INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

VIRTUAL VERIFICATION OF SPLIT LINES WITH GIVEN REFERENCES

Andreas Dagman and Rikard Söderberg

Abstract

Product development of today is characterized of shortened lead time, increased expectations on the products and lack of time. The importance of the aesthetic design has increased and many brands are no longer competing only with performance but with the design of the products.

This paper focus on the possibility to optimize relations between parts based on tolerance aspects and a fixed set of positioning schemes. A tool has been proposed to optimize split lines between parts based on tolerance aspects and a fixed set of locating schemes.

The possibility to evaluate design solutions is of high importance. The exterior design of many products involves a number of parts who are in relation between one another. In the automotive industry a big share of the quality aspects is assessed by these relations. The effect of visual and geometrical sensitivity may be evaluated in early stages of the product development process using non-nominal models. Thus time and cost reduction will be met and the visual quality will increase.

The tool can also be used as border crossing technical aid for both engineering design and industrial design to enable *styling concept evaluation*.

Keywords: evaluation of design, predictive design analysis, robustness.

1. Introduction

The exterior design of many products involves a number of parts which are in relation to each other. The visual appearance of these relations has a big aesthetic and quality influence on the product. In the automotive industry a big share of the quality aspects are prescribed by these relations. A way to use virtual environments to verify and predict quality appearance has been suggested by [1], [2]. The possibilities to, in an early stage of the product development process, *virtually verify* a concept to get a predictive design analysis, has become an important factor to cut the expenses in the product development phase. The traditional approach of applying *robust design* in this area has been to find the optimal locator positions that minimize variation and make the assembly less affected by the tolerances of the included parts, for example [3] and [4]. This way of optimizing the robustness of the design assumes the freedom to place locators wherever the optimal geometrical location is. However, often in production environment of today, the assembly strategy, i.e. how parts are located and assembled with fixtures and/or robots, is more or less fixed to a number of principle layouts.

Product development of today is characterized of shortened lead time, increased expectations on the products and lack of time. On top of this, persons in teams with different educational background and skills are trying to achieve the goal in their way. Concurrent engineering (CE) which has been described by [5] is one way to deal with this complex system. The possibility to analyse and evaluate a solution at an early stage of the product development process is invaluable. The result from the evaluation must be possible to interpret regardless of educational background.

2. Robust design

Many products of today are built up of several components. These are arranged in a way that makes them more or less geometrically dependent of other parts in the assembly. Geometrical variation is introduced to a product as component variation and assembly variation. The usual procedure at companies is that the suppliers control the component variation and the assembly variation is taken care of in-house by the assembly process. The final variation is dependent of the sensitivity of the concept. In a sensitive concept, component and assembly variation is amplified, whereas in a robust concept the variation is suppressed. Since the shape of the parts and the placement of the locators govern the robustness of the product, it is very important to achieve as high geometrical robustness as possible already in the concept phase. A CAT (Computer Aided Tolerancing) software, see [6] can be used for this purpose. Another alternative can be early robustness analysis. These tools are used in trying to foresee and avoid geometrical problems that are related to geometrical variation. They can also help out to create a robust design, insensitive to geometrical variation.

The relation between robustness and variation can be explained with a beam and a support, see figure 1. Concept robustness is controlled by the relation between input and output relation.

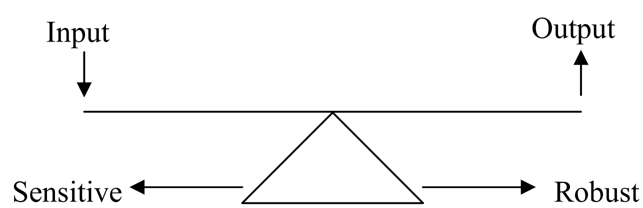

Figure 1. A beam support explaining robustness and variation.

