Quality criterion gap width – left a favourable, right a less favourable gap situation between bonnet and mudguard

Visualisation of Component Deformation for Virtual Quality Assessment

The calculation of deformation with numerical methods such as finite element analysis (FEA) includes the discretisation of the continuous part geometry in simple geometrical elements. This so-called meshing therefore involves a reduction in visualisation quality. With the aid of the DefoVis method, which is presented by Helmut Schmidt University Hamburg and Volkswagen AG, deformation status visualisation in the quality familiar from CAD systems is achieved by combining discrete calculation results with tessellation of the original CAD geometry. In combination with a ray tracing method, a realistic, photograph-like illustration of deformed parts can be generated, enabling virtual assessment of the appearance. As application examples in body development rear lid and bonnet installation are investigated.

1 Introduction

Besides the subjective perception of the observer, a vehicle‘s impression of high quality depends on many other influences and is difficult to ensure merely via adherence to selected parameters. In addition to the design and the material, the perspective, the light incidence angle, reflections and the shadow print play a significant role in assessing the impression of surfaces and their delimitation by means of joints. It is now possible to analyse complete vehicles from all sides in a virtual environment under realistic light conditions using the ray tracing method and virtual reality (VR) techniques long before the first prototype has been built.

This realistic, photograph-like depiction is usually carried out on the basis of fine tessellation of the CAD geometry wherein the originally continuous surface is divided into triangles. The realistic, photograph-like depiction is usually carried out on the basis of fine tessellation of the surface of the originally continuous CAD geometry. The realistic, photograph-like depiction of parts which are deformed, for example, due to installation forces, inherent weight or operating temperatures, is only possible to a limited degree using state-of-the-art technology. Due to reasons of computing time and accuracy, the simulation of complex parts is usually based on a simplified geometry via sub-division into simple, considerably coarser elements within meshing. Assessment of the impression of deformed components in the current course of car development is therefore dissatisfactory.

The DefoVis method, which is presented in the following, is able to assign the results determined using the coarser mesh, which is adapted to the simulation requirements, to the finely tessellated geometry to enable an illustration of the deformation without loss of quality. The resulting model can subsequently be used to generate a realistic, photograph-like depiction of the deformed components using ray tracing.

2 The DefoVis Method and the Example Rear Lid

The DefoVis method, which was developed at Volkswagen AG, uses elements and functionalities which already exist in the development process, and links these to improve the visualisation of part deformation. **Figure 1** shows the interaction of these elements with the developed method and the resulting geometry using the example of a deformed rear lid simulated with FEA. In this, the process, starting with the CAD model with the previously available constituents (left-hand side in Figure 1), has been expanded by the elements required for better visualisation (right-hand side in Figure 1).

The first element is the finite element mesh, which is usually generated using a pre processor based on the CAD geometry in terms of the most accurate possible representation of physical behaviour and moderate computing time. After the loads, storage conditions and material properties have been defined, the finite element solver, the actual simulation core, is used to calculate displacements at the mesh nodes, which represent the second element, which is required.

The third and final element is the finely tessellated component geometry, which can be exported to common CAD systems, for example in VRML format. Triangle refinement, for example by means of iterative splitting at the relevant, longest triangle edges, only has to be carried out in the case of ideally flat surfaces.

DefoVis first reads in the node co-ordinates and node displacements of the finite element model in order to approximate a global smoothing function for the displacement field with the help of non-linear regression, see for example [2]. This function is then evaluated at the point co-ordinates of the finely tessellated nominal geometry from the CAD system to calculate the corresponding displacement of these triangle nodes.

