

GENERATING HYBRID GEOMETRY MODELS FOR MORE PRECISE SIMULATIONS BY COMBINING PARAMETRIC CAD-MODELS WITH 3D SURFACE SCANNED GEOMETRY INSERTS

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Abstract

In general, every component shows differences to its ideal geometry of the designed CAD-model, i.e. due to deformations in the production process. Despite knowing the effects of deformations, the product developer always uses the ideal, non-deformed design model of the CAD-system for FE-simulations of a component. It seems rather doubtful that further refinement of simulation methods (e.g. using different non-linearities) makes sense, if the real manufactured geometry of the component is not considered for in the simulation process. Therefore, this paper describes an approach to use hybrid geometry models for simulations, which are mostly built of the parametric CAD-model, but areas with large deviations are substituted with surface reconstructed scan-inserts based on 3d surface scanned data, reconstructed to NURBS-patches. This procedure allows a more precise simulation as it considers deviations by minimizing the amount of data and the time for model preparation.

Keywords: Computer aided design (CAD), Product modelling, models, Simulation, Reverse engineering (RE)

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1 INTRODUCTION

Today's product development process is picking up the pace. To avoid performing complex and expensive testing including all iterations of the product development with a real prototype, various FE-simulations (finite element) for the functional validation of the desired characteristics are made. The discretization of a developed component and the use of the simulation conditions, like taking into account different non-linearities (i.e. material behaviour, contact situations, large deflections etc.), is a tremendous effort and is necessary to get precise and significant results.

In general, every manufactured component shows differences to its ideal geometry of the designed CAD-model (computer aided design), i.e. due to deformations in the production process. Besides random deviations, these differences can vary depending on the manufacturing process and the component size. In cutting processes the value is relatively small, but using other manufacturing techniques, process-related effects may occur and can trigger bigger deformations. So, spring back (Bartenschlager et al., 2013) and drapery (Birkert et al., 2013) may arise when using forming techniques (i.e. deep-drawing or bending). Besides that, using various casting processes (i.e. die casting or injection moulding), effects like shrinkage (Nee, 2014) and warpage, i.e. due to the solidification and cooling of the component in the die, due to separating sprue and overflow system or due to inhomogeneous temperature fields when cooling to room temperature at components with differences in wall thickness (Thoma et al., 2013), can also cause large deformations. Despite knowing the effects of deformations, due to the production process mentioned above, the product developer always uses the ideal, non-deformed design model of a CAD-system for the FE-simulation of a component (Gebhardt, 2011). It seems rather doubtful that further refinement of simulation methods makes sense, when the real manufactured geometry of the component is not considered for the simulation.

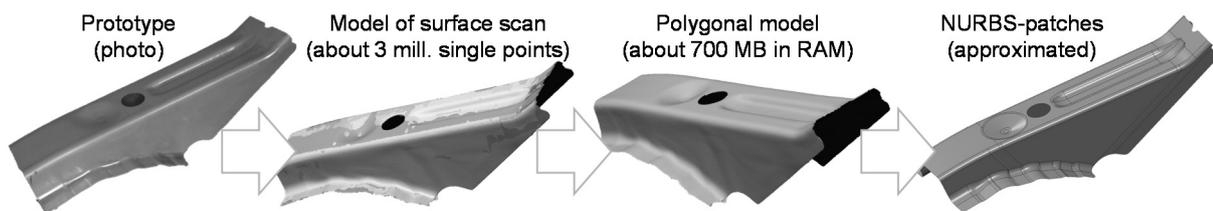


Figure 1. Sequels of scanned geometry with critical quantity of data

Reverse engineering (RE) is a way to represent those deviations of the real geometry. Within this process a 3d surface scan of a component/prototype is created with a laser line or structured light scanner. The scanner systems generate a point cloud, which is tessellated to a polygonal model afterwards. However, those models have the main disadvantage that it results in a high quantity of data (Figure 1). To avoid the big data problem a complex and time consuming reconstruction (Schöne, 2009) to mathematically described surfaces (mostly NURBS-patches, non-uniform rational b-splines) based upon the polygonal model must be performed.

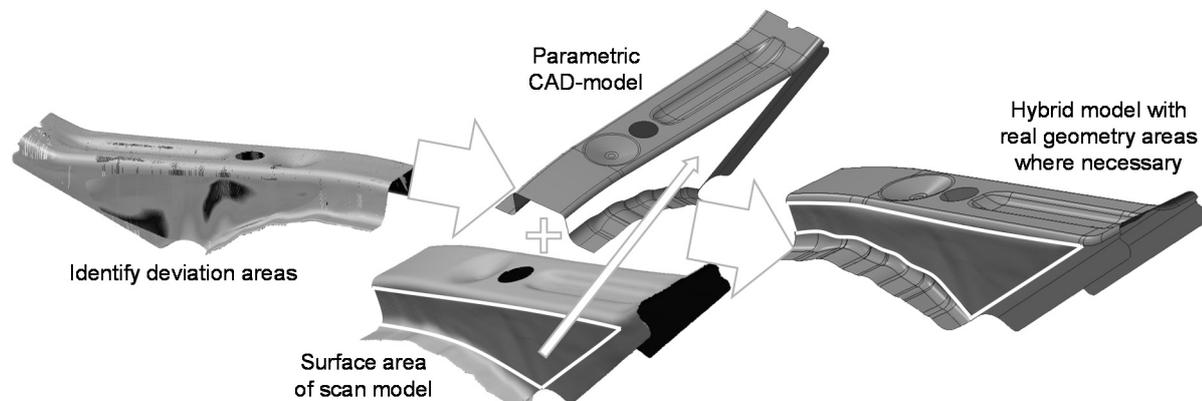


Figure 2. Hybrid model consisting of CAD-geometry and scan-insert to reduce quantity of data

Thus, to improve results of FE-simulations a real-world model, including deviations from the production process, should be used. Furthermore, a model with little quantity of data is required to allow the use of regular workstation computers within an acceptable period of time for running the simulation.

