simplicity of documentation, this method is used in mass production. Because of its common use in the press shop, the BM is to be used as the basis for the development of a quantitative criterion.

A test stand is build to investigate the influence of the blank quality, material thickness and BM geometry as well as the BM's installation height. Within the test stand the forces of the upper tool F_{UT} , the lower tool F_{LT} and at the BM F_{BM} are measured. The coining of the BM starts with the contact between the blank, the BM and the lower tool (Fig. 10, left). The tool

closure is defined at the time a force is measured at the upper tool (Fig. 10, right).

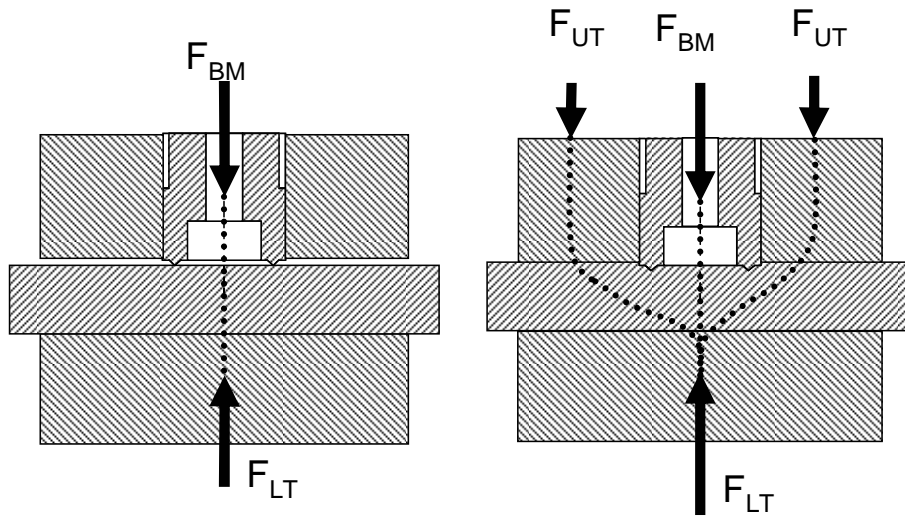


Figure 10 Force flow through bottoming marker at first contact and tool closure

The measurements on the test stand show that a strong dependence on blank quality, geometry and BM installation height is apparent. Therefore, the absolute embossing force cannot be used as a criterion for bottom dead centre as the material and the BM installation height vary.

This means that a criterion is sought that displays the greatest possible independence of the stated factors.

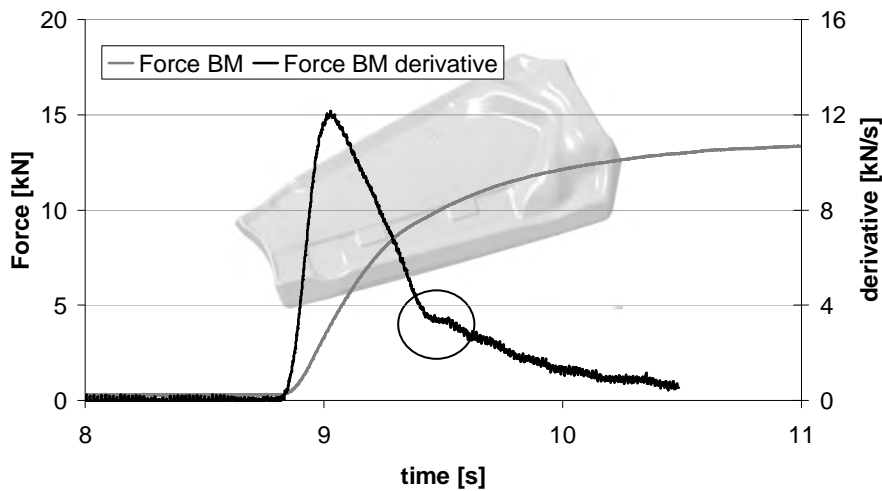


Figure 11 Validation using real component

The laboratory tests demonstrate that the force-time-curve of the BM can be subdivided into characteristic phases. One of these phases is tool closure. Extensive tests using the test stand have evidenced that the qualitative force-derivative-time curve of the BM is independent of material, material thickness, geometry and BM installation height. The defined criterion, a discontinuity in the force-derivative-time curve, determining bottom dead centre was subsequently validated and verified using real tools (Fig. 11).

The measuring unit developed provides a good criterion for the precise and reproducible determination of bottom dead centre.

4. RESULTS & DISCUSSION

The examinations on bending, stretch forming and embossing constitute a solid basis for comparison with the forming simulation. A design of experiments decoupled the different force proportions and their major influences from one another. For the embossing process – as the most influencing one on the necessary force requirement – it can be evidenced that the friction has a negligible influence.

