

Considering Tool and Press Elasticity within the Forming Simulation and Experimental Validation

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Summary:

There is an increasing demand for car body parts made of high strength steels nowadays. The prediction of forces needed for stamping these parts is very difficult due to elastic deformations of the tools and presses. These deformations cause a gap between the tools at the end of the stroke if the production press has different elastic properties than the try-out press. The pressed piece is not sufficiently formed unless an additional force is added to close the gap. To predict the magnitude of the total force needed the forming simulation using elastic tools, instead of standard rigid tools, has to be implemented. The disadvantage of this calculation method is a very high CPU time. To reduce the CPU time, several available speed-up methods are tested and checked for reliability on simplified models. The two most suitable are chosen after the analysis of results, and applied on the more complicated real case model where only the punch is considered elastic. After analyzing these results, the best method, called Tied Contact (TC), is chosen for the real case complete model application on a side member of the VW Tiguan and the results are compared to the experimental data.

Keywords:

press tonnage, tool / press deformation, deformable rigid bodies, static condensation, tied contact

1 Introduction

Increasing efficiency in the product development process is achieved by standardization and the synchronization 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 realized through digital factory techniques (e.g. simulation of production processes) and utilization 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 utilization, 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 advanced high strength steels results in significantly higher required forces and demands a more precise calculation of the required press tonnage.

The previously used values are based on an embossing force calculation using CAD software [2], 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 too 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.

This comprises the elastic properties of the tools which are usually not considered in forming simulations since they require a switch from rigid shell tool models to more complicated models which require significantly more calculation time. [5] To counteract this problem three speed up methods are presented. [1]

2 Procedure

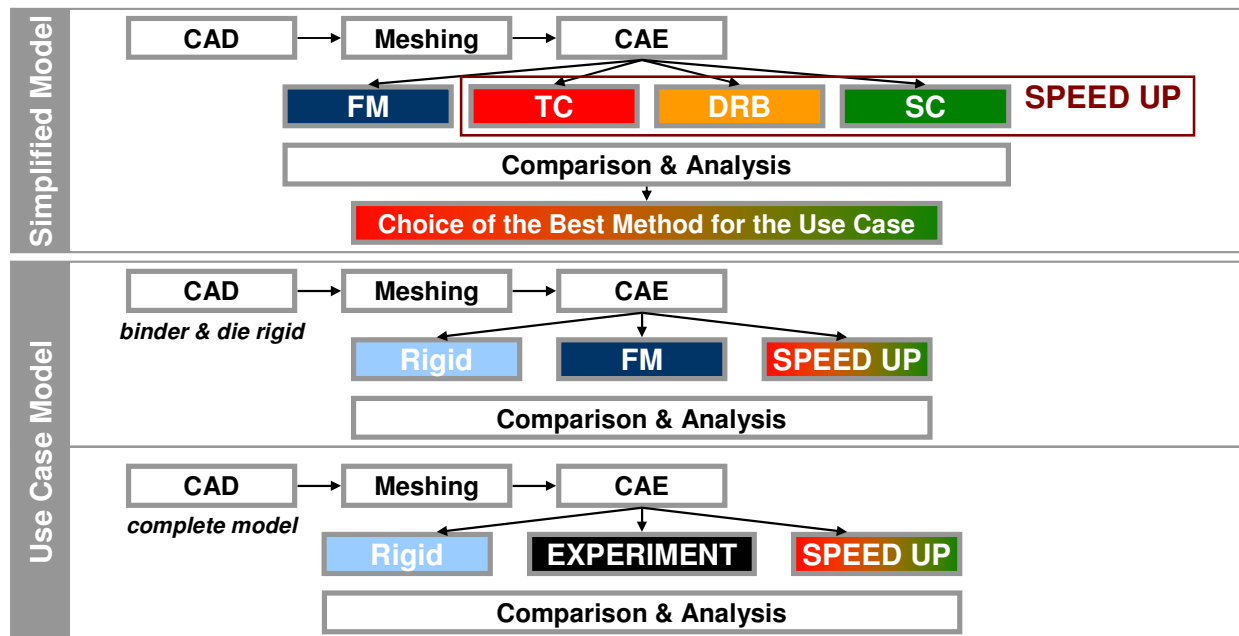


Figure 1: Steps for implementing and evaluating speed-up methods

FM=Fully Meshed Model, TC=Tied Contact, DRB=Deformable Rigid Bodies, SC=Static Condensation

As presented in figure 1 the approach is divided into three parts. At first the speed-up methods (Tied Contact TC, Deformable Rigid Bodies DRB, Static Condensation SC) are implemented using a simple u-channel tool model to decrease set-up times and the number of possible errors and are compared to a fully meshed model (FM) First conclusions are drawn out of these simulations resulting in applying

two speed-up methods on a simplified use case model. This model incorporates a homologous model for the press table, homologous model for the bottoming marker, an elastic punch model and rigid die and binder models. The best speed-up method is chosen for the complete use case model. This model comprises complete elastic tools as well as homologous models for the press table, bottoming marker and load cells which were used in experiments to measure the force distribution between the die and the ram. The use case is a VW Tiguan side member.

