Quantitative Surface Quality Assessment of Car Outer Panels with a Virtual Light Room

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Abstract. Perception is reality. A customers’ perception about the quality of a car is closely linked to the aspect of its outer panels and that reality translates into what motivates customers to choose one car over another. The smoothness of the panels, how much gap is visible and how that looks; these visual cues are considerations within a customer’s decision-making process. The process of choosing a new car is certainly subjective and varies from customer to customer, but Original Equipment Manufacturers (OEMs) agree that the visual appeal of the body of a car is a key factor. Building a car only to find surface imperfections results in huge costs in postproduction rectifying those perceived defects. The further into production these defects are found the more expensive it is to fix them. Some OEMs release cars into the buying cycle knowing that their engineering teams are still struggling to fix surface defects. There is a solution to this though. Numerical simulation. This action can and should be used to find surface defects very early in the design process. Surface quality assessment via numerical simulation is achieved by analysing different contours that relate stress or strain values. Other subjective criteria exist, but it is often very difficult to ascertain if a surface defect is severe enough to be detected by human eye. This paper describes a simulation methodology that, when used along with a software that reads surface light distortions and rates them, will give reliable results allowing engineers to fix problems before a car is built. This technology was developed using actual data supplied by a partnering OEM. Current examples will be presented, comparing parts “as designed” with parts “as manufactured”. After manufacturing parts will show variations caused by the stamping process such as skid marks, bumps, hollows, etc. All that can be accurately predicted by simulation.
1. Introduction

Over the past 20 years stamping simulation has proven to be accurate enough to well predict the outcome of almost all existing sheet metal forming processes. Initially we were able to check formability, looking mainly at thinning, wrinkling and Forming Limit Diagrams. Few years after that the bar was set higher by the industry who was looking for more complex results, such as springback. Materials got more complex requiring new and more advanced models. One of the more complex requirements is the ability to well predict surface defects, especially on car outer panels in loose and mounted condition, and doors & closures as presented in 2015 by G. Prajescu, and D. Schlatter at Forming in car body engineering in Bad Nauheim [6].

Traditionally, stamping simulations are analysed via some colour mapping on the part related to certain “contours” that allow to identify the potential issues on the parts. This methodology, which has been proved to be very efficient for the most common issues (thinning, plastic strain level, springback magnitude, distance to the targeted geometry…) has been evaluated also for checking the severity of the cosmetic defects such as dips and bumps. But, as presented by G. Prajescu, D. Schlatter and B. Changeux at NAFEMS France in Paris in 2016 [1], this methodology isn’t robust enough for cosmetic defects evaluation for two main reasons:

- No single contour (or formula combining several contours) that would be extracted from simulation and that would correlate with the quality assessments done in real life has been identified so far.
- The evaluation of the severity of the defect is highly subjective because is driven by human perception, which takes into consideration not only the defect itself, but also its position on the car body (example: a defect that would be in a zone where no light reflexion would happen wouldn’t be seen by the final customer). Therefore, evaluating a colour mapping may underestimate, or oppositely overestimate, the defect severity, which would lead to respectively the late discovery of some defects, or to over engineering parts and/or process to fight defects that would never be perceived by the final customer.

Under these circumstances, some alternative solutions have been searched and digital stoning solutions have been developed and are available in industrial software (figure 1). These new ways of evaluating the cosmetic defects, aiming at reproducing on simulated parts one of the tests (stoning) done in real life, have been industrially proven to reflect the reality (figure 2) and to allow identifying some zones of “risk of defects”. This methodology was still not allowing users to know accurately if the final customer would see those defects, and even less if they would damage the “feeling of high quality” of the entire vehicle.
Figure 1: comparison between real and digital stoning based on a numerical stamping simulation.