Accordingly, the aim of this work is to generate geometry models for simulation purposes which meet the requirements in terms of the possibility of parametric editing, small data size and in addition to provide the real geometry information of a manufactured component. Therefore, this paper describes an approach to use hybrid geometry models for simulations. These hybrid models result from the parametric CAD-model for the most areas of the part, but areas with large deviations are substituted by scan inserts. Those inserts consist of surface reconstructed NURBS-patches based on the recorded data set of a real components 3d surface scan (Figure 2). This procedure allows a more exact simulation as it considers deviations by minimizing the amount of data and the time for model preparation.

2 THEORY AND PROCESS OF CREATING HYBRID MODELS

The approach of creating a hybrid model contains many parts of the reverse engineering process. The entire process is shown below (Figure 3).

At first, a real component has to be digitalized. Therefore, different optical (laser and structured light), tactile and radiological scanner systems are used (Koch et al., 1998). These scanners record the surface in three dimensions with the light-section method, based on the basic principle of triangulation (Weckenmann, 2001). To compare the real geometry to the ideal geometry, the generated point cloud or polygonal model and the CAD-model have to lie on top of each other, called registration. This is done by using a best-fit-algorithm (Chen, 2012), (Herrmann and Moeser, 2008), mostly following to an interactive registration where users pick corresponding distinct points (Weckenmann, 2012). After fitting in, the ideal CAD-model must be compared with the detected real geometry data. The deviations between both are analyzed and can e.g. be displayed with a false-color plot.

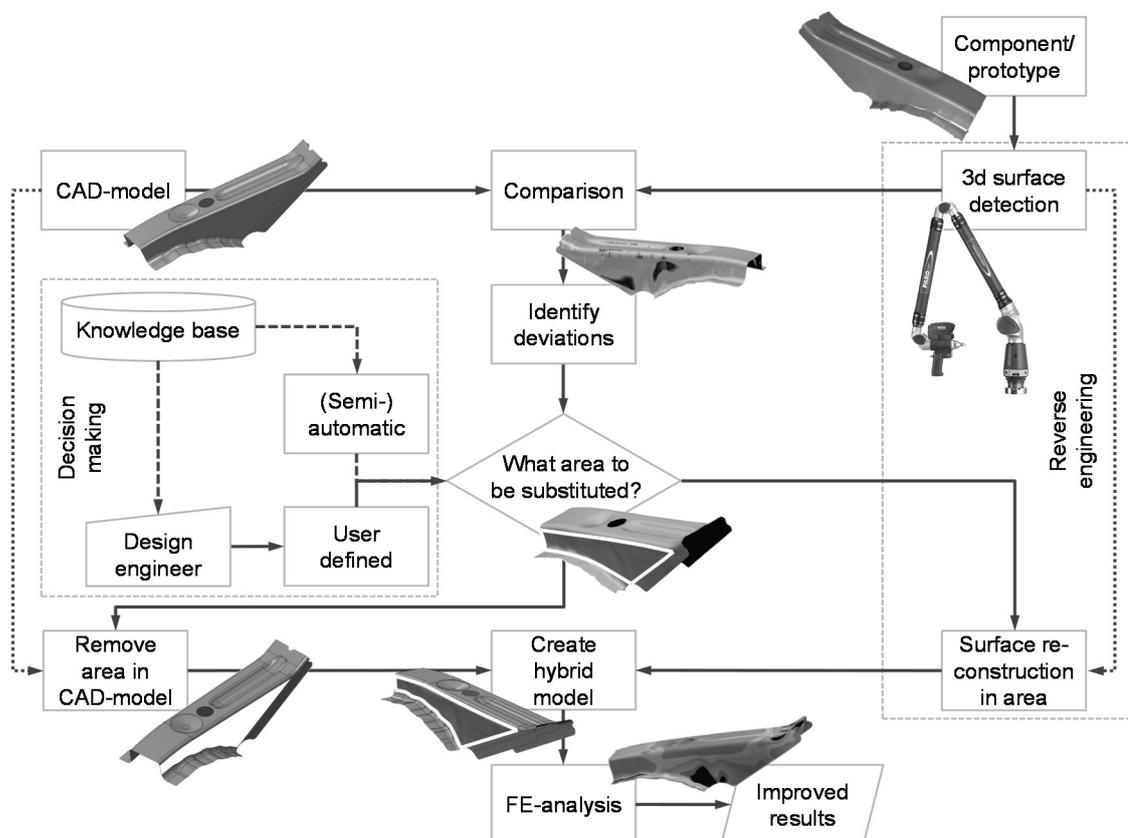


Figure 3. Process of creating hybrid models

A decision has to be taken concerning the shown deviations: Which areas of the ideal CAD-model should be substituted? Currently, the design engineer decides user defined, checking the false-color print and picking the desired faces manually by drawing curves around the desired areas. For the future a knowledge base could be established (for example containing flow of force or requirements of accuracy) to support the design engineer's decision making process since not every large deviation inevitably leads to bad or other simulation results than the ideal geometry. Furthermore, decision making and substitution of the surface areas could be done (semi-) automatically with the extension and implementation of a knowledge base.