3 Simplified models

For speeding up the study of the speed-up simulation methods the simplified model of a u-channel is used as start. This model serves as a tool for faster adjustments and successful launching of the used methods in LS-Dyna. The reason is that there are only few experiences using LS-Dyna for forming simulations with elastic tools; therefore it is the obligation to research and discover the right way of using them to obtain the correct results. The (forming) simulation methods considered and compared in this study are rigid tools, fully meshed (FM) deformable tools, and deformable tools with speed up methods. These speed-up methods are Tied-Contact (TC), Deformable Rigid Bodies (DRB), and Static Condensation (SC).

All methods are explicit methods while the DRB method has an additional static simulation step.

3.1 Deformable Rigid Bodies

This reduction method is based on the calculation of eigenvalues (EV) and its process in LS-Dyna is shown in figure 2. These EV are calculated in a static simulation. The data from this calculation is loaded to the forming simulation and used in the form of modes. Here, the considered part is defined as rigid. Its deformation is determined through the number of modes available and the type of loading since the type of loading determines which of the available modes will be used. From these chosen modes, the linear interpolation of the deflections is applied and the resultant deflection found. Therefore, more used EV lead to a more precise result. For example if only very simple loading is applied few EV are required to obtain a satisfactory result.

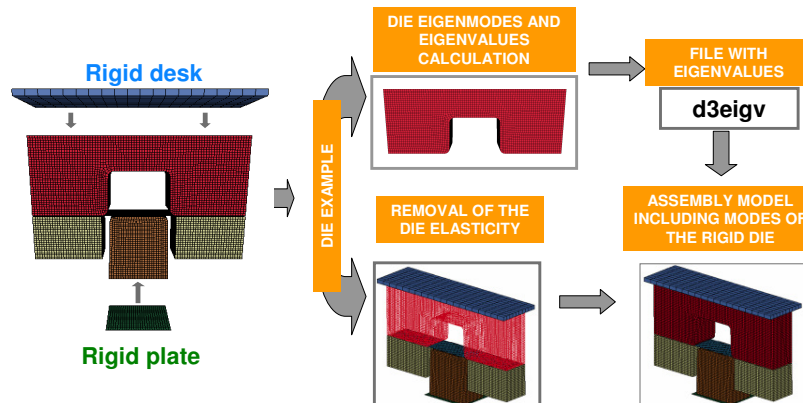


Figure 2: Process of setting up a deformable rigid body (DRB) simulation in LS-Dyna

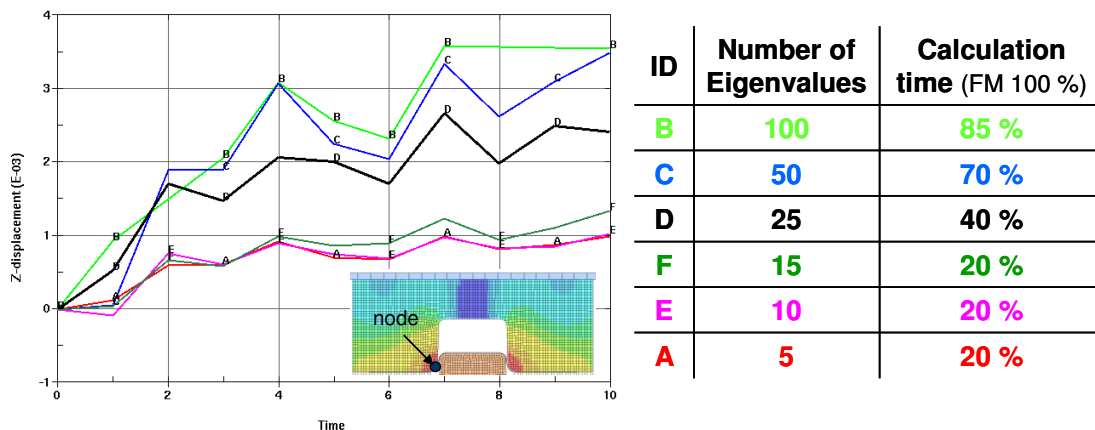


Figure 3: Influence of the number of eigenvalues in Deformable Rigid Body (DRB) method on nodal deflection and CPU time compared to the fully meshed model (FM)

The left graph in figure 3 shows the dependence of the deflection of the node using a different number of EV. Because the CPU time in our case is crucial, the comparison to the fully meshed model is introduced in percentage in the table next to the graph. Smaller numbers of EV lead to less calculation time and less precision is obtained. 100 EV can be used as the most precise result while still speeding up the calculation. However, 85% of the CPU time is not a satisfactory improvement. The result using 25 EV is still within the acceptable range of results and the CPU time is reduced to 40%. The further speeding-up leads to too big degradation of the results. Therefore 25 EV will be used from now on.

