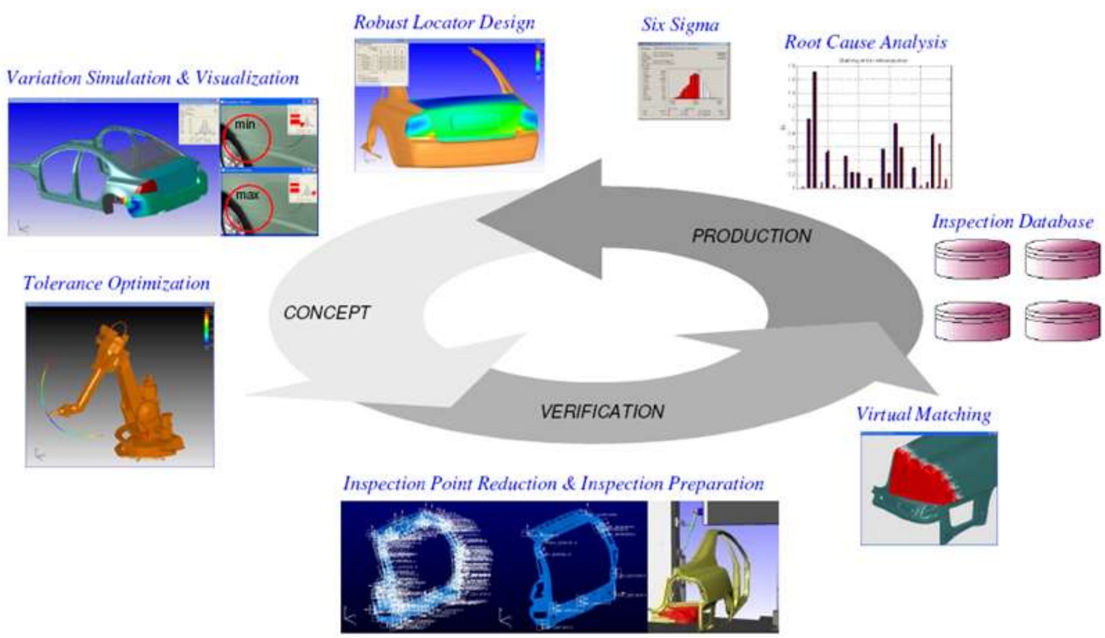
FFI

Virtual Verification from Forming to Final Assembly



Project within FFI – Sustainable Production Technique

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FFI

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**
For more information: www.vinnova.se/ffi

1 Executive summary

Increased demands on an efficient and sustainable automotive industry, driven by international competition and global demands on reduced use of resources, requires more efficient manufacturing systems.

The opportunity to virtually verify product and production concepts has the potential to drastically reduce the need for physical prototypes and test series. Furthermore, with virtual tools, the use light weight material will increase while it is possible to predict the consequences in an early phase of the project. With increased use of light weight material, the weight of the car body will decrease and hereby also the fuel consumption. This leads to more efficient and more environmental friendly transportation solutions. Another benefit is that the decreased use of prototypes and test series will reduce cost, time and resources as a consequence. Therefore, the development of tools and methods for virtual analysis, optimization and verification of manufacturing processes and production systems is of highest priority.

All manufacturing processes are afflicted by variation which may violate the fulfilment of assembly requirements, functional requirements or esthetical requirements like difficulties to reach desired form in all areas. For most manufacturing processes, the cost rises with requirements on decreased variation, which motivates robust design and manufacturing concepts. This project will focus on virtual development and verification of sheet metal (non-rigid) assemblies in all three phases of the product realization process (concept phase, pre-production phase and production phase).

By increased robustness in the manufacturing process, the material and energy consumption in the manufacturing process will decrease due the reduced amount of scrap and rework related to quality deficiencies. Decreased material and energy consumption are beneficial from an environmental perspective with consideration of the decrease in use of available resources and reduced emissions during the production process. Furthermore, increased product quality will strengthen the competiveness of Swedish industry.