Once the areas being substituted are defined, the CAD-model and the scanned data need to be updated to be combined. Within the CAD-surface-model the area or surface patches have to be selected and deleted or ignored. The detected point cloud must be tessellated to a polygonal model, if this has not already been done. The polygonal model is the base for a surface reconstruction to mathematically described surfaces instead of a polygonal mesh. Therefore, the design engineer draws borderline curves in form of the substituted area on top of the polygonal model. Inside these borderline curves, the polygonal model gets segmented to simple four-sided surface segments. Every segment is used to reconstruct a single surface patch by generating a NURBS-patch inside. Generally, the surface reconstruction is a very complex and time-consuming step. A huge advantage in this case is that only a small area must be reconstructed and different developed algorithms for automating the step of surface reconstruction (Katona et al., 2014a), (Wilke, 2000) can be used. All previous created patches form the new, real surface can finally be assembled with the CAD-model to the aspired hybrid model.

There are two ways to connect the ideal CAD-model with the surface reconstructed scan geometry in order to create hybrid models: depending on the distribution of relevant deviations the transition is situated within a surface or at its edges. Both versions differ in action and complexity. As the connection within the surface can be performed quite easily by drawing curves on the surface, cutting out the segment with some offset and filling the gap continuously, a connection at the edges is more difficult to handle. This is the case because CAD-systems cannot easily enlarge every surface automatically to have enough overhangs to trim. As a matter of fact, the user (design engineer) still has to do a lot of the work manually.

When finally the hybrid model is created, it can be used to perform the various FE-simulations for the functional validation of the desired characteristics of the component.

2.1 The process of reverse engineering (RE)

The first step of the reverse engineering process is used for generating real geometry data. Therefore, a component surface is gradually scanned with a laser line and/or a structured light scanner. The geometry normally is detected in form of a point cloud. Generally, reverse engineering describes the procedure of returning a real existing component into a CAD-model (Percoco, 2014). The process of RE is a generic process (Raja and Fernandes, 2008) and essentially includes three steps (Katona et al., 2014b), (Figure 4).

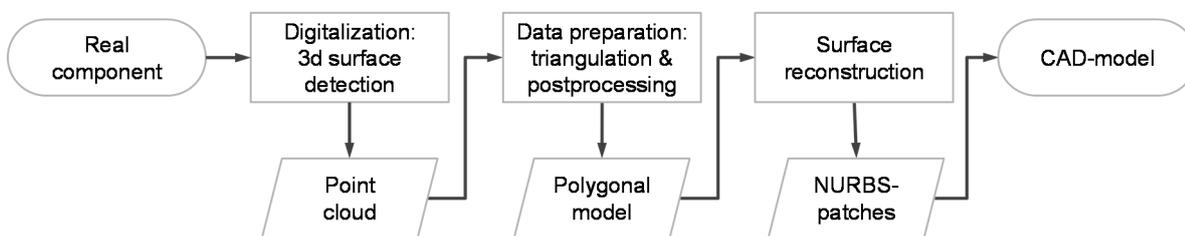


Figure 4. The process of reverse engineering (RE)

First of all, a digital point cloud of a component surface is produced by using suitable measuring equipment (often laser line scanners). These points only consist of the three xyz-coordinates and do not bear any relation to each other. A second step includes the generation of neighborly relations with suitable algorithms like Delaunay-algorithm (Ottmann and Widmayer, 2012) to create a polygonal model – this is also called triangulation or tessellation. Furthermore, a postprocessing of the scan data is frequently required (this implies smoothing surfaces, closing holes from undetectable areas or manual deleting of wrongly captured areas through noise or mounting brackets). The third and last step comprises the reconstruction into a CAD surface model. Therefore, the polygonal model has to be

segmented into three- or four-sided areas. Each area will be described as one surface patch later. A standard for a mathematical surface description is by using NURBS surfaces. These surface patches offer an exact description for both, analytical standard forms and free-form surfaces. Other advantages of NURBS-patches are: a relatively small memory usage, because only control points, grid and knot vectors have to be saved, as well as the speed and numerical stability of NURBS-algorithms (Piegel and Tiller, 1997). The surface reconstruction, in general, is a very complex and time-consuming part of the RE process. Approximately 80% or even more of the total time in reverse engineering is often used for segmenting and reconstructing the polygonal model to surfaces (Schöne 2009).

2.2 Strategies of creating hybrid models depending on the type of transition

As mentioned above, there are two strategies to create hybrid models depending on the distribution of the deviation (Figure 5).