3.2 Tied Contact

This method is based on the idea of decreasing the number of elements in the model using Tied-Contact (TC). The whole body of each part is coarsely meshed and only the surface with a certain thickness is finely meshed. These two parts are consequently "attached" together by the contact "tie" (see figure 4).

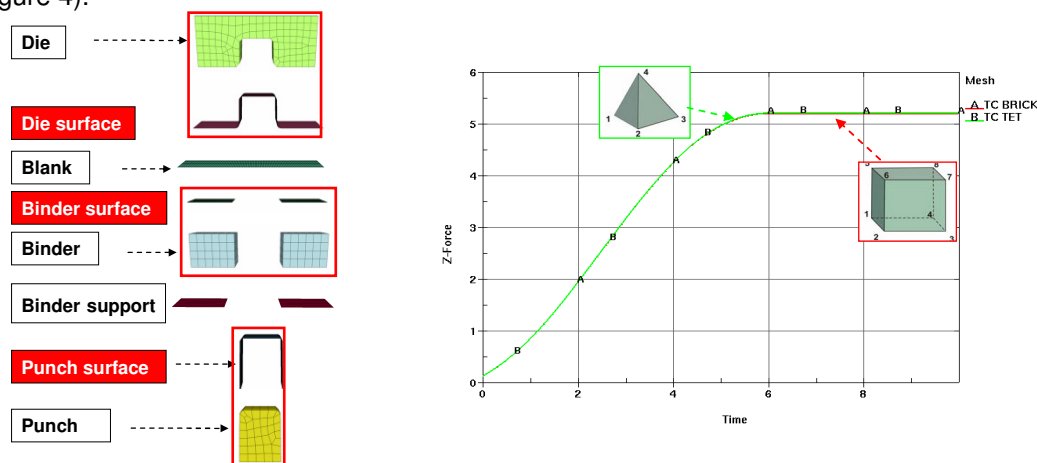


Figure 4: Coarsely meshed tool bodies and their finely meshed surfaces for the TC method (left) and influence of the tool body meshing on the total force (right)

Sudden transitions in zoning are permitted with the tied interfaces. This feature can often decrease the amount of effort required to generate meshes since it reduces the need to match nodes across interfaces of merged parts. [8]

The finer surface is to be chosen as the slave surface and the coarser volume is to be chosen as the master surface of the interface.

The tying of two surfaces is done in the following manner. First, mass and force vectors of each surface are calculated independently. Then the increments of forces and masses of slave nodes (in our case the fine surface) are distributed on and added to the mass and force vectors of master surface segments containing the corresponding slave nodes. When all corresponding vectors are summed over the interface, the acceleration of the master surface is computed. The acceleration of each slave node is interpolated from the accelerations of master segments containing the contact point of the slave node. Based on these values, the displacements and velocities are calculated in the usual manner. [8]

This method encompasses two major advantages. One is the low number of elements, which are reduced due to the coarsely meshed body. The second is lower set up time due to a relatively fast meshing process.

3.3 Static Condensation

This method speeds up the calculation by means of static condensation (SC) of the stiffness matrix of the individual parts. It embodies the condensation of all of the node properties to the selected boundary nodes of the part. These nodes include all of the mass and stiffness properties of the whole part and so it can simulate the exact behaviour of the condensed part in the artificial simulation. Each condensed part is included in the simulation in the form of a direct matrix input (see figure 5).