The project consists of three different work packages (besides an education and a report package). These three main work packages address different areas which are necessary to fulfil the overall scope of the project – virtual methods for verification of all three phases in the product realization process.

All the individual goals from resp. WP. in the project has been reached. Methodology and tools for virtual verification from forming to Car Body Complete has been developed during the project. The technique is ready for implementation in limited scale. The limitations are subassemblies for a limited number of ingoing parts and part size. Further development is needed for treating all parts in one model. Regarding these limitations, it is possible to do virtual verification of the assembly process regarding spot weld order, part variation, assembly sequence starting either from forming simulation or measured single parts.

Regarding the overall project goals, the results can be seen below:

- One Ph.D. degree
  Result
  During the project, the focus has been to develop a working tool. The PhD candidate has put strong effort in developing tools, which can be implemented in industrial applications during the project therefore we are aiming for licentiate degree in Q1 2014.

- 7-8 reviewed international journals or conferences papers
  Result
  7 reviewed international journal and conference papers has been published.

- Decreased lead time for geometry verification of the process from forming to final assembly with 20%
  Result
  This goal is difficult to measure until virtual verification technique has been implemented in car projects. However, since the technology has been proven in limited scale, the potential to achieve this goal is high. The demonstrators in the project, shows that you can significantly reduce the lead time in the geometry verification. A realistic prediction is that the reduction can be higher than 20% if you start from sub assembled details instead of manual analysis and assembly of every single part. This will be implemented in the next car project.

- Decreased variation in critical dimensions with 20%
  Result
  This result is difficult to measure until virtual verification technique has been implemented in car projects. However, since the technology has been proven in limited scale, the potential to achieve this goal is high.

2 Background

All manufacturing processes are afflicted by variation which may violate the fulfilment of assembly requirements, functional requirements or esthetical requirements like difficulties to reach desired form in all areas. For most manufacturing processes, the cost rises with requirements on decreased variation, which motivates robust design and manufacturing concepts. This project will focus on development of reliable virtual tools for verification of sheet metal (non-rigid) assemblies in all three phases of the product realization process (concept phase, pre-production phase and production phase).

The project will increase the potential to use light weight materials with the use of reliable virtual tools. The possibilities to test consequences of new materials in an early project phase increases the acceptance for usage. Increased use of light weight material will reduce the weight of the car body as well as the fuel consumption. This leads to more efficient and more environmental friendly transportation solutions.

The use of virtual tools will also increase robustness in the manufacturing process, the material and energy consumption in the manufacturing process will decrease due the reduced amount of cassations and rework related to quality deficiencies. Decreased material and energy consumption are beneficial from an environmental perspective with consideration of the decrease in use of available resources and reduced emissions during the production process. Furthermore, increased product quality will strengthen the competiveness of Swedish industry.

In sheet metal forming and assembly, individual parts are designed and formed resulting in geometrical deviation. During assembly, individual parts are clamped in fixtures, spot-welded together and then released. Due to initial part variation (from the forming process) and fixture faults (due to wear) the final assembly will deviate from its nominal specification. The ability to analyse, optimize and verify this process is a critical key to improve product quality, decrease lead time, improve the efficiency, decrease material usage and energy consumption and save money.

The means of managing variation and secure function, form and assembly, is accomplished as a number of activities throughout the product realization process. In the concept phase the product and the production concept are developed. Product concepts are analyzed and optimized to withstand the effect of manufacturing variation and tested virtually against available production data. In this phase, the concept is optimized with respect to robustness and verified against assumed production system by statistical tolerance analysis. Often Monte Carlo simulation is used. The visual appearance of the product is optimized and product tolerances are allocated down to part level. Optimization of locator, support and assembly sequences which has a major impact on the geometrical quality of the final assembly, i.e. how well all the parts will fit together and how surfaces will bend and deform during assembly are defined in the late concept phase. However, the state of the art do not fully meet the industrial requirements and in this project both methods and virtual tools will be further developed towards industrially applicable methods and tools for variation simulation, sequence analysis and optimization.