Simple transformation of the individual points of the finely tessellated geometry using the determined displacements rules out topological errors, indicating the robustness of the method. The quality of the approximation depends on the course of the calculated displacement function and on the smoothing function which is used. If the order of the smoothing function is less than the order of the

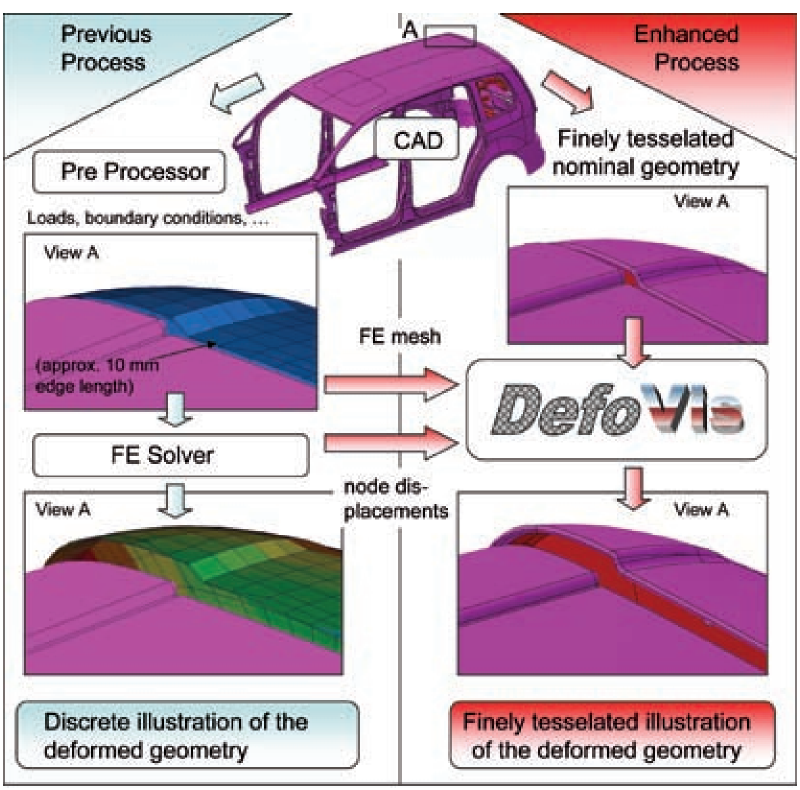
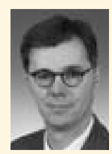


Figure 1: Improved visualisation of component deformation with the DefoVis method using the example of a deformed rear lid (previous, left, and enhanced process, right)

The Authors

MSc Dipl.-Ing.(FH) Georg Ungemach is a doctoral candidate in the Body Design Analysis department at Volkswagen AG in Wolfsburg (Germany).

Prof. Dr.-Ing. Frank Mantwill leads the professorship of Machine Elements and Computer-aided Product Development at the Helmut Schmidt University, Universität der Bundeswehr, in Hamburg (Germany).



Dr.-Ing. Michael Rund is team leader in the Body Design Analysis department at Volkswagen AG in Wolfsburg (Germany).

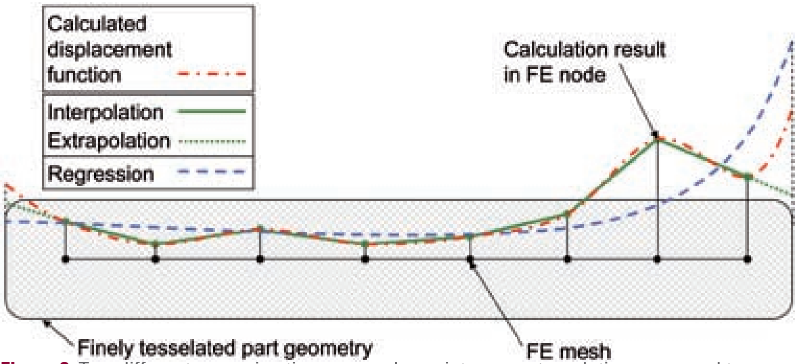


Figure 2: Two different approximation approaches – inter- or extrapolation compared to regression

problem-describing differential equation, the approximation error has to be checked if regression is used.

If the deformation, which occurs, is extensively non-linear, as in the case of car crashes or forming processes, for example, regression is less suitable for approximation. The local deformation, which frequently occurs in these cases, cannot usually be depicted with sufficient accuracy by global functions. A combination of inter- and extrapolation therefore have to be adapted to visualise non-linear displacement devolutions. **Figure 2** illustrates the principle difference of both approximation approaches.