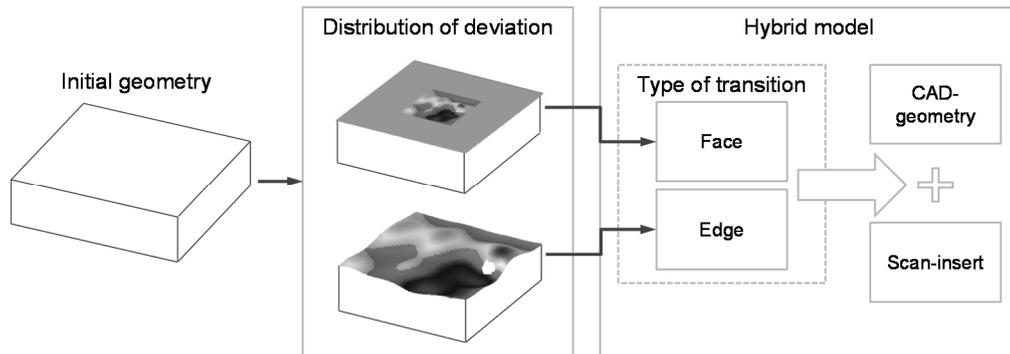


Figure 5. Strategies of creating hybrid models depending on the type of transition

On the one hand, the deviated area occurs within a smooth surface. In this case the hybrid model is created with the transition at a face. On the other hand, the transition for hybrid models lies at edges if a whole surface includes relevant deviations. Both strategies are described in detail below.

2.2.1 Transition at face

The first strategy is used when most of the deviated area occurs within a smooth surface (Figure 6). Hereby, the part of deviation gets surrounded by curves and a segment with the same contour is cut out of the initial CAD-surface-model with an offset. Afterwards, a surface reconstruction of the scanned geometry is performed in that area. At last, the gap between the cut surface and the surface reconstructed scan geometry is filled continuously. Geometric third-level continuity (curvature continuity) is used to get smooth transitions. This includes a positional continuity (G0), where the end positions of two surfaces match, as well as a tangential continuity (G1), which implies that the end vectors of the surfaces are parallel and pointing in the same direction. Curvature continuity (G2) indicates that the end vectors have the length (Autodesk, 2014).

This method offers a great potential for automation.

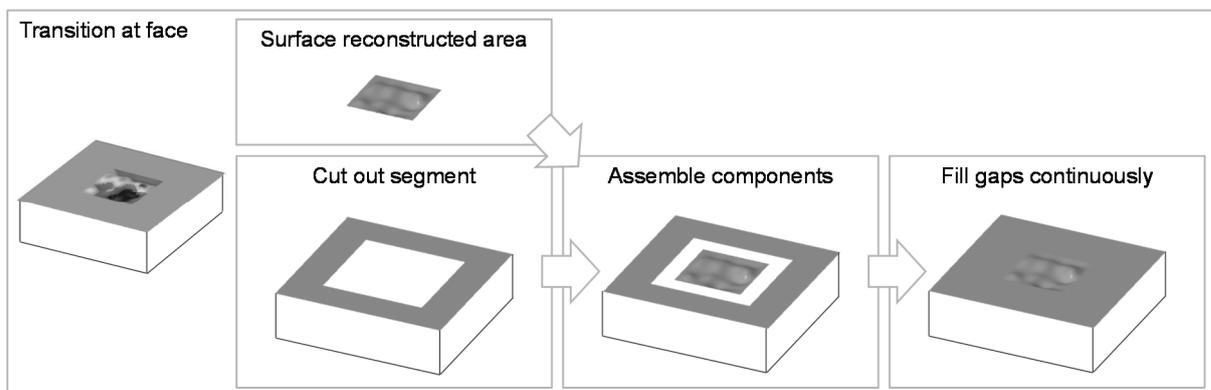


Figure 6. Creating a hybrid model with transition at a face

2.2.2 Transition at edge

The application of the second strategy takes place when almost the whole surface including the edges on each side needs to be substituted (Figure 7). In this case the whole surface of the initial CAD-model is deleted and within that borders a surface reconstruction is produced based on the scan data. To reconstruct the edges, both, the open CAD-model and the scanned surface, are enlarged continuously until they overlap at every position. The overhangs get finally trimmed to close the model.

Applying this method is very complex at the moment since the surfaces cannot be enlarged automatically for the most part. The design engineer still has to do a lot of manual work to get all surfaces overlapped everywhere.