In the pre-production and production phase, during assembly of newly produced components, form errors are discovered that can cause either functional or esthetical problems. One commonly used way of compensating for this is to reposition the components by adjusting their locators. Traditionally this is done by assembling a number of components, measuring the deviations to surrounding parts, adjusting the locator points, reassembling the components and measuring the result. This is repeated until the result is satisfactory, and is a quite time and effort consuming activity. Furthermore, it is necessary to consider the variation in the forming process. Based on inspection data from the initial components and the variation simulation model all trimming activities are performed in the computer tool presented. However, these methods are not reliable enough and require data from production. In order to increase the usage of virtual tools, it is necessary to improve the reliability as well as finding methods to use the tools without the need for production parts/results. If the analysis can be based on virtual results, it is possible to start the analysis earlier in the project and hereby give input to the project in an early phase. Necessary changes are more costly the later they are implemented in a project, therefore it is desired do as much changes as possible early in the project. Ability to analyze and optimize the whole process chain from forming to final assembly, requires both virtual tools for each individual process and tools for mapping of results between all ingoing processes. These tools are not available today.

This project utilizes the results which are available today and take one step further to be able to analyze and handle also compliant (non-rigid) components and assemblies. The project also investigates and proposes FEA-levels, procedures for material characterization and how to use and visualize results. This project will develop virtual tools and methods for coupling all processes from forming to assembly together (including variation). With these tools it will be possible to analyze the consequences of different concept choices and production consequences already in the concept and pre-production phase. This will lead to improved quality and decrease production disturbances with less cassations and energy consumption as consequence.

3 Objective

All manufacturing processes are afflicted by variation which may violate the fulfilment of assembly requirements, functional requirements or esthetical requirements. Another issue is the difficulties to reach desired form in all areas. For most manufacturing processes, the cost rises with requirements on decreased variation, which motivates robust design and manufacturing concepts. This project will focus on virtual development and verification of sheet metal (non-rigid) assemblies in all three phases (concept phase, pre-production phase, industrialisation phase) of the product realization process. An Industrial PhD-student will develop/improve existing virtual methods to support the above mentioned product realization processes with support from Volvo Car Corporation and Chalmers university.

4 Project realization

The project consists of three work-packages with a number of sub-areas as described below:

4.1 WP 1: Virtual Matching of Non-rigid Assemblies

During assembly of newly produced components, form errors are discovered that can cause either functional or esthetical problems. Matching is a process where form errors in individual parts are compensated or adjusted by adjusting locators or position of individual surfaces or features. In earlier projects, research results on virtual matching of rigid part have been presented. This project utilizes these results to take a step further to develop tools and working procedures that also include matching of non-rigid parts and assemblies.

Analyzing bending and deformation of non-rigid parts and assemblies often includes the use of finite element analysis (FEA). FEA are often very computationally expensive and must therefore be optimized for it particular purpose. Within FEA, the type and order of elements used as well as the resolution of the mesh are all parameters that influence the precision of the result but also the computational time. In this project, an industrially practically level of parameters suited for non-rigid matching will be investigated and proposed. This also includes techniques for modelling the assembly process.

Effective use of research results requires good ways of communicating and visualizing the analysis results. In earlier work on virtual matching for rigid parts, color coding, arrows and adjustment instructions was proposed to communicate analysis results into useful actions. Here, these ideas will be further developed to include also non-rigid matching and matching of surfaces.

4.2 WP 2: Assembly Sequences in non-rigid Assemblies

Sheet metal assemblies are often spot-welded together. In the automotive industry hundreds of sheet-metal parts are joined together by thousand of spot-welds. The position, the number of welds and the welding order has a major impact on how well all the parts will fit together and how surfaces will bend and deform during assembly.

Another factor of influence is the position and support parts during assembly and how they clamp the parts together. It is also important to regard the sequence in which sheet metal parts are assembled together which as well influences the final geometrical quality of the product.

In this project, these issues will be addressed and the research team will further develop industrially applicable methods and tools for the above mentioned problems.