Depending on the placement of the support the input variation will either increase or decrease the output variation. If the support is moved to the left the input variation will lead to an amplified output variation. And if the support is moved to the right the output variation will not be as affected as in the first example and the robustness will increase. This means that input and output are depending on each other and the placement of the support. This relationship can be expressed as following:

$$\begin{bmatrix} \text{robustness} \\ \text{variation} \end{bmatrix} = \begin{bmatrix} x & 0 \\ x & x \end{bmatrix} \begin{bmatrix} \text{locators} \\ \text{tolerance} \end{bmatrix}$$

Since the position of the locator controls two important product characteristics, this should be treated first. Based on final requirements for the output variation and known sensitivity (relations between input and output), the tolerance for the input variation may then be determined.

In the automotive industry a quality aspect is brought in to this area. The relationship between the doors, hoods and panels are important from this point of view. The possibility to make the split lines tighter and more accurate gives the impression of a good craftsmanship. The splits are actually something measurable which is important to be able to give a grade of the car. This impression is very important in the competition between different brands and models. These relations can also be looked at from an aesthetic point of view. The importance of working with the visual product form is discussed in [7]. These relations are one of the parts that underlie the *Quality Appearance* (QA) *Index*, see [8]. The QA Index measures the over all quality appearance of a product using statistical simulations.

2.1 The seam function

The *seam function* was introduced in [9] as the relation between two parts over a specified distance and describes the most frequently used quality characteristics for evaluations of geometrical variation in automotive body design. Typically, seam variation is measured and evaluated in two directions, the gap and flush directions. To be able to efficiently evaluate flush and gap along the seams of an automotive body, they must be generated more or less automatically in the CAT environment. For that purpose an algorithm for automatic seam generation is developed and used for seam variation evaluation. The algorithm uses points and lines to create seams, see figure 2. Several chaining options and criteria are then available. The measure used in this experiment has been point-to-point measures which mean that the seam function creates measures between two points, one on each part.

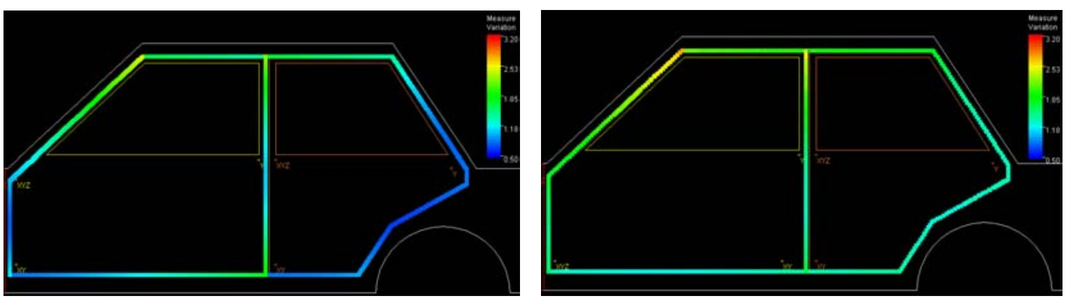

Figure 2. Seam variation, flush direction [9].

2.2 The 3-2-1 Locating scheme

All parts in an assembly are positioned with a positioning scheme. A frequently used scheme in the automotive industry is the 3-2-1 system, where six theoretical points are used to lock six degrees of freedom for a part, three translations and three rotations, see figure 3. Three points forms a plane, A1, A2 and A3, which locks two rotations and one translation. Two points, B1 and B2, forms a line that locks one rotation and one translation. The final point, C1, locks the remaining translation. The locating points are represented in reality by physical locators such as planes, holes and slots. This is the foundation how to place components in an assembly structure.

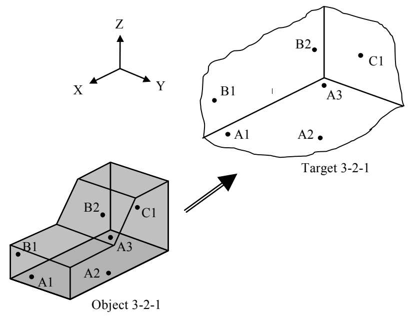

Figure 3. The 3-2-1 locating scheme.

