APPROACHING A RELIABLE PROCESS SIMULATION FOR THE VIRTUAL PRODUCT DEVELOPMENT

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Summary

In this paper an outline for a strategy to include manufacturing effects in subsequent simulations for the virtual product development from an industrial point of view is given. Especially the conditions for a successful mapping of geometry and results between different applications are discussed. An example shows the significance of the inclusion of previous simulations in the final assessment of a part.

Keywords: virtual product development, reliable simulation, mapping

1 Introduction

The aim to shorten lead times gives the need for frontloading. This is only possible with appropriate software tools which are able to deal with uncertain data (part, material) in a minimum of time. In the beginning of a development process, i.e. the concept phase, neither the parts are fully determined nor the materials to be used. Despite this feasibility and part performance have to be established. This is done by virtual examination and optimization. Since this requires a lot of simulation loops the calculation times have to be small and transfer between different tools must be easy. From this point of view simplifications of physical processes are justified provided the consequences are understood and the results are not severely compromised.

While the forming process defines the properties of a part to a large extent it is not the only process step giving rise to important changes of its behavior. For example joining processes like welding are equally relevant. For feasibility studies it is sufficient to simulate each process step separately. However, to predict the mechanical properties of a structure purely by simulations every process step and their interactions should be taken into account. For welding simulations this is complicated if a forming simulation has been made previously. This is due to different formulations of the material properties in the different programs, the change of material orientation during for forming process and the completely different meshes which call for a mapping of the state variables. The aim to develop automotive parts virtually and to reduce the number of manufacturing prototypes and physical tests demands a reliable process simulation including all manufacturing steps.
2 Virtual process chain

The virtual process chain is the result of a projection of all process steps a part is subjected to in reality on a numerical procedure. This is performed as a sequence of numerical simulations for each process step [1,2]. In reality every step changes the properties of the part. To include this, all simulations must be coupled and the results must be transferred from one to another model. The aim of the virtual process chain (Figure 1) is to deliver simulation results with increased accuracy and better agreement with measurements while at the same time reducing the effort to set up single simulations. Thus it is also possible to reduce the lead-time needed for the development.

![Figure 1: Virtual process chain.](image)

A typical process chain for automotive sheet parts basically consists of forming, joining and assembly. The final stage always consists of testing and evaluating the part’s behavior thus safeguarding a satisfying performance. All subsequent steps are included in the virtual chain in different levels of accuracy, which is inherent to the kind of process [3]. Deep drawing simulation has reached a high level accuracy nowadays, whereas e.g. accurate welding and machining simulations are not yet practicable. To include these effects an augmentation of a numerical model based on measurements is needed. This results in a simplified model which features only the main properties [4]. The results have to be assigned to the respective CAD/CAM database to ensure that CAD and result files belong together. For casting a similar chain can be formulated.

3 Tasks of the virtual process chain

In the virtual process chain all changes to the part with respect to the geometrical form, the material constitution and stresses and strains have to be taken into account. If this requirement is to be fulfilled then every manufacturing step has to be represented in a simulation. This is of course not always feasible like for machining or welding. For these
steps the numerical model has to be modified by hand in order to consider all changes to the part and get at every stage a complete representation of the parts state as possible. The CAD of a part or assembly prescribing the target shape at the end of production process. In reality the actual geometry differs from this shape to a certain degree as a consequence of the manufacturing process. Simulating the single process steps and including the corresponding shape changes enables to evaluate the final geometry of a part. Compensation strategies can be derived and subsequently verified. Typical applications are minimizing springback after forming and welding distortion. During the production process the shape of the part becomes more complex. This is reflected in the simulation, where meshes and models used at different stages and for different parts of an assembly are not naturally compatible. These can differ with respect to element type, mesh density, material formulation, position and orientation. Also the state variables are generally incompatible.

A reliable process simulation can only be obtained if the communication between the single simulation steps is seamless and without human interaction. At present this is still not the case. Merely some specialized interfaces have been described in literature, e.g. coupling sheet forming to crash simulation. Eliminating the human interaction requires material models which are applicable in all simulation programs, alternatively and even better programs which can handle very complex and advanced models. This is currently not the case, therefore only some material aspects can be transferred between different simulations. Especially the combination of isotropic and kinematic hardening is problematic; the orientations of the anisotropic directions is not part of an output set.