4.3 WP 3: Virtual analysis of process chain from forming to final assembly

Virtual tools for analysis of the whole process chain, from forming to final assembly, require both virtual tools for each individual process as well as tools for mapping of results between ingoing processes. WP 1 and WP2 focuses on the individual processes while WP 3 focuses on couplings and integrations between different processes.

Virtual forming analysis is today an established technique. However, spring-back (geometry variation after forming) is still a difficult effect to predict. Furthermore, variation analysis needs to included in the analysis.

In order to use the results from forming analysis, efficient method for mapping of results, both regarding geometry after forming process and variation. Furthermore, it is necessary to include different form of input data to be handled by the assembly analysis (simulation, measured data etc.)

In this project, methods and tools will be developed to handle this analysis.

5 Results and deliverables

5.1 Efficient calculation methodologies for virtual assembly

During the project, new methods for efficient calculation methodologies for assembly processes regarding ingoing part variation have been developed. The methodology can be seen in figure 1.

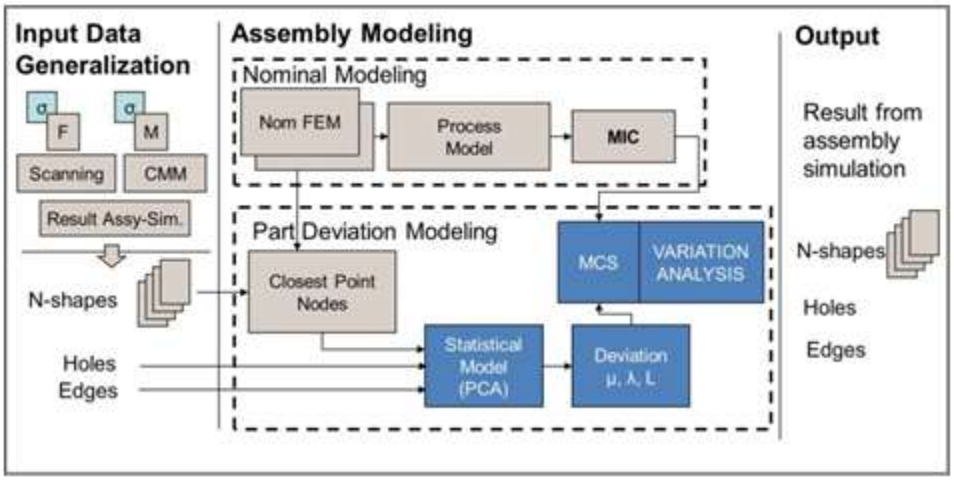

Figure 1. General description of calculation method (Lindau et al, 2013).

Using this technique means that input data to the assembly simulation can come from either measured data described by scanned data or discrete data. Another input can be data from virtual tools as sheet metal forming simulation. By using nominal models as base, the measured results can be used independently from source and hereby, an efficient calculation tool has been created. Furthermore, by use if simplified statistical models, the caluclation will be efficient.

5.2 Efficient usage of measurement input data

In order to have the correct input from production data, it is important to start from a situation which is not over-constrained. If the start condition of the ingoing parts are over-constrained, the inbound stressed would not be included in the assembly analysis and hereby the analysis would not be correct. Therefore a technique has been developed for simple transformation from non -constrained condition to a constrained condition. Hereby, measurement of non-constrained parts can easily be transformed to a constrained condition and results can be supplied to both virtual analysis and report of part deviation based on the same measurements. A description of the technique can be seen in figure 2.