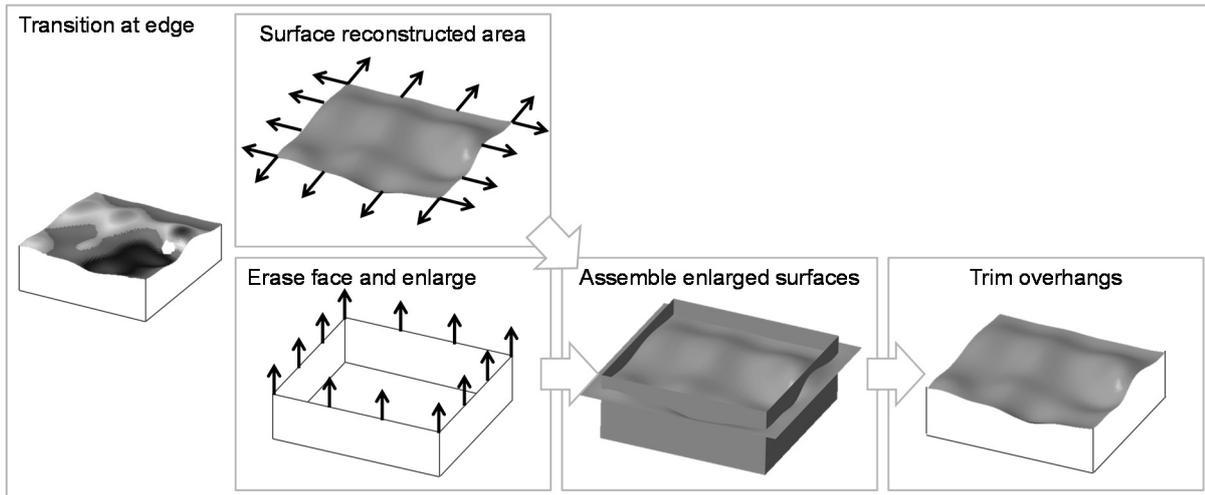


Figure 7. Creating a hybrid model with transitions at edges

3 DEMONSTRATING THE APPROACH USING EXAMPLES

Following, two examples illustrate the previously presented approach, each using one of the described strategies. These examples are based on real industrial applications and represent a higher degree of complexity. That is done to demonstrate the closeness to reality of this approach.

3.1 Complex deep-drawn component with transition at faces

Sheet metal parts normally show no sharp edges due to the production processes like bending or drawing. Thus, the method with *transition at faces* is used to create a hybrid model of the complex deep-drawn sheet metal component in this example.

There are some deviations in different areas of that component which can be recognized (Figure 8). Reasons for that could be, for example, tool wear or a too low hold-down force.

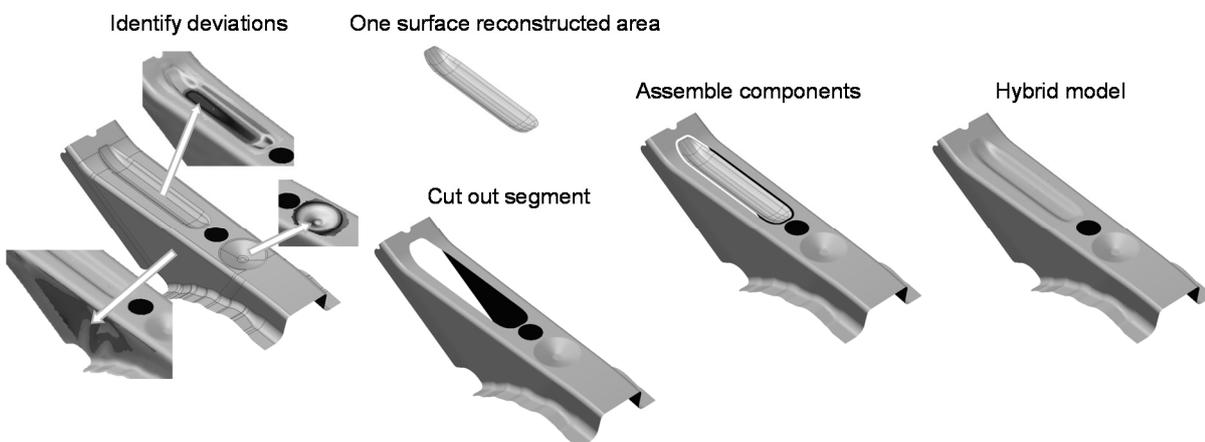


Figure 8. Deviated areas at a complex deep-drawn component and hybrid modelling with transition at faces, realized with programmed tools within PolyWorks and SolidWorks

On top of the component both the longish and the cone bead show deviations to the CAD-model. In addition, drapery can be detected on both sides. For the hybrid geometry model every of those mentioned single areas with large differences from the CAD-model to the surface detected model is substituted by a scan-insert to compensate these deformations.

The substitution of the identified areas is supported by PolyWorks, a software for processing and analysing three-dimensional datasets (Duwe, 2014), because the used CAD-systems show weaknesses in connecting the CAD-model and the scan-insert with the right continuity. Furthermore, within PolyWorks triangulation of the point cloud, postprocessing of the polygonal model and surface reconstruction of the insert are performed. The most important aspect of using this software in particular is that a high degree of automation of the whole process can be achieved for every scan insert with already available programmable additional applications (Katona et al., 2014a) within PolyWorks.

The analysis of the component with an FE-simulation shows different results when using the ideal CAD-model or the corrected hybrid model. This is a consequence of the deviations triggered in the production process (Figure 9). In both cases the component is meshed in similar ways with shell elements and the same boundary conditions, forces and material definitions are applied. The deviations of the model are already visible in the meshed hybrid geometry model. The classification in the qualitative colour plots are identically, too, to show the differences between the ideal and the real geometry model.

