Assembly simulation development and validation project with industrial applications

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Abstract. Full digitalization has been applied more intensively in the automotive industry. The virtual engineering of single part is established since many years. Currently, the digital process chain is expanding to the assembly process. The assembly engineering teams should be effectively supported to define the assembly process; the assembly process should make products that fulfil the required quality requirements. A detailed simulation representing the future assembly process has to be setup. In an early phase based on CAD data, in the course of the engineering process the model can be enriched with forming simulation data and even real measurement data. Based on the assembly definition, critical issues can be identified and fixed already in the virtual world. Detailed evaluation of the geometrical deviation of the assembly can be made. This methodology is validated on an industrial automotive component.

1. Introduction

The automotive industry is in a transition mode, as various mobility and people-centric trends are impacting the automotive market [1]. Moreover, various technology trends related to the development of smart factories and industry 4.0 are affecting the automotive industry. As a result of these trends, many car makers are attempting to become more agile and resilient by implementing business and organizational changes. Through the increased use of simulation technology and digitalization of stamping and assembly processes costs are further reduced. The virtual engineering of single part is established since many years. Currently, the digital process chain is expanding to the assembly process.

In this paper, we discuss a three-year project between AutoForm Engineering and Fontana Group on the simulation of the BiW assembly process. During this project three assembled subgroups were studied. AutoForm Engineering focused on the improvement of its software solutions. Fontana Group
contributed with its experience and consolidated know-how of its stamping and BiW technical offices. In the first phase, it has been verified whether the software was able to represent the challenges and complexity required by the real world. In the second phase the simulation result was validated on a hood. The pillars on which the project was launched were:

- Improvement of the AutoForm-Assembly simulation software to be able to represent a variety of real assembly processes in bodywork production
- Application of AutoForm-Assembly to the assembly processes of multiple components and validation of the accuracy of the simulation in terms of deviation of the final shape (springback)
- Validation of efficient simulation techniques to model state-of-the-art assembly technologies, including hemming processes.

This assembly process involves the production of paneled sub-assemblies in which the geometric complexity of the parts is an important constraint. Just think of the variety of shapes, materials, thicknesses and artifacts (molded, extruded, die-cast, etc.) that can be found combined in a BiW. The assembly and hemming process is more than combining a few pieces of sheet metal; it can be an extremely advanced process with no more restrictions on the number of components or operations sequence. The combination according to the correct assembly method is in fact the only starting point of the process. The simulation should represent the real (future) process and should be able to define:

- how the pieces will be constrained in space
- how they will be joined
- what thermal deformations will occur (e.g. welding points and furnace firing)
- which mechanical joints are applied (clenching, riveting, hemming, etc.)
- without forgetting the final quality of the assemblies in terms of geometric deformations and aesthetic appearance.

The possibility of fully simulating and accurately representing the complete assembly processes in production is the ultimate objective. Single detailed simulations to analyze the behaviour of a specific joint or constraint had been possible for years, but it was not possible to carry out a broad spectrum of process simulations in a cycle time compatible with the car development timeline.

2. Assembly Verification

In the first phase it has been verified whether the assembly software was able to represent the challenges and complexity required by the real world. In this phase two subgroups were selected for verification, a fender group and a hood assembly. Most illustrations are shown as sketches since the real parts pictures cannot be shown due to confidentiality. First limitations identified were the representation of the extruded structural components and the flexibility in representing the sequence of assembly operations. This latter issue can be shortly explained on the fender group assembly.

The fender is produced by assembling the skin to the inner frame group and this package is inserted on the hemming bed. For proper positioning and (pre-) fixation outer and inner are not joined by hemming only, but are subjected to riveting and laser welding. So, the process definition has to be able to independently define when the individual parts are loaded into the machine, in what order and with which loading direction. In addition the method plan must be able to indicate which type of processing (assembly, hemming, curing, springback measurement) is performed in each operation. A variable number of assembly operations should be defined and alternated with assembly, hemming or curing. The scheme of the supports and the loading sequence of the pieces are also assigned manually to each operation and a series of automatic checks allow the operator to validate the hypothetical choices.

Essential process data checked are:

- the contact areas between the different parts (mating check for possible welding)
- the effectiveness of the number and position of the constraints on the stability of the loaded pieces (stability check)
- the collision areas during loading (collision check).
The possibility of having a precise and systematic control of the supports and clamps allows to speed up the engineering phase and to foresee any corrections before the equipment is built.