3. Split line optimization

This paper focus on the possibility to optimize relations between parts based on tolerance aspects and fixed sets of locating schemes. The overall question in this work is how the initial product geometry shall be split into parts in the most robust way, i.e. how to achieve the most robust product architecture with respect to placement of split lines? The split line, the parallel edges, between two plane plates, will be analysed, see figure 4. The distance between all edges shall be equal for all relations in a product, to achieve an aesthetically well balanced product structure. The distances in foci are in the plane (gap) and in the normal to the plane (flush). A change from this is going to lower the total customer and producer impression of the product. An optimal relation between the two plates, from a geometrical and tolerance point of view, shall consist of two parallel edges with minimum variation in flush and gap direction, for a given set of locating schemes.

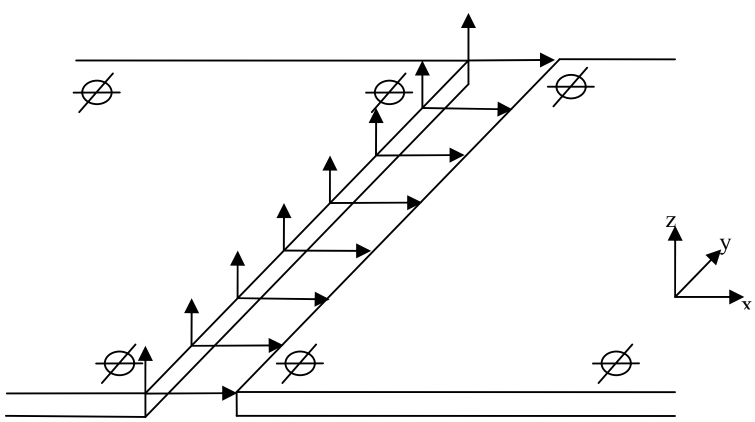

Figure 4. A split with measures in gap and flush directions.

4. The experiment set up

Optimizing the relation between surfaces/plates from a tolerance point of view has so far in most works presented implied finding the optimal location of locators. In this paper the prerequisite has been changed. We are here going to fix the position of the locators and determine where the best suited area for a split line is located. This way of working can be seen as a complement to the traditional way of optimizing locator points. The possibility to find the best suited area between two parts for a split line with given locator position may be a good help in the early stages of the product development process, especially when evaluating and developing “styling” concept with respect to geometrical variation. The models being used in the evaluation phase are non-nominal. A CAT software, in this case RD&T, is here used as a workbench. Two parts, shaped as rectangles, were modelled and placed on top of each other, to be able to use the seam function. The locators were placed at the right side of one part and on the left side on the other. In RD&T the user has different possibilities to define positioning systems. In this case a 3-point system was used to position the parts.

4.1 The 3-point system

The 3-point system is similar to the 3-2-1 system with the difference that only three points are used. The first locates the part in three directions, the second in two and the third in one direction. In figure 5 the position of the locators and their locating directions are shown. All the locators are able to move in the Z-direction and the arrows shows the additional displacement possibilities.

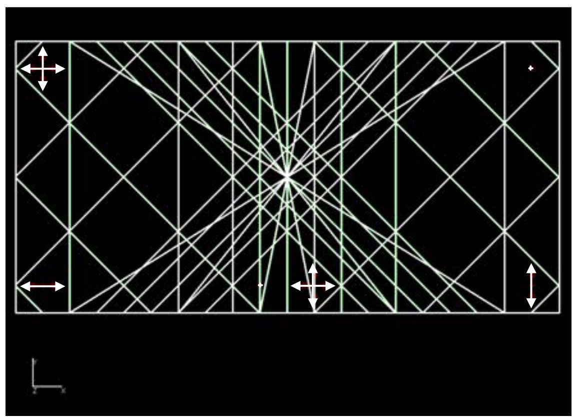

Figure 5. The grid of seams on the two plates. The arrows show the location and the freedom of movement of the locators.