Based on that status, the complete “cosmetic defects evaluation process” used at several OEMs has been analysed and it has been observed that the first step of this process was not the stoning, but rather a visual inspection performed by a trained individual that, after positioning the part on a device (in a position that would correspond to its real position on the car, such as a door is placed vertical and a roof horizontal…) in front of a light room, looks at the part and rates the potential defects according to an established severity criterion. Only then, a stoning is performed at the location of each identified defect to understand the root causes so that some action plans can be engaged to correct those defects.

Based on this refined understanding of the real cosmetic defects’ evaluation process, some trials have been engaged to reproduce this visual inspection inside a virtual lightroom, in which a simulated part was positioned (figure 3).
Figure 3: Example of a simulated door (zoom on the door handle area) inside a virtual light room.

This new approach allowed to quickly prove that if a proper simulation methodology was used (chapter 2), the worker was able to better acknowledge the severity of the defects, but then, the issue of subjectivity became more present, exactly like in real life where two different workers are sometimes giving quite different defects estimation, in the real light room like in the virtual one.

To solve this situation, some tests of automatic defect severity evaluation based on image analysis coupled with artificial intelligence have been engaged.

2. Finite Element Method Simulation Methodology

Several work steps are required to allow an accurate prediction of the part geometry using Finite Element Method, which is a prerequisite to any virtual light room inspection:

- Tool meshing

A detailed tool mesh is required to minimize the impact of the discretization of the tool geometry on the blank. Advanced meshing parameters are used in a dedicated template to ensure that the mesh is at the right size and with the right density. A larger mesh, even localized, could result in fake marks in the blank that will be visible in the virtual light room.

- Blank initial mesh and refinement during the calculation

Since the size of the defect that must be captured during the simulation is rather small (figure 4), a fine blank mesh must be obtained at the end of the forming simulation (before springback during where no further refinement will occur). For this purpose, and to save computation time, an initial mesh size of 12mm is chosen, coupled with 5 levels of refinement. These settings will result in a minimum element size at the end of the complete simulation of 0.75mm which is still compatible with the shell element formulation used during the computation.
Figure 4: Typical size of a cosmetic defect around a door handle [2] justifying the requirement of a very fine mesh at the end of the stamping simulation

- Forming speed reduction at the end of the forming stage

To avoid numerical artefacts associated to a too high forming velocity, where the blank would excessively oscillate at the very last instants of the forming stroke, and as in reality where the forming speed is progressively reducing to zero near the bottom dead point, the velocity of the forming tools is reduced to a low value few millimetres before the reach of the Bottom Dead Point (BDP):

- Until 20mm to BDP, velocity is constant and set to 5000mm/sec.
- Between 20mm and 10mm to BDP, a linear ramp from 5000mm/sec to 1000mm/sec is applied.
- From 10mm to 0mm to BDP, velocity is constant again and set to 1000mm/sec.

- Springback

At the end of the forming, the part is in good agreement with the tool’s geometry. To reveal the dips and bumps that will appear when the tools will be reopened, a springback stage is added after the forming stage, which will correspond to the tool’s reopening happening at the end of the forming stroke (figure 5).

An accurate springback prediction is very important as most surface defects will show up or get worse in a sprung part. A wrong springback prediction may lead to defects that do not exist or defects that have a different magnitude than the actual ones.

To ensure a good springback calculation some advanced material models are being used. Since the deformation path in some zones of the part may correspond to a succession of traction and compression, a YOSHIDA-UEMORI kinematic hardening model is used.
In case where some additional forming stages (corresponding to other trimming and/or forming operations) would be required, some intermediate springback between each operation must be added, coupled with gravity stage at the beginning of the next forming operation to properly represent the real and full forming process.

To ensure a fast-enough turnaround time for refined models, the computation can be performed on several cores in parallel (typically 16 or 32 cores).

- **Realistic Rendering**

Along with a good springback result, the quality of results rendering is of the same importance. A bad rendering may change the perception of existing defects.