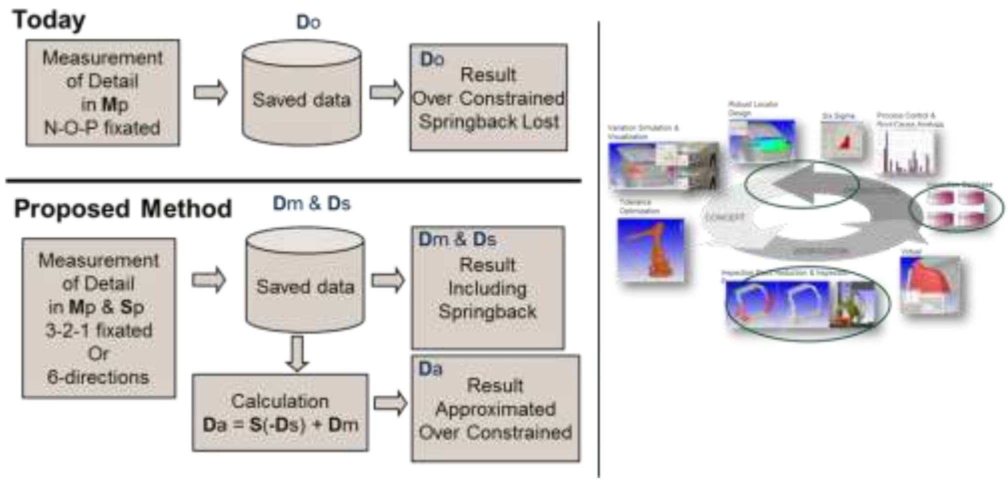

Figure 2. Description of technique transferring non-constrained measurement to over-constrained measurements (Lindau et al, 2012).

5.3 Methodology for using sheet metal forming simulations in virtual assembly analysis

Another source for input data is to start from sheet metal forming simulations. Technique for using this source has been developed during the project and has been proven to work including part variation from the forming operation. The study has been based on numerical data and no verification to produced parts has been made. However, the results indicates that the methodology is working and since results from virtual assembly analysis based on measured data using these tools shows good agreement between numerical and practical results the conclusion is that if the results from forming simulations are trustworthy, the results from assembly analysis is too. Figure 3 describes the above mentioned methodology. Within this study, it was also proven that using a simplified model using PCA-technique was successful.

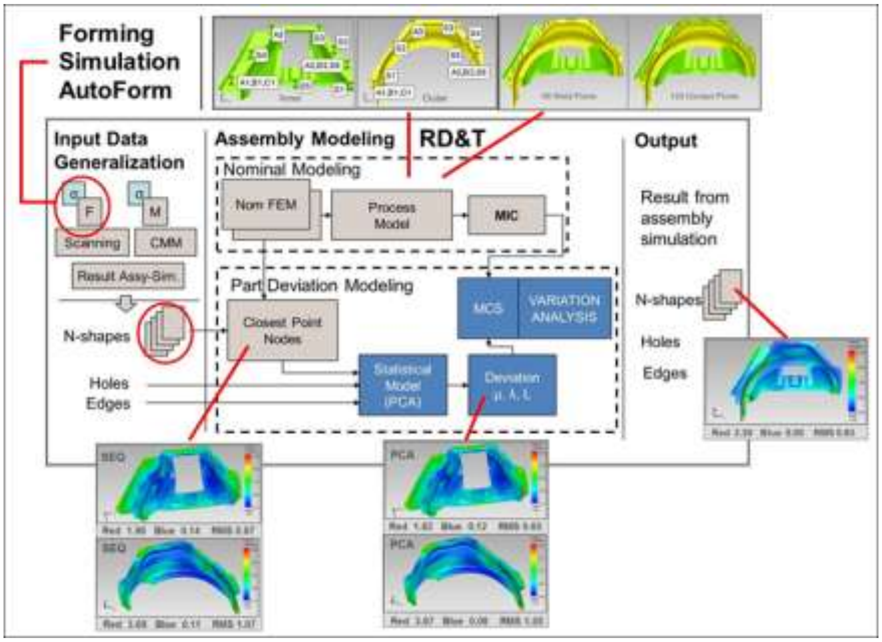

Figure 3. Methodolgy for using sheet metal forming simulation as base for virtual assembly analysis (Lindau et al, 2012).

5.4 Methodology for analyses in early phase using morphing technique

So far, virtual analysis of the assembly process has been performed in a phase in a project which requires the part design is ready. It would be beneficial to have ability to predict the assembly process already in the design phase. Methodology for this has been developed in the project by using morphing techniques in early stages on design models. The technique is described in figure 4 and with this technique, visualisation of variation of ingoing parts can be seen based on deformable models.