In the Fontana Group's assemblies there are all types of metallic and non-metallic components of different nature. We came across tubes, extrusions of different shapes and sections, die-casted elements, forged elements, composite elements, etc. which by their nature can in no way be treated like a stamped sheet. The Fontana Group required that all kind of formats be used for importing these parts. This request was fundamental for the volume of products handled by Fontana Group. It resulted in a software even more flexible and suitable for the needs of both markets: mass production and premium brands; this latter very often shows a combination of components that are different in type. We therefore made it possible to join different solid elements with stamped sheets and not just sheets with other sheets in multiple overlapping layers.

In Figure 1 we explain the assembly process sequence, showing possible complexities and occurring boundary conditions. This figure shows the assembly process of a door like it has been defined in the AutoForm graphical user interface. This overview shows the different assembly operations and which parts or sub-assemblies are joined. Operations A-10 and A-20, two small sub-assemblies, are created. Both the clamps and the weld points are indicated with little symbols in order to analyse the assembly definition. Operation A-30 shows how several sheet metal parts are joined to the door inner stamping. Additional stamped parts as well as the sub assembly from operation A-10 are joined on the door inner in operation A-40. In operation A-50 more parts including the sub-assembly from A-20 are joined. Last joining operation is A-60, the complete inner assembly is finalized. Operation G-70 is the hemming operation, the outer panel is hemmed around the inner sub-assembly. The last operation is M-80, this operation represents the measurement station. This figure illustrates a complete assembly sequence of a door and shows some of the challenges in assembly. Important boundary conditions are the above mentioned process data but also the accessibility of welding robot and the cycle time optimization.

![Figure 1. Schematic illustration of process sequence of a door assembly including the indication of the clamps and joints in each assembly operation.](image)

With the second component (hood) under study, we focused on what data and what results can be generated in the different phases of process development.
2.1. Process Engineering

In the early stages of engineering the CAD geometries of the parts are the only inputs available for the simulation, but with these it is already possible to make a large number of analyses on the stability of the process: the verification of the loading sequence, the position of the supports, the lowest number of closures to be used and the geometric deformation of the assembled group with nominal parts (no thinning, no residual stresses). With the influence of the stress introduced by the joining technology both thermal- and mechanical-joining can be evaluated. These definitions are the foundations of the assembly process. If well-defined the final production can start efficiently with a short ramp-up times. For reasons of development time of the component, the BiW engineering cannot afford to wait for more detailed data produced by the stamping colleagues on the complete cycle of the individual component. The first analysis can start immediately with the first CAD0 mathematics just released by Product Development.

2.2. Process Validation

After simulating the bodywork performed with nominal CAD0 data, it is possible to replace these data with the results produced by a full cycle stamping simulation (“.asm” file). Keeping the process unchanged, the tension and thinning data of each part (or of the most interesting ones) are included, reaching a further level of accuracy compared to the initial analysis. In this second calculation it is possible to evaluate the further effects induced by the residual stresses and the springback when the component is loaded and constrained on the assembly jig. The effects induced by the stamping process will then be carried over into the bodywork process and added in the final result. This analysis gives a much better representation of the real assembly process and results in more accurate results.

2.3. Process Optimization

However, a stamped part can slightly deviate from the simulated part, e.g. shape or geometry (springback) might slightly differ from the result generated with the stamping simulation. The causes can be manifold, manual interventions for setting up the tooling, geometric revisions not updated in simulation, variability of the material used in tool-shop and production, etc. These differences can generate such a difference that the stamping simulation data no longer reflect the physical component. To satisfy this operational need and not limit the analysis performed with CAD0 data or asm-data, a third possibility was introduced: directly import the data of a scan (“.stl” file). The product development phase can therefore be simulated from start to finish, using the most up-to-date and useful data for the analysis to be carried out in succession.

![Diagram](Figure 2. Maturing the assembly simulation with subsequent inputs: Nominal Parts from CAD – Forming Simulation Results, asm file – Real Measurement via geometry scan, stl data.)

Starting in the early phase of the care development the assembly process is defined using CAD data. When time moves on, more mature data from the stamping simulation become available. In the last phase of the development the first physical parts fall off the press. Having the flexibility to easily exchange input data enables the engineer to use the most mature data available. This methodology allows
the engineer to mature the assembly process simulation over time and a more and more reliable representation of the assembly process is available.