The static condensation of the stiffness matrix of the part is based on the mathematical recalculation of the matrix. In this procedure only the nodes and their representatives in the matrix are kept which are important for the forming process, namely the nodes which are probably in contact with the blank. These values include the condensed properties of all other nodes. [4,3]

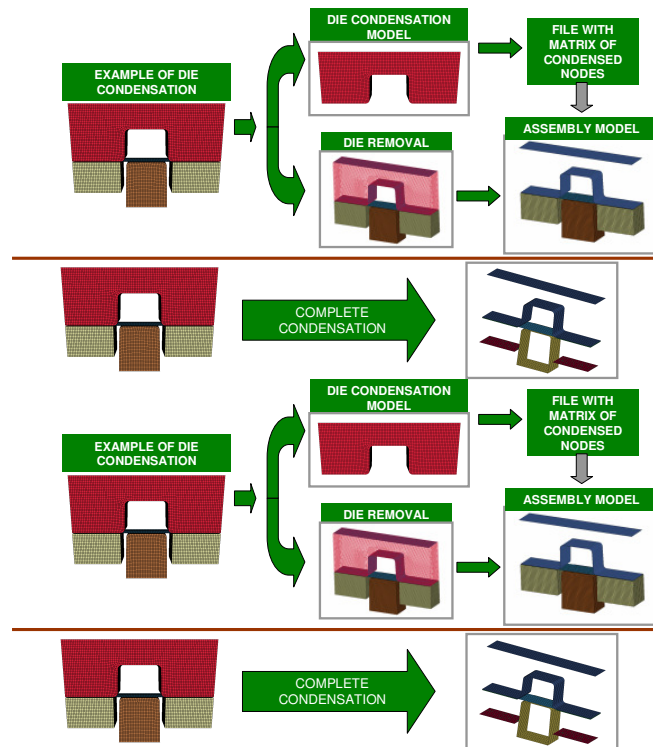


Figure 5: Process of the Static Condensation (SC) method in LS-Dyna

In this set-up of the SC-method only one degree of freedom (DOF) in z-direction is considered. When using all DOF, this method gives exactly the same results as the FM. However, the calculation time and the size of the .dmig file increase enormously with each additional DOF - far beyond the calculation time of the fully meshed model. Since the purpose of this method is to speed up the calculation a compromise is found by using only one DOF.

3.4 Comparison of simplified model results

Each of the speed up methods has different calculation characteristic, and thus the characteristics of the structures are also different. For press force related studies it is crucial to take deflections of the structures as well as the forces needed to close the gaps between the sheet and the tools into consideration. Therefore the characteristics of the simplified structures like deflections and reaction forces on the one hand and the numerical requirements like CPU time, memory, capacity, and set up time on the other hand are shown in table 1.

Table 1: Simplified model results

	FM	TC	DRB	SC
Die max deflection	100%	<u>123%</u>	<u>82%</u>	65%
Die node deflection	100%	<u>103%</u>	<u>105%</u>	8%
Max force	100%	<u>97%</u>	<u>111%</u>	107%
CPU time	100%	<u>7%</u>	<u>50%</u>	129%
Memory capacity	100%	<u>9%</u>	<u>1 714%</u>	8 000%
HD capacity	100%	<u>10%</u>	<u>900%</u>	11 500%
Set-up time	medium	<u>low</u>	medium	High
ranking		<u>1</u>	<u>2</u>	3

The fully meshed model (FM) is considered to be the etalon. The best results are underlined. The tied contact (TC) method is the best one in almost all measured parameters. Its deflections and forces are very similar to the FM and the CPU time is decreased by 93%. The low set-up time thanks to the low meshing time requirements is also remarkable. The deformable rigid bodies (DRB) method is also a possibility of speeding up the simulation. The forces and deflections are also comparable with the fully meshed model and the CPU time is decreased by 50%. The disadvantage is the set-up time which is caused by the time consuming meshing of the elastic tools. In spite of the decreased degrees of freedom (DOF) in the static condensation (SC) method the CPU time results are unacceptable. This is caused by the huge number of nodes in contact with other parts which is typical for forming

simulations. Therefore, for the following use case punch model application the TC and DRB method are used.

4 Simplified use case

For time saving purposes at first only the lower parts of the press are considered as elastic, namely the bolster plate, virtual plate and the punch. The binder and the die are considered rigid (see figure 6). This helps to compare the methods on the real case within an acceptable time period.

The lower parts of the press are the most important because most of the tools and press deformations take place there due to the usually stiffer ram. [6] This approach determines the most suitable speed-up method for the use case; it means the method which gives the closest result to the maximal force obtained from the fully meshed model.