Most stamping simulation software work with a finite element mesh, which essentially do not produce a smooth curved surface. A mesh with big elements of varying sizes has a wavy reflection when viewed in a virtual light room. The virtual light room is a 3D environment with computer graphics functions able to simulate the reflection on the mesh surface. It considers that the angle between the incident ray and the mesh element normal is equal to the angle of the reflected ray and the mesh element normal.

Having a fine enough mesh to allow for a smoother surface and a better reflection would result in too many elements and unrealistic calculation times using today’s available hardware. Because of that, a specific methodology was developed and fine-tuned to allow best fringe reflection results with a reasonable mesh size.

To create the reflection image, the computer graphics software traces back the rays arriving at the camera, reflecting on the surface, and exiting the lighting. This surface mesh is obtained by simulating a homogeneous mesh with final element size around blank thickness. The size of the final polygonal mesh elements is homogeneous and in a small size, such that the image does not present waviness in the reflections.

- **Assembly Simulation**

During assembly processes, panel shapes may change and that can affect the surface quality. As demonstrated by H. PORZNER at IABC in Dearborn in 2018 [5], the assembly process, considering positioning, closing, hemming, spot-welding, gluing, etc. can make the surface defect look less visible or even more important.

The assembly simulation has then two main advantages: The first one is to understand, beforehand, if after assembly the part will be within the expected tolerances. Maybe after assembly many of the component level deviations will get fixed, so all the time and cost used to fix each component was lost. Secondly, in terms of surface defects, the same may occur as defects may get better or worse after assembly (figure 6).
3. Light Fringes and Defects Classification

When a software can correctly predict the shape of a part or assembly after springback, the light reflections seen in a light room is again subjective: some might say that one part looks good and agrees with the expected quality standards, some might say that part is not acceptable [7]. The challenge is now to classify the defects automatically, using an algorithm that could represent what most of the auditors would say about parts in an actual light room.

To resolve these problems, a software solution was developed using actual data supplied by a partnering OEM. The software can read light fringe reflections (Figure 7) and rate them based on a standard criterium (Figure 8), and it can be customized to fit different criteria used by any OEM. The software is based on artificial intelligence techniques, so the more parts are analysed the more precise and smart the software becomes.

![Figure 6: Assembled hood in the virtual light room (Courtesy of Ford) [4]](image)

![Figure 7: Fringe light reflections](image)

![Figure 8: Defects classifier example](image)
The camera and lighting system is always positioned at a standard size and distance from the surface (Figure 9), allowing for standardized image capture. Thus, it is possible to obtain a smooth and realistic reflection on the surface with: i) a realistic simulation of the physical phenomena in the mesh, ii) a mesh with a uniform size of the elements, iii) a mesh with an element size smaller than the spatial resolution of the camera rendering, iv) a set of lighting patterns with high contrast, v) a lighting with standardized size, distance, and angle, and vi) a virtual camera that captures images with standardized resolution, size, distance, and angle.

In terms of accuracy and validation against actual measurements, the software shows a very good agreement as shown hereunder (Figure 10 and 11).

**Figure 9: Standard camera and lighting position**

**Figure 10: Defects spotted by inspector**

**Figure 11: Defects spotted by software**
4. Conclusion

By using a stamping simulation methodology that can produce reliable results with good turnaround time, one is able to provide surface defects assessment virtually in a light room, in the same manner OEMs check their cars. The rendering quality from stamping simulation results is good enough to enable light fringes reflection analysis, from which one can classify the defects automatically using artificial intelligence. The system used to classify the defects can learn by itself and better detect defects the more parts are analysed. The defects classification is automatic and does not require a calibration phase.

A potential next step to further increase accuracy of the shape predicted by the simulation software could be to ease the consideration of the impact of tools deformation during the forming stage, which can induce variation on the contact pressure between the tool and blank, leading to slight modifications of the panel shape, and thus on the perceived quality level, as presented by M. Vrolijk, T. Ogawa, A. Camanho, M. Biasutti and D. Lorenz at ESAFORM 2018 in Palermo [8].

5. References

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