Another aspect is the automatic generation of input decks for the succeeding analysis steps. This would require a program which not only parses the output of a previous analysis step but also adds command lines for the next simulation tool. Simplified models are also part of the input data for the meta-model which comprises everything needed for the complete virtual process chain.

The minimal requirements are considerably less ambitious but nonetheless lead to improved results. A minimal version of the proposed aim would dispense with the automatic generation of input files and restrict to the parsing and mapping of results needed for a subsequent simulation. For processes which include deep drawing these are the actual geometry including the thickness of the sheet, the plastic equivalent strain and the stresses in the sheet. Mapping of the thickness and the state variables is discussed in the next section.

4 Mapping between two applications

The state of a part at the end of one production step is always also the state at the beginning of the next step. This is an obvious statement for real parts but it should not be taken for granted that the same is true for simulations. Actually a transfer of results between different simulation tools will almost always result in a loss of information. In general the problem of a mapping process can be defined as follows:

- two different grids – the target and the import grid – are given,
- the position of the two grids are arbitrary in space,
- simulation data exists on the import grid and is searched for the target grid,
- different orientations and different formulations of stresses and strains,
- different material formulations (e.g. Hill48, Mises).

The transfer of the part geometry from the deep drawing coordinate system into the global car coordinate system must be completed as automatic as possible. To do so and to ease the inclusion of further simulation tools a unified format is applied.

Figure 2: Starting point for the positioning iteration (left) and final position (right).

A good starting point for a successful positioning procedure is found by adjusting the centre of mass and the main inertia axis of both grids, see Figure 2. In case of similarities in the inertia axis it should be tested if a 90° rotation around an inertia axis gives a better starting point with respect to the average distance between both grids.

Figure 3: Plastic strain on the forming (upper left) and structural grid (right) and the computed mapping error (lower left).

The optimization problem is to find the minimum average distance between both meshes by varying rigid body displacements. Different methods for calculating the average distance of two grids are possible, depending on the desired accuracy and the
computational costs. In practice a sufficiently accurate position for data mapping can be found by calculating the average distance based on the closest node distance. Obviously, this value will never become zero for different meshes.

After positioning the part the mapping procedure takes place. For each element of the target grid a number of mapping points is specified for numerical averaging of the import element values. For every mapping point the respective import element has to be found. This is similar to the task of a contact calculation: Find the intersection of a ray – given by the mapping point and the normal of the target element – with a surface – given by import elements. The result of this procedure is the mapping table, which assigns the import element number to the mapping point. So the value for a target element can be averaged out of the values of the associated import elements. Figure 3 shows the result of this procedure for the plastic strain distribution of a deep drawn part (PAM-STAMP example Coupelle, ESI).

As typically for finite element calculations the error depends on the mesh density. This also applied for data mapping. The average value of the target element compared to the single values of the import elements give the total mapping error. It is an essential point to visualize the mapping error. Figure 3 shows the mapping error in the lower left corner.

To establish this mapping procedure in the virtual product development an inhouse software tool (INPRO DATOR) was developed and integrated into ALTAIR HyperWorks. HyperMesh was used to visualize the grids and the positioning results, HyperView shows the imported data, the mapped target data and the Mapping error.

5 Test case

The effect of considering the manufacturing effects is shown in a calculation of the strength of a suspension link from VW Braunschweig. The carrier and the plate are deep drawn parts. The bushing, carrier and plate are joined by welding. In the strength test the axial buckling load is determined. The calculated forming results are mapped onto the structural model. In addition to this the influence of the welding process is included by assigning a plastic equivalent strain and initial stresses to the seams (see Figure 4).

Figure 4: Equivalent plastic strain from the forming process and welding model.

With the metal sheet thickness, the hardening due to the plastic strain, the initial stresses of the forming simulation and the simplified weld model the prediction of the buckling load gains significantly in quality as shown in Figure 5.
A significant part of the gap between CAD based calculations and the measurements (light blue) was eliminated by considering the forming effects (blue curve compared to green curve in Figure 5). Applying the effects of welding in form of a hardening of the weld seam material and an initial stress in the seam gave a complete agreement between calculation and measurements (red curve).

### 6. References


[2] K. Kose, B. Rietman: Combining forming results via weld models to powerful numerical assemblies, ESAFORM 2004, Trondheim, Norway