3. Industrial Validation

The second phase of the collaboration project focused on the analysis of actual results. The validation of the AutoForm Assembly simulation was carried out on another hood assembly. It was decided to limit the analysis to mechanical operations in order to have a direct correlation between what is actually produced and what is simulated. The thermal process step, the glue curing in the oven was omitted from the study. The validation focused on the following assembly process (see Figure 3):

- In the first assembly station A-10 four sheet metal parts are joined to an extruded component by welding and riveting. All structural components (brackets and stiffeners) have been imported as nominal CAD0 data
- In A-20 two sheet metal components are welded on the inner frame. For the inner frame it was decided to import the scan data of the real stamped part, to better replicate the real geometric deformation seen in production
- In a third assembly station, A-30, the sub-assembly extruded component is mounted on the inner frame
- The inner subgroup assembly process is followed by a hemming station G-40 in which the inner subassembly is inserted on the skin and the hemming flanges are folded by robots with three steps and two differently shaped wheels. For the hemming process, the outer panel was imported as full cycle stamping simulation result to have a better correspondence with the residual stresses existing on the real piece (important for the evaluation of possible aesthetic defects). Only three sides were hemmed, right-bottom-left, the top side hasn’t been hemmed (see Figure 4). All process data (tools, forces, paths, tipping, etc.) have been set in simulation to faithfully replicate the equipment and the actions performed by the production machinery
- The result of the hemming was finally positioned on the virtual control gauge respecting the tip and the real closures, taking out a measurement map M-50 (not shown in Figure 3). For the measurement the CAD0 assembly is the reference.

![Figure 3. Schematic representation of the four assembly stations of the hood assembly process.](image)

A hood assembly was picked out of the running production at the same stage of the process and was placed on a measuring gauge, taking out a measurement report and a scan map of the external surface. This map, combined with the measurement report, was used for the validation of the assembly process simulation results.

3.1. Assembly Measurement Results

To validate the result four sections on the outer part have been defined according to the sketch in Figure 4. On those four sections the position on 3D space was measured and compared with the ideal position according to CAD0. The measurement was done after the hemming operation and the deviation represents whether the geometry perfectly fits into the car assembly. The deviation is measured in
normal direction from the hood, at the top no hemming was done. The results of the measurement (scan) and simulation (AF) are shown in Figures 5 - 8.

Figure 4. Sketch of hood outer with definition of measurement sections, left – right, top – bottom. Numbers indicated the start and end of the measurement points.

Figure 5 and 6 show the deviation at the left and right of the hood outer respectively. Generally the measurement and the simulation match well. On the left the deviation of the measurement points 1 – 11 is less than 0.3mm but on the right the measurement and simulation are spot on. At the corner, measurement point 12, we see a relatively high deviation of more than 1.0mm. This deviation has been introduced due to the manual modification during assembly trials. These modifications haven’t been re-simulated. What also catches the eye when comparing left and right is that although the hood is symmetrical the deviation isn’t symmetrical. The unsymmetrical results, both of the measurement and the simulation, are caused by the unsymmetrical stamping result of the inner frame. Keep in mind that we imported for the simulation the inner frame stl-data of the real stamped part to better replicate the unsymmetrical deformation seen in stamping.

Figure 5. Measurement (scan) and simulation (AF) at the left side of the hood

Figure 6. Measurement (scan) and simulation (AF) at the right side of the hood

Figure 7 and 8 show the deviation at the top- and bottom-section of the hood. Since the four sections go around the hood, point 1 from the top corresponds with point 1 from left, point 35 from the top corresponds with point 1 from right. The relative large deviation in the corner at point 12 of the left section corresponds with point 1 of the bottom point 12 of the right corresponds with point 21 of the bottom section. Also the sections are not symmetric, neither the measurement nor the simulation. The deviation in the top- and bottom-sections show that the unsymmetrical inner frame was very dominant for the overall geometrical deviation. The methodology to replace simulated data by measurement data turned out to be crucial in representing the real assembly result. The simulation result matches very well with the measurements.
This virtual assembly validation showed that the assembly process can be very well simulated. The geometrical deviation can be predicted within a few tenths of a mm. Knowing the deviation before the first physical trials and having identified the most critical area enables to take countermeasures immediately. The countermeasures effectiveness can be validated with help of the simulation beforehand. With this simulation methodology the number of physical assembly trials can be reduced and cumbersome trial and error can be eliminated. After this validation activity, Fontana Group started to use AutoForm Assembly to analyse the production process of different parts (fenders, hoods, doors, etc.) to anticipate and prevent possible critical scenarios in the production start-up phase.

4. Conclusions
The first phase of the project confirmed that it is possible to properly represent productive assembly processes. All critical and essential process steps can be modelled in the available software. In the second phase, we were able to validate currently available simulation software on a complex industrial assembly process. Several critical aspects of the real process have been highlighted during the project thanks to the transparency carried out by the digital process twin modelled in simulation. The validation of the results allowed to certify the accuracy of the calculated result, demonstrating that the precise description of the assembly process allows to obtain the real geometric deformation of the assembled component. The simulation methodology enables engineers to mature the assembly process in the developments phase by defining a digital twin. This reduces the cumbersome trial and error loops and it contributes to a more effective car development.

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