4.2 The seam grid and colour coding

In this experiment set up, a number of seams were created to be able to measure between the parts. The parts used in this research set up were 2D plates; however the method can be used on other types of more complex surfaces. The seams changed both in angle and direction see figure 5. The goal with the seam direction and angles were to create a closer grid in the center and a more spread grid at the edges. The reason behind this is the fact the two parts shall be divided in the Y-direction with three locators on each part and the most interesting area will be in the centre of the plates. A number of seams with an angle of 45 degrees were set up and number of seams with different angles running through the centre point was also added.

The measurement of the area can also be done by using a number of points in pairs, one from each part. By adding a large number of point pairs on the two parts the same result may be achieved. During this experiment, the seam function has been the only method used.

When all the seams had been created a variation analysis, using Monte Carlo simulation technique were performed to analyze variation in the measures

All the measures could then be simulated and visualized with colour coding of variation or amplification. By using the colour coding feature in RD&T, areas that had less measure variations were detected (coloured in blue, the darker area). Different measure interval creates different colours. The seam grid and the colour coding made it possible to find patterns on the parts. A big advantage by use of colour coding is that the function gives a simple overview so that different competences easier can understand the results and have opinions about them.

During the tests, only the locators were affected by tolerance changes, the shape of the parts themselves did not change. The results were shown both in gap and flush directions. To be able to see the placement influence of the locators, the position of the points were altered. The location points were alternated between four positions on each plate. The number of points and placement locations made a number of set up possibilities to be solved. The results were analyzed to see if patterns were possible to find.

4.2 Evaluation of flush

First the results were analyzed from a flush point of view. As can be seen in figure 6 we were able to see areas that were less effected by the measure variation. Depending on the placement of the locators different patterns were created when the colour coding were applied.