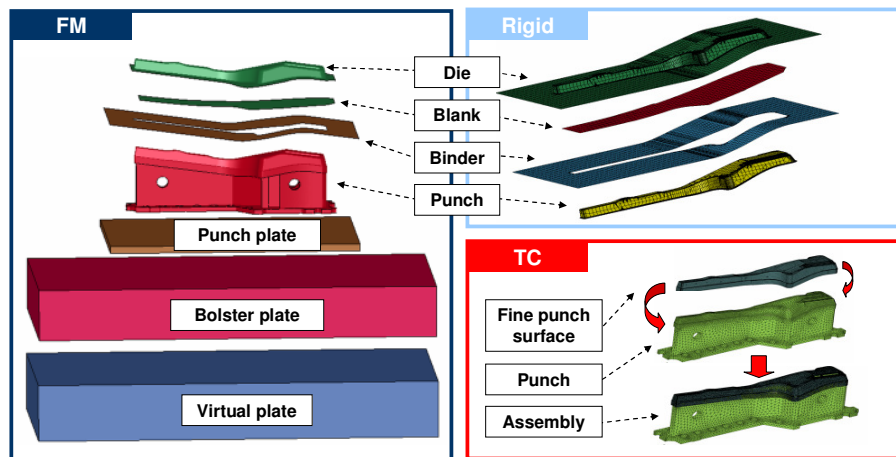


Figure 6: Assembly of the fully meshed model (FM), rigid model (Rigid) and surface assembly of tied contact (TC) method

The functionality of this simulation is as in reality. The punch is static and the die descends from the top and pushes the blank against it. The movement-speed of the die is determined through a trapezoidal form. The binder follows the given load curve with a loading of 1000 kN. Common speed-up methods, namely time/mass-scaling and adaptive remeshing are used.

4.1 Homologous models for bolster plate and bottoming marker

From former experiments a homologous model for the deflection properties of the bolster plate of a certain press is deduced. It consists of the bolster plate and the virtual plate, see figure 6. Their young's modulus is altered to match the real deflection properties. [7]

The bottoming marker is often used in mass production to check whether the part was adequately formed or the tool closure was reached, respectively. An advanced version, the electronic bottoming marker (eBM), incorporating a force sensor was developed and presented [6]. In order to ensure comparability between the simulation and measurements with the eBM a homologous model for the eBM is incorporated into the simulation. It consists of a single volume element placed on the die where the eBM is positioned in reality. In a series of experiments the required force for embossing the eBM was identified. From this value the required contact normal stress between the blank and the volume element is derived for which the eBM would have been embossed. [7]

Both homologous models were validated previously.

4.2 Tied Contact experiences

Problems occur due to the high part complexity causing geometrical differences between the fine surface and coarse body. Because of this a big variation of the distances between the surface nodes and the coarser volume nodes appears and the software has difficulties in finding the volume surface segments assigned to the fine surface nodes. A script was provided by DYNAmore which enables an easy identification of problematic nodes. However, it is necessary to move nodes manually in order to make the simulation run correctly.

4.3 Comparison of speed-up methods to fully meshed model

For the simplified use case the fully meshed model (FM) simulation is considered as etalon.

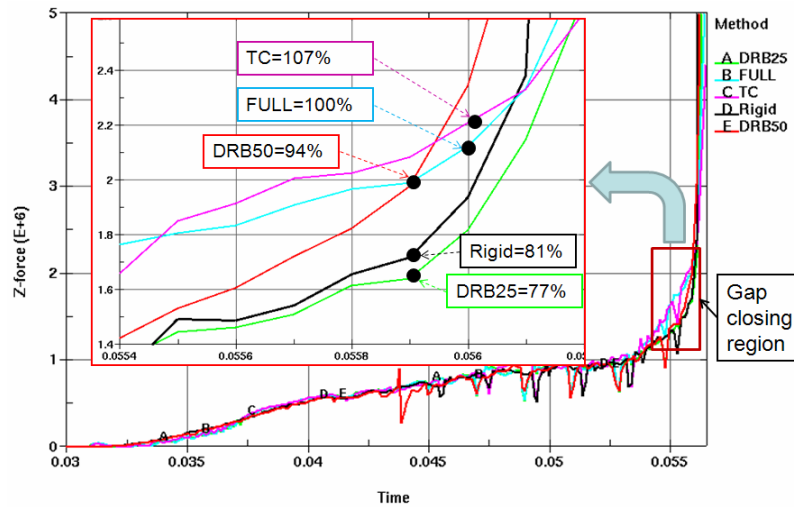


Figure 7: Tool closure points according to the electronic bottoming marker (eBM) homologous model for different simulations

Figure 7 shows the contact force of the punch surface and the point of tool closure determined by using the homologous model for the electronic bottoming marker (eBM).