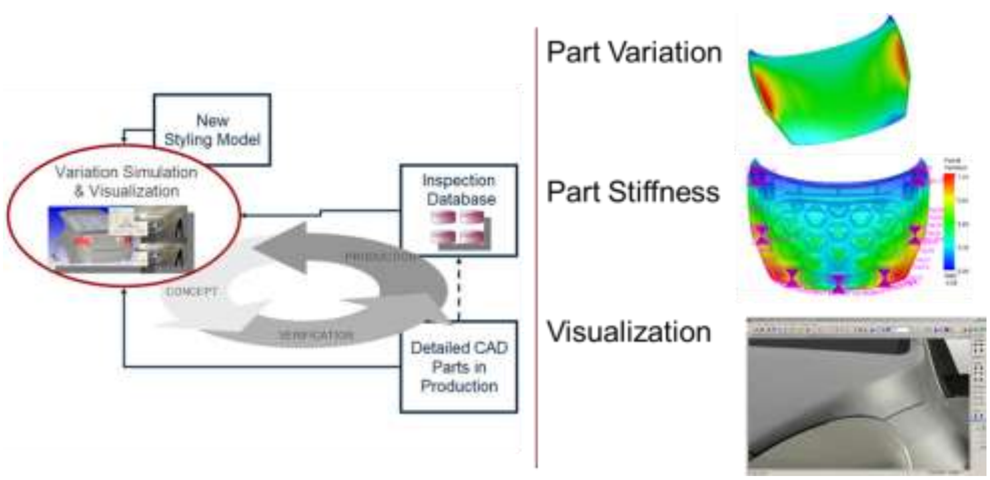

Figure 4. Description of analysis in early stages (Wagersten et al, 2013).

5.5 Improvement of accuracy by analysing clamping forces

In order to improve the accuracy of the results in the virtual verification of the assembly process, a study of effect of clamping forces has been done. In order to improve the virtual description of the clamping forces, a methodology for including correct clamping forces in the virtual assembly analysis has been done. The results indicates that it is necessary to include an improved description of the clamping forces in the model (Lindau et al, 2013).

5.6 Methodology for decreasing model sizes

A large limitation is the model size. When the assembly structures complexity increase, the model sizes increase very much. Therefore, a study is ongoing to find an alternative calculation method in order to decrease the model size.

6 The relevance of the project to the programme

6.1 Contribution to targets

Increased demands on an efficient and sustainable automotive industry, driven by international competition and global demands on reduced use of resources, requires more efficient manufacturing systems.

The opportunity to virtually verify product and production concepts has the potential to drastically reduce the need for physical prototypes and test series. Furthermore, with virtual tools, the use light weight material will increase while it is possible to predict the consequences in an early phase of the project. With increased use of light weight material, the weight of the car body will decrease and hereby also the fuel consumption. This leads to more efficient and more environmental friendly transportation solutions. Another benefit is that the decreased use of prototypes and test series will reduce cost, time and resources as a consequence. Therefore, the development of tools and methods for virtual analysis, optimization and verification of manufacturing processes and production systems is of highest priority. This contributes to the programs targets of decreased weight of vehicles, usage of virtual tools in the engineering process and higher productivity in the engineering process.

With increased use of virtual tools, it is possible to develop processes which are more robust and generates less deviation from nominal values. By increased stability in the manufacturing process, it also will decrease the material and energy consumption in the manufacturing process due the reduced amount of scrap and rework due to quality deficiencies. Furthermore, the increased quality will also increase the competiveness of Swedish products and strengthen the Swedish industry. This contributes to the program targets of decreased environmental influence of the manufacturing process.

The knowledge and results from the project is directly transferable to other automotive companies but also to other industrial segments like building, construction and biomech. Success in reaching the goals of the project will open up new research and market opportunities. Increased long-term collaboration with partners from new segments is expected.

The research team has a good track record when it comes to project management, research, technology transfer and implementation.