The advantage of inter- or extrapolation method is the exact match of the approximated displacement function at the calculation nodes irrespective of the approximation quality. The disadvantage is the higher programming and computation effort because, contrary to the regression method, assignment of the fine geometry points of the component to the finite elements of the calculation model first has to be carried out.

The result of approximation using DefoVis is the finely tessellated, deformed geometry. The classic example in car body engineering is the rear lid, which is deformed by the effect of the gas spring forces during installation, as a result of which the gap curve between the rear lid and the car body is influenced. **Figure 3** compares the gap curve of a deformed rear lid with the relevant, detailed views of an undeformed rear lid. It can be recognised that there is no loss of visualisation quality, particularly at critical points with filigree radius transitions.

3 Further Application Examples in Body Development

Next to the example of a deformed rear lid in the following a bonnet installation and tolerance specifications will be illustrated.

3.1 Deformation as a Result of Bonnet Installation

When closed, the bonnet of a car is secured at the front by the lock, and additionally lies on the stop buffers. These stops are consciously adjusted in such a way that the bonnet is pre-stressed when closed and is simultaneously flush with the wing. This pre-stress helps among other things to avoid so-called flow induced flutter at high speeds.

After calculating the deformation resulting from installation, DefoVis is used to generate a deformed geometry model in unaltered visualisation quality. **Figure 4** illustrates the nominal CAD geometry, the FEA model and the deformed geometry of the bonnet, which is fed back into the CAD system. Once the model has been fed back into the CAD system, gap and flushness measurements based on the points of the

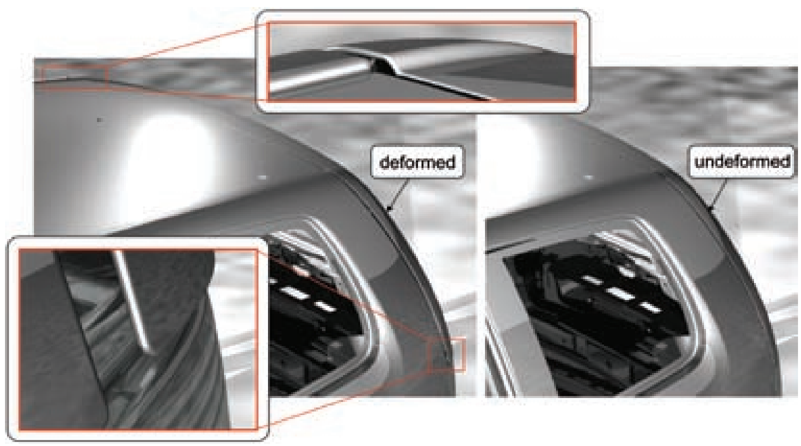


Figure 3: Visualisation of deformation using DefoVis and ray tracing using the example of a rear lid (at the deformed rear lid a bigger gap occurs)

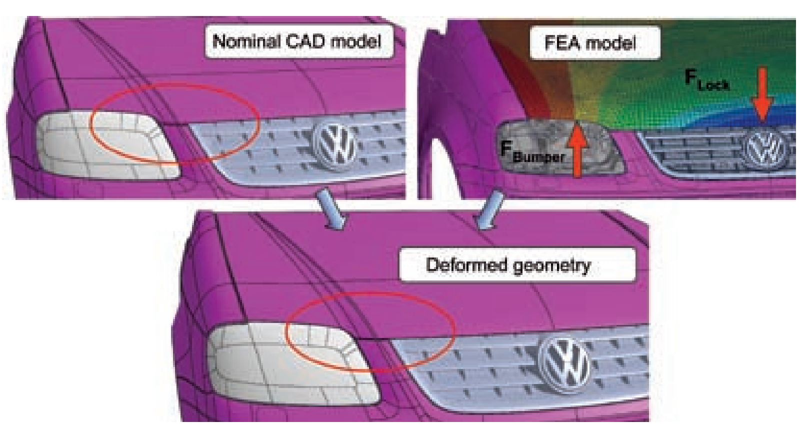


Figure 4: Deformation of the bonnet as a result of installation – the changed impression is difficult to assess

Figure 5: Better assessment of the gap curve of the installed bonnet using the ray tracing method

finely tessellated, deformed model can be carried out using the functions available in the CAD system.