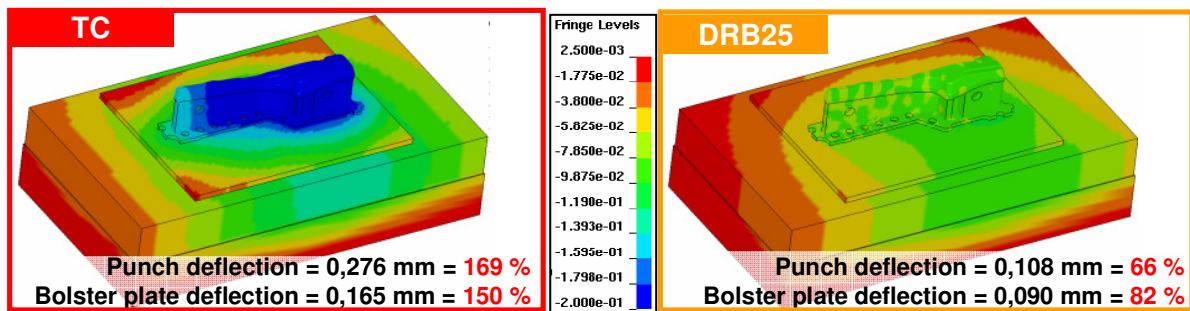


Figure 8: Deflections of tied contact (TC) model and deformable rigid bodies (DRB) model with 25 eigenvalues (EV) compared to the fully meshed model

Figure 8 shows the maximum deflection of the punch and the bolster plate at the same force level for tied contact (TC) and deformable rigid bodies (DRB) method with 25 eigenvalues (EV). 100% equals the deflection of the FM.

The comparison between FM, DRB with 25 EV and TC is shown in Table 2. The best results are underlined. The TC method is the best one in most measured parameters. The punch deflection value represents the displacement of a node of the punch which is dislocated the most. The value for the bolster plate deflection is yielded in the same way. The meshing of the FM-model and the DRB-model are identical which means the tools' element-size is getting finer towards the contact surfaces. The meshing of the TC-model has an equal element-size for the tools and their surfaces, respectively. So the difference in the deflection-categories between the FM- and the DRB-simulation show a stiffening effect of the DRB-method with 25 EV while the difference between FM- and TC-simulation can be caused by different element-sizes. The force at closure is only 7% higher than in the FM calculation. The other interesting result is the CPU time which is decreased more than five times. The set-up time is still much lower due to the meshing process simplification. The decrease of capacities requirements due to the lower number of elements in the system is also remarkable. The DRB method is also applicable but only with consideration of 50 EV. The lower number of EV increases the stiffness of the structure too much and the obtained result is very bad. As shown in the table where DRB with 25EV was considered, the resultant force is even lower than in the rigid model which is unacceptable. The disadvantage of using 50 instead of 25 EV is the increase of CPU time above 70%. Therefore, for the next step the TC-method is chosen.

Table 2: Simplified use case results

	FM	Rigid	TC	DRB 25 EV
Punch deflection	100%	-	169%	<u>66%</u>
Bolster plate deflection	100%	-	150%	<u>82%</u>
Force at tool closure	100%	81%	<u>107%</u>	77%
CPU time	100%	3%	<u>19%</u>	50%
Memory capacity	100%	19%	<u>38%</u>	120%
HD capacity	100%	17%	<u>37%</u>	1043%
Set-up time	medium	very low	<u>low</u>	high
Punch deflection compared to experiment				
Ranking	-	-	1	2

4.4 Comparison of simulation to experimental results

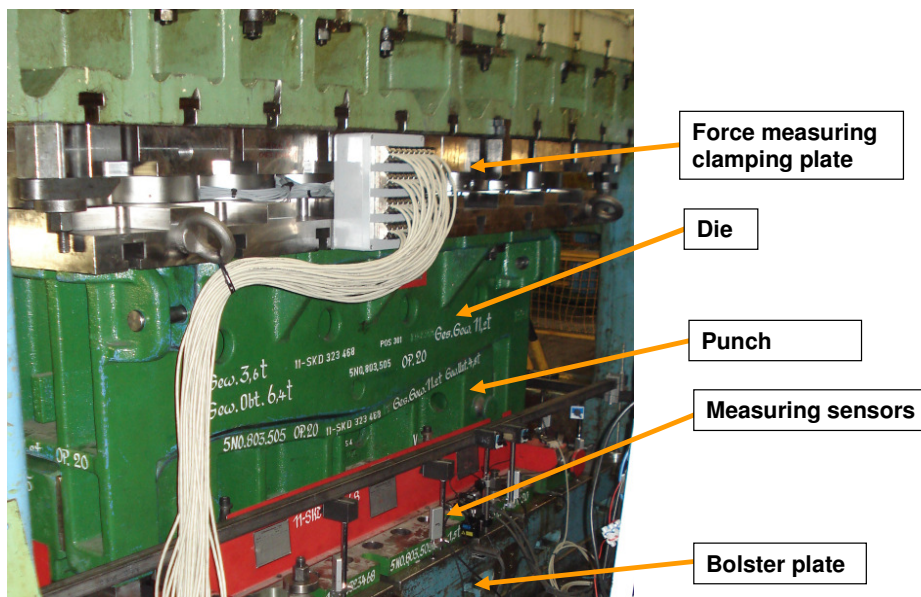


Figure 9: Measuring system for sensing forces and bolster plate deflection during a forming process