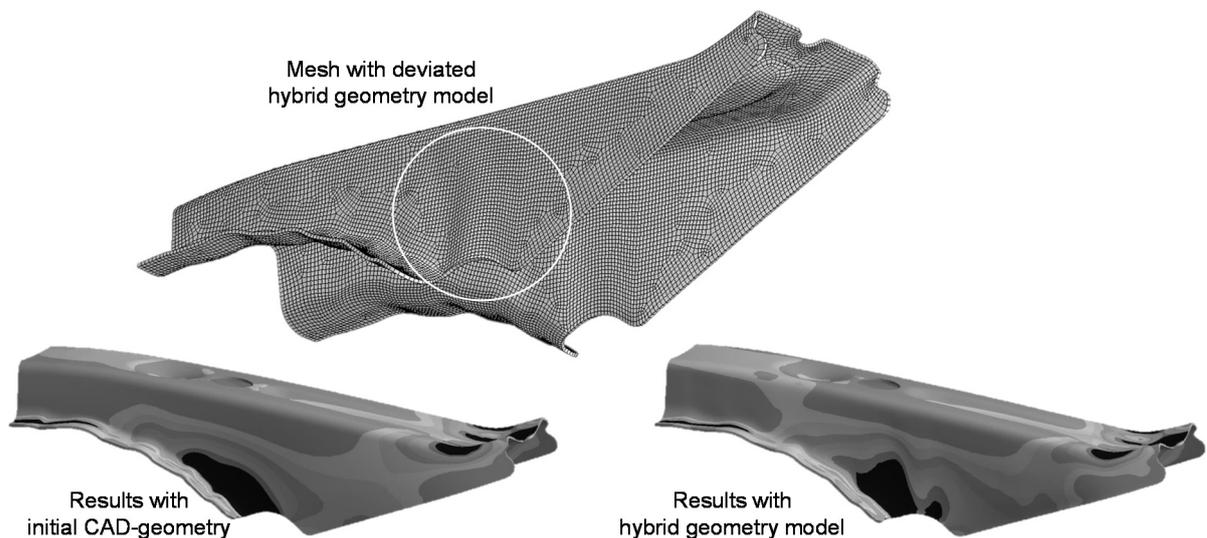


Figure 9. FE-mesh of real geometry model with integrated deviations by using a hybrid model and in comparison a qualitatively displayed result plot

3.2 Injection moulded snap with transition at edges

An example for *transition at edges* is given by using an injection moulded snap. In this assembly of a rear mirror system a spring presses down a snap to hold the right position of the mirror. Due to the production processes the faces are not even everywhere so that the contact region is not over the whole surface but only to some smaller areas (Figure 10).

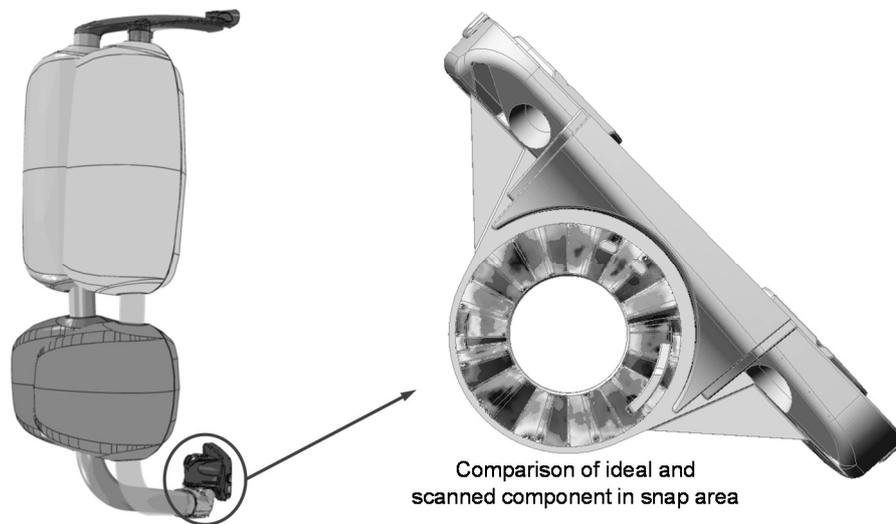


Figure 10. Assembly of a rear mirror system with deviations in snap area (with kind permission of MEKRA Lang GmbH & Co. KG)

This leads to different results of simulation and test bench when running a vibrational analysis. To minimize the deviations and come closer to reality a hybrid model of the component, with a scan-insert at the snap is created and used for comparative simulations. All ideal snap surfaces are erased in the CAD-model and substituted with 3d scanned and reconstructed surfaces to generate a hybrid geometry model (Figure 11).

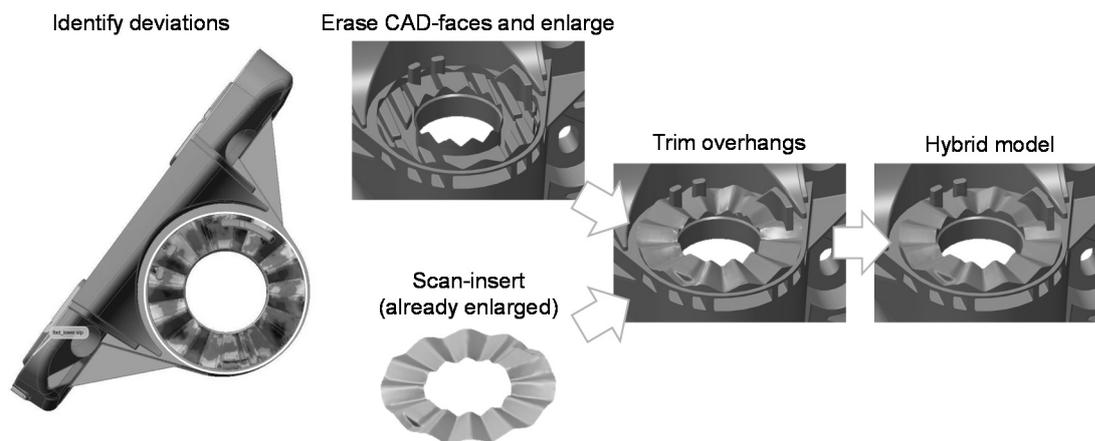


Figure 11. Injection moulded component with a snap to hold the right position, hybrid modelling with transition at edges using PolyWorks and CREO