The measurement of two presses with a mounted tool allowed the impact of tool and press on the maximum force requirement to be quantified. Here, the interaction between bolster plate and ram deformation has a substantial impact. The tool itself plays a subordinate role as it can, due to its minor rigidity, not provide a major appreciable contribution to the compensation of the degree of global deflection – but it has an influence on the load distribution. This factor of influence is of course only of consequence where the tool was initially in try-out with different rigidity characteristics of the press. Cambering the tools is in this respect one option for compensating the deflection behaviour.

All examinations have shown that the factor decisively influencing the maximum force is the precise determination of bottom dead centre. In this regard, a measurement methodology relying on currently common methods has been developed which allows a reproducible determination of bottom dead centre. The measuring unit has already been validated in real tools.

5. CONCLUSIONS

Higher-strength steels require a substantial increase in press forces which can lead to existing presses reaching the limits of their capacity. A precise prediction of force requirements is therefore indispensable.

The experiments decoupling the parts of the total forming force from each other lead to the conclusion that only the bending and ideal forming force have an influence on the necessary force at the bottom dead centre. Commonly used simulation software using shell elements is restricted due to high ratios of sheet thickness to bending radii of reinforcements. An option is the usage of a volume-element modelled blank to achieve an improved calculation precision for embossing, as compression stresses across the material's thickness can be modelled as well as modelling of smaller radii improve [1]. To reduce computation times, it is favourable to perform a mapping of shell elements to solid elements just before bottom dead centre is reached.

The knowledge of the impacts on the required press force leads to the consideration of individual press parameters within the planning process. Knowledge of the respective machine characteristics is therefore indispensable. To reduce computation times here, substitute models should be used to accommodate the tool [4]. To accommodate the press, a phenomenological substitute model has been established which is, in turn, adapted to the measurements via optimisation [6].

Employing a bottoming marker equipped with measurement devices facilitates a precise and reproducible determination of bottom dead centre and the resulting minimal force requirement. This will in future allow for the raising of the press's stroke range in order to minimise the stresses applied to the tool and the press. This criterion was correspondingly transferred to the simulation and offers a substantially more precise force calculation.

6. ACKNOWLEDGEMENTS

Parts of the work performed were subsidised by the Federal Ministry for Education and Research (BMBF) within the context of the “Researching future production” concept under the subsidy ID 02PU2000 and were supported by the project administrator Forschungszentrum Karlsruhe (PTKA), department for production and production technology (PFT).

7. REFERENCES

1. B. Adams, S. Keil, K. Juhr: Simulationsgestützte Presskraftberechnung für das Ziehen von Karosserieteilen, *Abschlußbericht zum AGIP – Forschungsvorhaben*, Osnabrück, 2005
2. B.-A. Behrens, C. Sunderkötter: Bestimmung von Kennwerten zur Beschreibung der Umformeingenschaften neuer und gefügter Feinblechhalbzeuge für den Streckzieh- und Tiefziehprozess durch vergleichende Untersuchungen, Fünftes Industriekolloquium SFB 362 „Fertigen in Feinblech“, Clausthal-Zellerfeld, 2005
3. P. Bagon: Genauigkeit im Presswerk. Überlastsicherung als Sensor zur Kraftmessung verwendet., *Blech Rohre Profile Vol. 3* Nr. 45, 1998
4. A. Haufe, D. Lorenz, S. Mandel: Konzepte zur Abbildung großer Werkzeugstrukturen mit reduzierten Modellen in der Blechumformung, *12. Dresdner Werkzeugmaschinen-Fachseminar*, Dresden, 2007
5. G. Heidrich, R. Bernard, B. Griesbach: „Presskraftberechnung – Die alte und neue Herausforderung“, *9. ISD-Workshop*, Stuttgart, 2006
6. S. Kulp, R. Struck: „Eine neue Methode zur Rückfederungskompensation von Blechformteilen“, *VDI-Tagung*, Würzburg, 2006
7. R. Krimm: Berechnung der lastabhängigen Maschinenauffederung zur Verkürzung der Anlaufzeit neuer Transferwerkzeugsätze, *Berichte aus dem IFUM*, Hannover, 2006
8. M. L. v. Schwerin: Entwicklung einer Methodik zur optimierten Gestaltung von Umformwerkzeugen, *utg Forschungsberichte Band 42*, München, 2007
9. M. Stillger: „Finite Element Analysis of Press Forces at Stamping Processes using LS-Dyna and Comparison with Test Results“, *3. LS-DYNA Anwenderforum*, Bamberg, 2004
10. M. J. Träger: Untersuchung des Einflusses der Pressenelastizität auf den Einarbeitsprozess von Karosseriewerkzeugen, *utg Forschungsberichte Band 42*, München, 2007