The measuring system is illustrated in figure 9. Due to the presence of the tool the most measuring sensors are placed close to the edge of the bolster plate. The deflection below the tool is measured by eddy current testing devices positioned in the T-slot. In total 34 points on the bolster plate are measured. [6]

During tool closure, at die forces of 6000 kN (binder 1000 kN), deflections on the edges of the bolster plate are up to 0.27 mm and below the tool 0.39 mm displacement are measured.

In former experiments the press characteristics were determined, showing a skewness of the bolster plate.

Table 3: Simulation results compared to experimental results of bolster plate deflection and max. force

	Experiment	Rigid	FM	TC	DRB 25 EV
Deflection average	100%	-	51%	<u>77%</u>	41%
Force at tool closure (eBM)	100%	73%	90%	<u>97%</u>	70%
Ranking	-	-	2	1	3

Table 3 shows the averaged deflection of the bolster plate. For the measured points in the experiment the corresponding nodes in the simulation are considered. Since the skewness of the bolster plate is not a feature yet of its homologous model, the simulation results show a more symmetric deflection pattern. The calculated force of the TC-model is very close to the experiment. Due to a not yet sufficient deflection calculation - but the best compared to the others - it might overestimate the total force with the complete model.

While a better approximation of the experimental results by all models could be expected the tendencies observed before, namely that the TC-model loses and the DRB-model gains stiffness compared to the FM-model, are confirmed.

5 Use Case

5.1 Simulation set-up

The force measuring clamping plate – consisting of two steel plates connected by 36 load cells with each other – is in reality placed between die and ram to measure the force and force distribution. Its homologous model is composed of an elastic plate according to the lower of the real plates and the rigid load cells. The ram deflection can be neglected in this case since deflection measurements showed a maximum deflection of 10 μm compared to the bolster plate with 0.57 mm at half of the rated tonnage on the specific press.

Figure 10 describes the assembly of the individual parts. The parts below the punch are identical with the fully meshed model with elastic punch in the previous section.

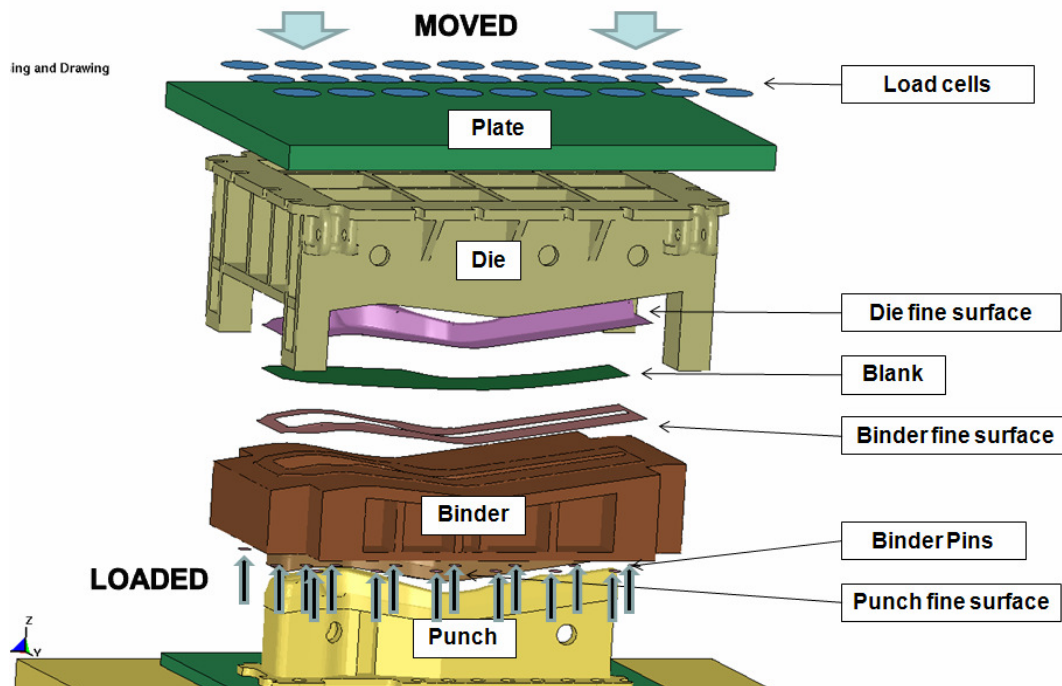


Figure 10: Assembly of Complete use case model with tied contact (TC) method

The functionality of this simulation is similar to the fully meshed punch model in the previous section but the die in this case is moved by the load cells. The load on the elastic binder is applied through rigid pins placed below the binder at the spots according to the experiment.