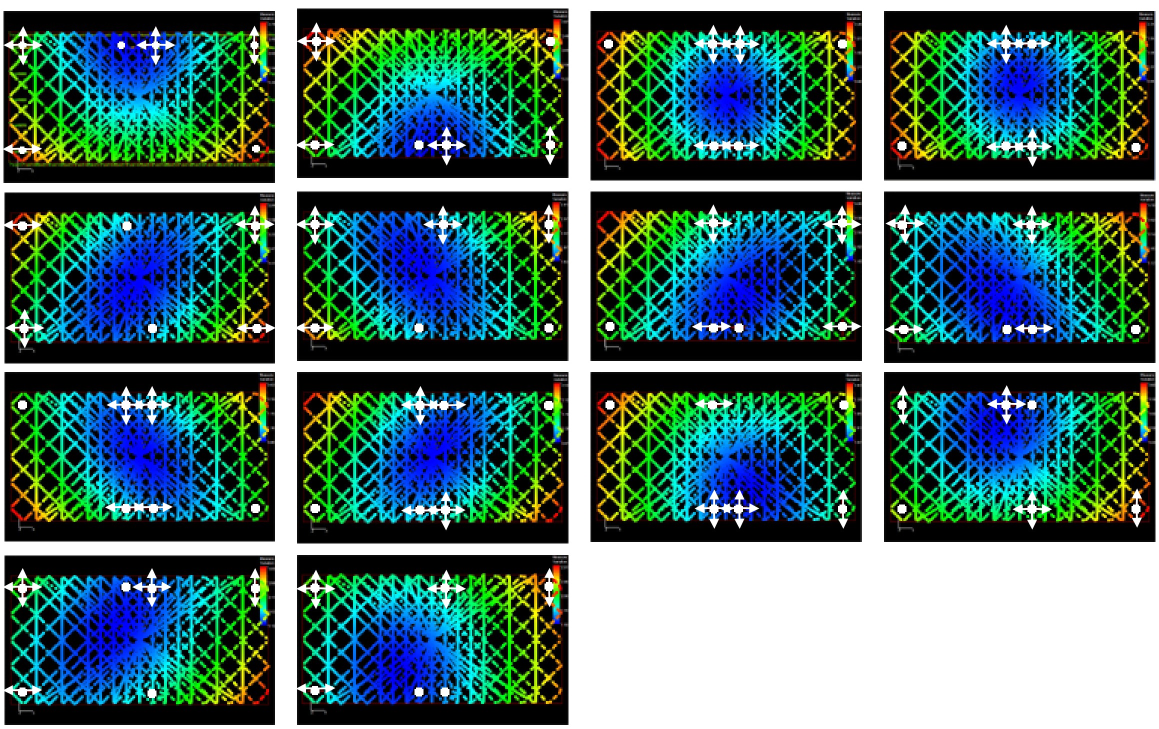

Figure 6. The colour coded results for flush.

4.3 Evaluation of gap

When observing the results for gap directions almost the same patterns as in flush were found, however not as clear. Because the gap measures are perpendicular to the side of the part the direction of the split lines also influenced the results. As can be seen in figure 7, the vertical seams have lower variation compared to the ones with an angle. When increasing the angel of the seam against the horizontal plane, the variation increases as well. High variation takes place in the outskirts of the parts.

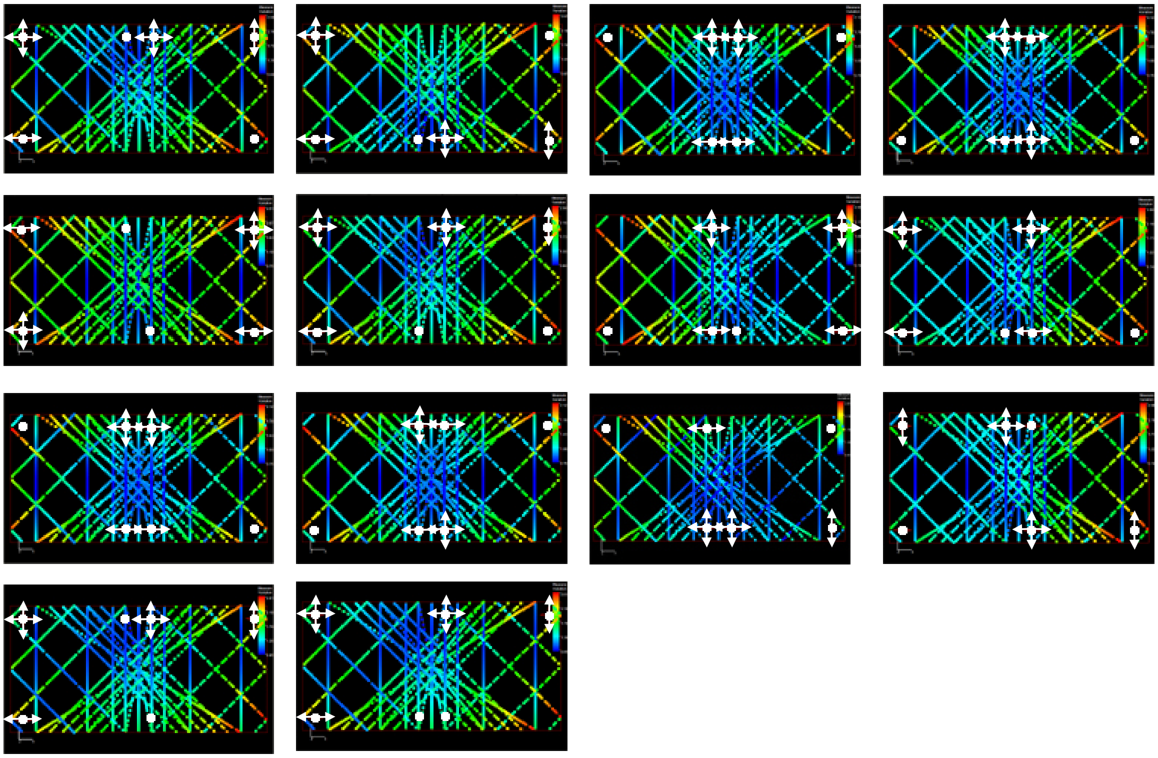

Figure 7. The colour coded results for gap.