High manual effort is necessary for the substitution of the real faces because the used CAD-systems are not able to enlarge faces tangentially automatically. Consequently, non-native CAD-formats like STEP-files (standard for the exchange of product model data) can be assumed as a reason. However, for a general validity the use of a neutral format within the three characteristics of neutral CAX-formats according to Troll (2014), data consistency, size of data and flexibility, should be aspired. The huge varieties in procedure according to the different components complicate a universal automation, but within a specific group of components it might be realized.

No universal algorithm for building up a hybrid model seems feasible today, due to the complex curves being formed by erasing CAD-faces and due to the manifold constraints regarding the transitions of CAD-faces and scan-inserts. From the author's point of view automation is only realisable for groups of products which have a similar shape.

With the new hybrid model, comparative contact simulations are performed (Figure 12). As suspected, it can be recognized that the real contact is existing only in small areas of the snap's surface. Depending on this, the performed vibrational analysis provide results for the frequency which match a lot better to test bench results than performed simulations using the non-deformed CAD geometry.

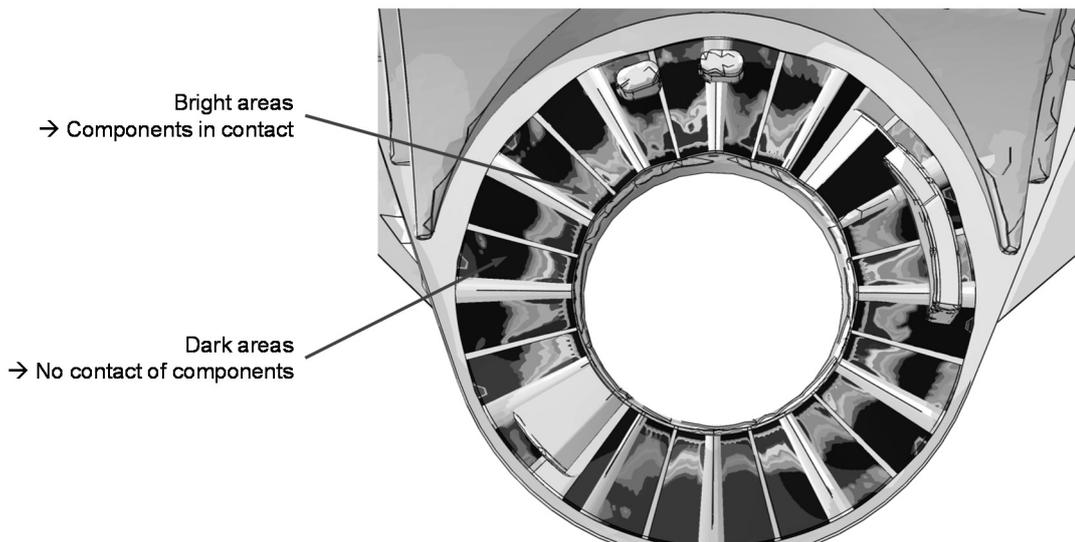


Figure 12. Real contact situation in snap area, which delivers better matching results of the simulation to test bench results (with kind permission of MEKRA Lang GmbH & Co. KG)

4 FUTURE FIELDS OF RESEARCH

To make this application useable in general, the automation of both strategies of transition should be pushed forward. The best way to realise this would be the use as a functionality within the common environment of a design engineer, thus a CAD-system. Furthermore, a combination of transition at faces and edges has to be aspired to cover the whole scope of application.

In addition, it is a present concern to substitute the three-dimensional surface scan of the real component with a simulated model (for example using software AutoForm or Moldflow). Consequently, the engineer has the opportunity to analyse the component with real geometry data in an early phase of the product development process, even before there is a deformed component as a prototype at hand. Within the context of a “digital mock-up” (Scholz et al., 2006), the renunciation of the real manufactured prototype has to be aspired.

Last, the identification of the CAD-faces to be replaced by scanned faces has to be automated further. As stated above, this could be realised by combining various approaches like analysing the distribution of forces partly in correspondence to the direction of scanned crinkles and appropriate reference values from a knowledge base.

5 SUMMARY

To sum up, every produced component differs in its geometry compared to the ideal model of the CAD-system. As shown in the prior examples, at the one hand a complex deep-drawn component with transition at faces and on the other hand an injection molded snap with transition at edges, deviations due to the production process can in fact trigger relevant influences on the results of desired and performed analysis. The approach of creating hybrid geometry models with scan-inserts, meaning elements with real geometry, detected from a prototype and generated with reverse engineering techniques, described in this paper shows an opportunity to come closer to reality with CAD-models and simulations. Therefore, self-created applications within PolyWorks and SolidWorks are implemented to realize parts of the presented approach.