5.2 Experiences

The attachment of the bottoming markers (eBM) to the finely meshed surface was in this case problematic. The usual way which is used in the previous sections is an extra node set constraint which works only for tying nodes to a rigid surface. In the complete model there are no rigid bodies in contact with the blank; thus tying the eBM to the die surface which is tied to the die is tested but does not work out as expected since the stability of the simulation decreases. So the eBM homologous model could not be used in the first simulations yet.

The large masses, also due to mass scaling, which are moved in this simulation with relatively high speed of 2 m/s lead to high kinetic energies resulting in erratic contact forces between the load cells and the top plate. Load cells and plate are not bonded to each other so the contact is not as steady as in reality. In fact the load cells seem to ‘throw’ the plate and the die instead of pushing them. Bonding the load cells onto the plate increases the control over the die-movement but will make it harder to measure the forces in between.

The recommended maximum movement speed of 5 m/s is a standard limit for forming simulations using rigid tools. Those simulations do not suffer from huge moved masses. Reducing the speed with

the complete tool model reduced this problem but wasn't overcome yet. The downside of course is due to the explicit calculation the increase of calculation time.

The current results are not satisfying yet in terms of functionality of all modelled parts as mentioned above and did not allow a fully experimental validation with all measured data so far. The next steps will deal with these difficulties of implementing the eBM homologous model and investigating the influence of the movement-speed on the result accuracy.

6 Conclusion and Outlook

The only convincing speed-up method in this examination is the tied contact (TC) method. It provides low CPU times while ensuring a good quality of the results. However, the ability of the software to find the tying segments still needs to be improved.

The static condensation (SC) method fails in its current implementation since acceptable results are only achieved by high CPU times, making the SC-method at this point a slow-down method.

For the deformable rigid bodies (DRB) method a problem remains the estimation of the right number of required eigenvalues (EV) for obtaining good results. It influences directly the required calculation time and thus the effectiveness of the DRB-method to speed-up the calculation. But it might be an interesting approach for a combination with the TC-method to overcome the complex preprocessing.

A general conflict emerges between the need for fast movements of the tools. To keep the calculation time for explicit simulations low, problems due to large kinetic energies produced by the mass of the fully meshed moved parts such as binder and die occur.

Combining elastic tool models and homologous models for the bolster plate deflection properties and the electronic bottoming marker (eBM) with a speed-up method like the TC-method is a promising way of obtaining a more precise calculation of the tool closure and required press forces while increasing the required CPU time compared to a simulation using rigid tools in an acceptable range.

Further research will comprise the improvement of the current use case simulation for a detailed comparison of the results to experimental results.

7 Acknowledgements

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8 Literature

- [1] Haufe, A., Lorenz, D., Mandel, S.: "Konzepte zur Abbildung großer Werkzeugstrukturen mit reduzierten Modellen in der Blechumformung", 12. Dresdner Werkzeugmaschinen-Fachseminar, Dresden, 2007
- [2] Heidrich, G., Bernard, R., Griesbach, B.: „Presskraftberechnung – Die alte und neue Herausforderung“, 9. *ISD-Workshop*, Stuttgart, 2006
- [3] Lingbeek, R.: "Challenges in die design", University of Twente, 2008
- [4] Roll, K., Hoffmann, J.: Eine Möglichkeit zur Berücksichtigung der elastischen Werkzeugeigenschaften bei der Blechumformsimulation", LS-Dyna Anwenderforum, Bamberg, 2005
- [5] Roll, K., Bogon, P., Ziebert, C.: "Innovative Methoden zur Auslegung von Umformwerkzeugen im Fahrzeugbau", *wt Werkstattstechnik online*, J. 97 Heft 10, 2007
- [6] Struck, R., Kulp, S., Behrens, B.-A., Krimm, R.: "Investigation of impacts on the required press force", *IDDRG 2008*, Olofström, Sweden, 2008
- [7] Struck, R., Kulp, S., Härtel, S.: "Numerical analysis of forming processes regarding the prediction of press forces", *Numisheet 2008*, Interlaken, Switzerland, 2008
- [8] LS-DYNA – Theory manual, 2006