Simple negation of the approximated displacements can additionally be used to generate a model which only deforms to the desired nominal geometry due to the effect of operating loads, the so-called pre-stressed model.

Despite the improved depiction of the deformed bonnet in Figure 4, the changed impression is difficult to assess. For this reason, the resulting geometry is visualised using the ray tracing method to enable an impression of the gap curve under realistic conditions. The nominal geometry is compared to the geometry of the deformed bonnet in **Figure 5**. Whilst the decreasing gap between the bonnet and the radiator cowling shows a uniform transition, a tapering shadow print occurs between the bonnet and the headlight; this was not visible in Figure 4.

3.2 Quality Assessment of Tolerance Specifications

During the mass-production of cars, it must always be assumed that components will reveal deviations from their nominal dimensions due to diverse influences during the manufacturing process. These deviations are usually randomly distributed and must not exceed defined limit values, in order to guarantee the function on one hand and to ensure that the vehicle's impression meets the manufacturer's quality requirements on the other hand.

In the following example, deformation states calculated with FEA are used to represent different tolerance situations. This is carried out via a linear combination of unit load cases at the relevant quality features. In this way, the force combination required to enforce a specified tolerance situation can be determined by solving a linear system of equations. This methodology has already been implemented in a Catia-integrated tool for compliant assembly variation analysis in cooperation with the software development company Dimensional Control Systems Inc. (see [3] or [4] for the underlying theory).

Figure 6 compares two limit states generated with DefoVis. Under the chosen light and visibility conditions, the selected images clearly show that tolerance situation 2 (Figure 6 bottom) is significantly less favourable than situation 1 (Figure 6 top), although numerical evaluation of the gap dimensions leads to the conclusion of an equivalent situation. This realistic visualisation of the gap situation gives rise to an improved decision making basis to enable quality criteria for gap widths and flushness to be defined in advance.

4 Further Applications and Outlook

The underlying approach to combining the calculation results of coarse discretisation with the finely tessellated geometry can also be used to visualise the results of multi-body simulations (MBS) and interactive deformation within a VR environment. Whilst the actual calculation is restricted to a few elements due to reasons of efficiency, the visualisation quality following calculation can be significantly improved using DefoVis.

The option of collating the calculation results with the CAD data additionally enables the development of integrated CAE systems based on extended data structures. In this way, models which include the design as well as the simulation elements and therefore the physical properties of a product can be developed. Thus, the method which is shown is a further step towards an integrated product model.

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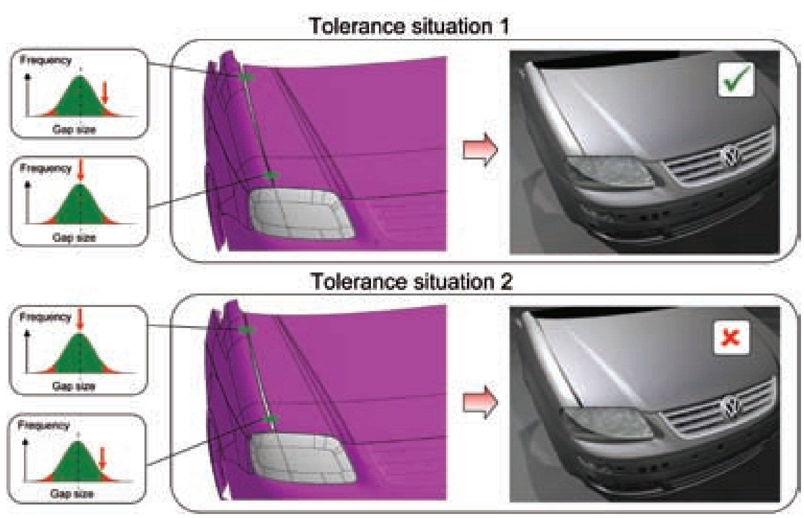

Figure 6: Virtual quality assessment of tolerance specifications using DefoVis and ray tracing at the bonnet