The advantage, that only specific areas of a three-dimensional scanned object have to be redesigned with surface reconstruction for that purpose, can be pointed out. Once the real geometry in form of a prototype is available, a simulation with real geometry data can be performed to improve the FE-results for more realism and reliability.

REFERENCES

- Autodesk (2014) Introduction to Continuity Terminology [online], http://www.aliasworkbench.com/theoryBuilders/TB3_continuity1.htm (26-Nov-2014).
- Bartenschlager, J., Dillinger, J., Escherich, W., Günter, W., Ignatowitz, E., Oesterle, S., Reißer, L., Stephan, A., Vetter, R. and Wieneke, F. (2013) Fachkunde Metall. Haan-Gruiten: Europa Lehrmittel.
- BFS (2013) Forschungsverbund für effiziente Produkt- und Prozessentwicklung durch wissensbasiert Simulation – FORPRO² [online], <http://www.forschungsstiftung.de/Projekte/Details/Forschungsverbund-fuer-effiziente-Produkt-und-Prozessentwicklung-durch-wissensbasierte-Simulation-FORPRO.html> (26-Nov-2014).
- Birkert, A., Haage, S. and Straub, M. (2013) Umformtechnische Herstellung komplexer Karosserieteile – Auslegung von Ziehanlagen. Berlin, Heidelberg: Springer Vieweg.
- Chen, L. M. (2012) Digital Functions and Data Reconstructions – Digital-Discrete Methods. Harlow, Essex, New York: Longman Scientific & Technical, Wiley.
- Duwe-3d AG (2014) PolyWorks [online], <http://www.duwe-3d.de/en/products/polyworks> (28-Nov-2014).
- FORPRO² (2014) Forschungsverbund FORPRO² [online], <http://www.forpro2.tum.de/index.php?id=5&L=1> (26-Nov-2014).
- Gebhardt, C. (2011) Praxisbuch FEM mit ANSYS Workbench – Einführung in die lineare und nichtlineare Mechanik. München: Hanser.
- Herrmann, J. and Moeser, M. (2008) Reverse Engineering – Vom Objekt zum Modell. Allgemeine Vermessungsnachrichten, Vol. 5, 27-36.
- Katona, S., Koch, M. and Wartzack, S. (2014a) Reale Bauteilgeometrien simulieren – Automatisierte Flächenrückführung. Digital Engineering Magazin, Vol. 4, 38-40.
- Katona, S., Koch, M. and Wartzack, S. (2014b) Reverse Engineering – Prozess, Technologien und Anwendungsfälle. In: Rieg, F. and Hackenschmidt, R. (eds), 16. Bayreuther 3D-Konstrukteurstag, Lehrstuhl für Konstruktionslehre und CAD, 17-Sep-2014, Universität Bayreuth.
- Koch, A. W., Rupert, M. W., Toedter, O. and Häusler, G. (1998) Optische Messtechnik an technischen Oberflächen. Renningen-Malmsheim: Expert.
- Nee, A. Y. C. (ed.) (2014) Handbook of Manufacturing Engineering and Technology. London, Springer.
- Ottmann, T. and Widmayer, P. (2012) Algorithmen und Datenstrukturen. Heidelberg: Springer.
- Percoco, G. (2014) Reverse Engineering. In: Laperrière, G. and Reinhart, G. (eds), CIRP Encyclopedia of Production Engineering, Berlin, Heidelberg: Springer.
- Piegel, L. and Tiller, W. (1997) The NURBS-Book. Berlin, Heidelberg: Springer.
- Raja, V. and Fernandes, K. (eds) (2008) Reverse Engineering – an industrial perspective. London: Springer.
- Scholz, E., Burckhardt, C. and Dietrich, S. (2006) Digital Mock-Up in der Produktentwicklung [online], <https://fbme.htwkleipzig.de/fileadmin/fbme/informationen/TVorstellung/DMU.pdf> (12-Jan-2015).
- Schöne, C. (2009) Reverse Engineering für Freiformflächen in Prozessketten der Produktionstechnik. Habilitation thesis, München: Dr. Hut, Fakultät Maschinenwesen der Technischen Universität Dresden.
- Thoma, C., Volk, W., Branner, G. and Eibisch, H. (2013) Simulation based Optimization of the dimensional Accuracy for thin-walled Structural Components in Aluminium High Pressure Die Casting. In: Gießerei Rundschau 60, 9/10, Wien, Verlag Strohmayer KG.
- Troll, A. (2014) 3D-Datenaustausch und Datenformate. In: Rieg, F., Steinhilper, R. (eds) Handbuch Konstruktion, München, Hanser.
- Weckenmann, A. (2001) Sensors for Workpieces – Macro-geometric Features. In: Tönshoff, H. K. and Inasaki, I. (eds), Sensors Applications – Volume 1: Sensors in Manufacturing, Weinheim: Wiley-VCH, 71-98.
- Weckenmann, A. (ed) (2012) Koordinatenmesstechnik – Flexible Strategien für funktions- und fertigungsgerechtes Prüfen. Münchn, Wien: Hanser.
- Wilke, W. (2000) Segmentierung und Approximation großer Punktwolken. Dissertation, Fachbereich Mathematik der Technischen Universität Darmstadt.

FORPRO²

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