4.4 Discussion of flush and gap evaluation

Some differences between flush and gap evaluation results can be noted. The main differences were the angle influence in the flush direction. The grid has been applied to a schematic picture of a car, see figure 8, to show a simple picture how the tool can be used.

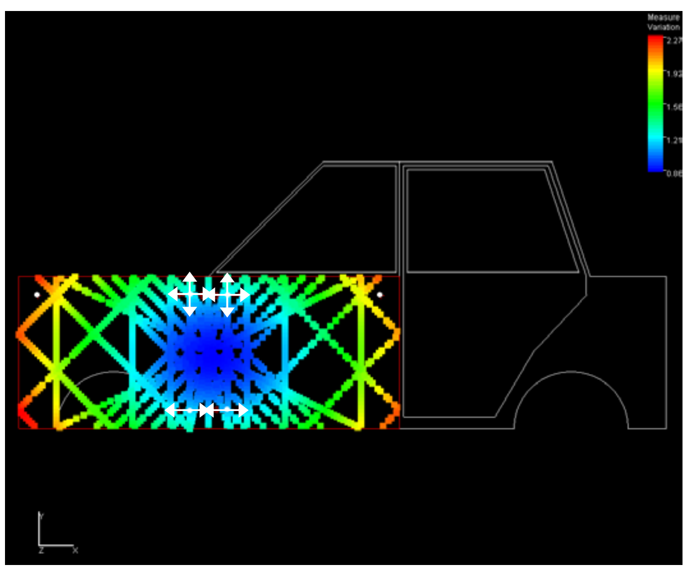

Figure 8. The seam grid applied on a car structure.

By using the variation results from the grid of seams, the minimum measure variation in a number of levels in the Y direction were found. The minimum measure variation locations were then marked at the plates and linked together to create a line, as can be seen in figure 9. This line shows the optimal way, from a tolerance point of view, to split two parts with given locators position. The optimizing of the split line can be described by an algorithm for automatic split line optimization. This tool has the possibility to become a good help for designers in the early stages of the product development process. To be able, in early stages of the product development process, determine in what area the split line shall be placed, to make the product less affected by tolerances will decrease the cost and time consumption.