6.2 Uniqueness and news value

State of the art concerning virtual geometry assurance does not involve processes outside the assembly process. Hereby, the input is depending on either data from previous experience or data achieved late in the project phase (when try-out parts are available). To take one step forward and to fully use the potential of virtual tools, it is necessary to find tools/methods were the forming process is included in the input generation for virtual geometry assurance process. Hereby, it is possible to have a closed virtual loop early in the project phase and use the full advantage of virtual tools. It is not necessary to wait for try-out parts.

Regarding the assembly analysis, it is possible to handle part variation in the assembly process as well as spot weld location. However, the technique needs further development and therefore, another task in this project is to:

- Include more processes in the virtual analysis (e.g. assembly sequence, clamping sequence, spot weld sequence)
- Optimize of the process.
- Improve the simulation models

Altogether, this will improve the accuracy and usefulness of the virtual analysis.

Decrease of the lead-time with more efficient methods and improved communication of results will broaden the acceptance for the new virtual technique and also contribute to improve the common level of knowledge. Easier interpretation of the results and possibility to deeper analysis of governing mechanisms in the geometry assurance process will improve both quality and robustness of products and processes.

7 Dissemination and publications

7.1 Knowledge and results dissemination

The results have been distributed via national and international conferences and journal articles. Furthermore, the results have been presented at open national seminars at Wingquist Laboratory at Chalmers. The research group at Chalmers have worked together and used the knowledge from different fields to move the research frontier forward in their resp, field.

Furthermore, the results have been implemented in projects at Volvo Cars with good results.

During the project, continuous education of personnel at Volvo Cars has been done. The results have also been used in the education of master students at Chalmers University.

7.2 Publications

Lindau B., Andersson A., Lindkvist L., and Söderberg R., 2012, Statistical shape modeling in virtual assembly using PCA-technique, 4th CIRP Conference on Assembly Technologies And Systems, Ann Arbor, USA.

Lindau, B., Lindkvist, L., Andersson,A. and Söderberg, R.,2013, Statistical Shape Modelling in Virtual Assembly, using PCA-Technique, Journal of Manufacturing Systems.

Lindau, B., Lindkvist, L., Andersson,A. and Söderberg, R., Body In White Geometry Measurements of Non-Rigid Components, a Virtual Perspective, ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2012, August 12-15, 2012, Chicago, IL, USA

Lindau, B., Lindkvist, L., Andersson,A. and Söderberg, R., Using Forming Simulation Results in Virtual Assembly Analysis ASME 2012 International Mechanical Engineering Congress & Exposition, ASME, IMECE 2012, November 9-15, 2012,Houston, Texas, USA

Wagersten, O., Lindau, B., Lindkvist, L., Söderberg, R., Using Morphing Techniques in Early Variation Analysis, ASME 2013 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, IDETC/CIE 2013, August 4-7, 2013, Portland, Oregon, USA

Wagersten, O., Lindau, B., Lindkvist, L., Söderberg, R., Using Morphing Techniques in Early Variation Analysis, 2013, Journal of Computing and Information Science in Engineering

Lindau, B., Lindkvist, L., Wärmefjord, K., and Söderberg, R., Aspects of fixture clamp modeling in non-rigid variation simulation of sheet metal assemblies. ASME 2013 International Mechanical Engineering Congress and Exposition, IMECE 2013, November 13-21, San Diego, California, USA.

8 Conclusions and future research

The project has proven the functionality to use forming simulation as input to assembly simulation and developed techniques to include variation into the analysis. During the project, many issues have appeared which have been addressed. Hereby, complementary methods for increased efficiency in the virtual assembly have been developed and also techniques for usage of different input sources. Furthermore, the work with developing analysing methods in the design phase (where only rough models are available) based on deformable parts has been initiated.
However, large data models are a remaining restriction, which limits the usage of the developed technique. This issue is addressed by analysis of methods for decreasing the model size with affecting the accuracy of the results, together with more efficient calculation methods.
Proposal for new research questions:

- How can we improve the efficiency in the calculation for analysing complete Body in White?
- How can we include non-metallic parts in the analysis?
- How can we improve the accuracy in the results by improved description of input data?
- Optimisation of the assembly process

9 Participating parties and contact person

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