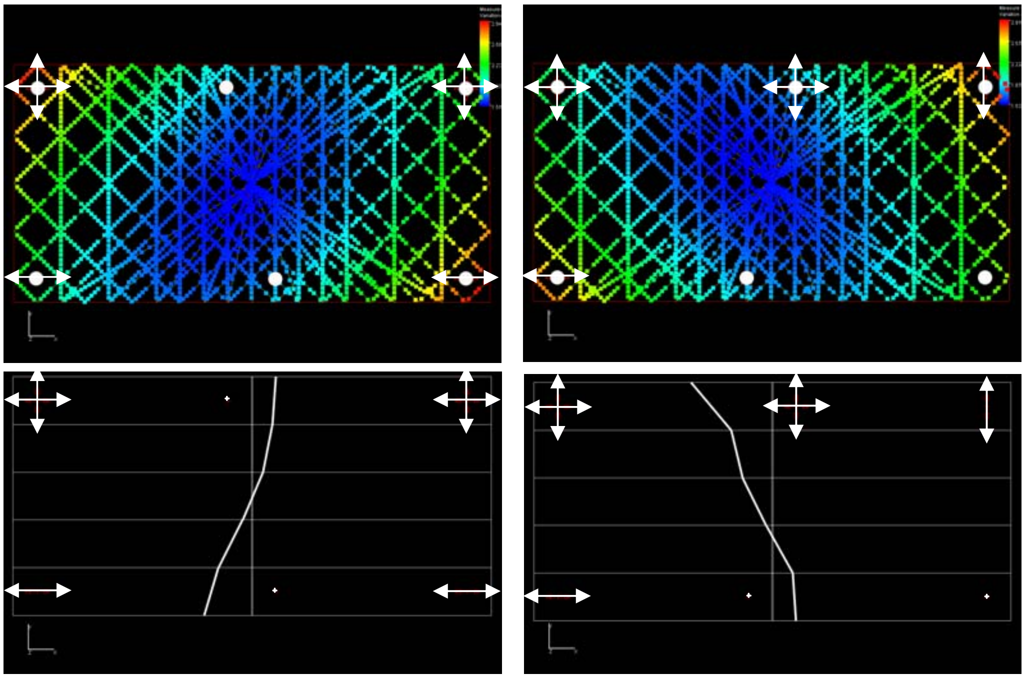

Figure 9. The ultimate split line orientation according with given locator positions.

5. Conclusions

In this paper we have proposed a method to optimize relations between surfaces/plates based on tolerance aspects and a fixed set of locating schemes.

The possibility to, in an early stage of the product development process, be able to evaluate design is of high importance. With a tool as the purposed the effect of visual and geometrical sensitivity may be evaluated in early stages of the product development process, using non-nominal models. Thus time and cost reduction will be met and the visual quality will increase. The tool will give an insight of possible solution changes of the geometrical shape. By receiving proposal for the most tolerance independent solution, alternatives can be found quickly which will improve the product architecture. It will also be used as border crossing technical aid for both engineering design and industrial design to enable styling concept evaluation. The result may be implemented in a CAT system that can give proposals on both reference locations and geometry changes, when using locked reference locations. This will increase the total solution quality of the final outcome.

6. References

[1] Maxfield, J., Dew, P. M., Zhao, J., Juster, N. P., Taylor, S., Fitchie, M., Ion, W. J. and Thompson M., "Predicting Product Cosmetic Quality using Virtual Environment" Proceedings Of 2000 ASME Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Baltimore Maryland, September 10-13 2000.

[2] Maxfield, J., Dew, P. M., Zhao, J., Juster, N. P., Taylor, S., Fitchie, M. and Ion, W. J., "Predicting Product Cosmetic Quality in the Automobile industry" Proceedings of the 33rd international Symposium an Automotive Technology and Automotation (ISATA 2000), Dublin, Ireland September 25-29.

[3] Camelio, J. A., Hu, S. J. and Ceglarec, D. J., "Impact of Fixture Design on Sheet Metal Assembly Variation", Proceedings of the 2002 ASME Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Monteral, Canada, September 29 –october 2, 2002, DETC2002/DFM-34167.

[4] Söderberg, R. and Lindkvist, L., "Computer aided assembly robustness evaluation". Journal of Engineering Design, Vol. 10, No. 2, 1999 pp. 165-181.

[5] Vos, R. G., "The emerging basis for multidisciplinary concurrent engineering, In E. J. Haug (Ed), Concurrent Engineering: Tool and Technologies for Mechanical System Design", Springer Verlag. 1993, pp. 111-127.

[6] Söderberg, R. and Lindkvist, L., "Two-Step Procedure for Robust Design Using Cat Technology", Proceedings of the 6th CIRP International Seminar on Computer Aided Tolerancing, Enschede, the Netherlands, Mars 22-24 1999.

[7] Warell, A., "Design Syntactics: A functional Approach to Visual Product Form", Doctoral Thesis, Chalmers University of Technology, ISBN 91-7291-101-8, Göteborg, Sweden, 2002.

[8] Wickman, C. and Söderberg, R., "Increased Concurrency Between Industrial and Engineering Design using CAT Technology Combined with Virtual Reality", Proceedings of Advances in Concurrent engineering, CA, USA, July-29 Augusti 1, 2001.

[9] Söderberg, R. and Lindkvist, L., "Automated Seam Variation and stability Analysis for Automobile Body Design". 7th CIRP International Seminar on Computer Aided Tolerancing, ENS de Cachan, France April 24-35 2001.

Corresponding author:
Andreas Dagman
Division of Engineering and Industrial Design
Product and Production Development
Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telephone: +46 (0)31-772 1472
Fax: +46 (0)03-772 5858
E-mail:andreas.dagman@me.chalmers.se