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VIRTUAL FIXTURING: INSPECTION OF A NON-RIGID DETAIL RESTING ON 3-POINTS TO ESTIMATE FREE STATE AND OVER-CONSTRAINED SHAPES

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ABSTRACT

When the geometry of a non-rigid part or pre-assembly is measured fully clamped (over-constrained) in a measurement fixture, the spring-back information and influence from gravity forces are usually lost in the collected data. From the 3D-measurement data, it is hard to understand built in tensions, and the detail's tendency to bend, twist and warp after release from the measurement fixture. These effects are however important to consider when analyzing each part´s contribution to geometrical deviations after assembly.

In this paper a method is presented, describing how free state shape and over-constrained shape of a measured detail can be virtually estimated starting from acquired data when the part or the preassembly is resting on only 3-points. The objective is to minimize the information loss, to spare measurement resources and to allow for a wider use of the collected data, describing the geometry.

Part stiffnesses, part to part contacts and gravity effects are considered in the proposed method. The method is based on 3D-scanning techniques to acquire the shape of the measured object. Necessary compensations for part stiffnesses and gravity effects are based upon Finite Element Analysis (FEA) and the Method of Influence Coefficients (MIC).

The presented method is applied to an industrial case to demonstrate its potential. The results show that estimated over-constrained shapes show good resemblance with measurements acquired when part is over-constrained in its measurement fixture.

Keywords: non-rigid, sheet metal, measurement, assembly simulation, geometry assurance and virtual fixturing.

NOMENCLATURE

BIW	body in white
CAT	computer aided tolerancing
FEA	finite element analysis
MIC	method of influence coefficient
MLP	master locating points
SPC	statistical process control
PCF	part coordination fixture
detail	part or pre-assembly
scale	linear color plot scale used in figures

1. INTRODUCTION

This section gives a description of how dimensional control of sheet metal details in automotive industry is usually performed today. The problem formulation and scope of the paper are also introduced.

1.1 Dimensional control of non-rigid parts

In mass production, e.g. in the automobile industry, dimensional control is one essential task among others to secure the final quality of the assembly. Robust product and process design solutions are sought to minimize the production costs associated with variation and offset from nominal shape of assembled parts and the intended fault free process [1]. Today, there is an increased use of virtual tools in concept, verification and production phases aiming to enhance the understanding of complex multistage assembly processes. Variation simulation of non-rigid sheet metal assemblies is one such virtual activity [2-4], aiming to predict the geometric outcome of the Body in White (BIW).

Car body assemblies consist of many parts and pre-assemblies that are non-rigid by their nature. The geometric requirements set on these details are mostly based on experience gained from previous production. In addition, the stored historic data mostly describes the geometric deviation from nominal in discrete key control points, i.e. capability points, collected in an over-constrained condition.

The geometric requirements are usually followed up using statistical process control (SPC) methods, based on measurement data from details positioned in measurement fixtures [5]. These fixtures often distort the free state shape[1] of the details, forcing them closer to the nominal shape, since they constrain more than six degrees of freedom[2] of the detail. In addition, the measured part is exposed to the gravity field and minor fixture deviation from nominal, which also deform a non-rigid part, see Figure 1.

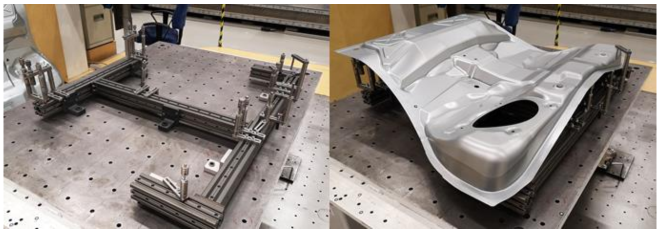

FIGURE 1: OVER-CONSTRAINED RIGGING OF PART

Without knowing the clamping forces when a part or pre-assembly is measured in an over-constrained manner, the detail´s tendency to spring-back after release is lost in the collected data [6]. This makes it hard to understand and analyze each part´s contribution to geometrical deviations after assembly and its effect on surrounding non-rigid parts. Knowing the free state shape will enhance the quality of the analysis and is a pre-condition for non-rigid virtual assembly studies.

1.2 Virtual assembly of sheet metal parts

For BIW sheet metal assemblies, physical verification of the geometry outcome is still the dominant method used in pre-series built to verify the outcome before going into production and ramp up. Type bound matching and trimming fixtures, also called PCF-equipment, are used to study how the non-rigid sheet metal parts fit together. Part to part conflicts and weld sequences are studied, trying to minimize the spring-back effects and the geometry mean offsets and variation.

The latest development in several areas such as process databases, measurement technology, non-rigid assembly simulation and computational power, allows the use of virtual methods that has the potential to replace much of the physical verification in the future.

In Figure 2, an example of a virtual assembly modelling setup is presented. The lay-out describes the intended process and the Process Design / Simulate database [7] holds information about the parts, pre- or sub-assemblies to be assembled, locating schemes, spot weld points to be set and their sequence[3]. With this information an assembly simulation model can be built. In this case the CAT-tool RD&T [8] is used to model and simulate the non-rigid behavior of the intended process.

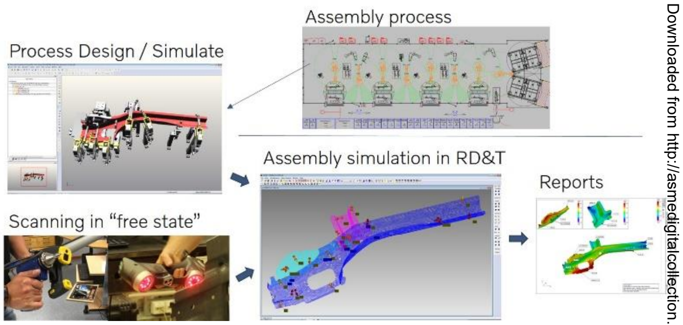

FIGURE 2: VIRTUAL ASSEMBLY MODELLING SETUP

The non-rigid variation simulations performed in RD&T is based on Monte Carlo simulation (MCS). Method of influence coefficients (MIC) [3, 9] is used to speed up the calculations, extended with efficient methods for contact modelling [10, 11], and weld sequence analysis [12].

If the nominal model is fed with realistic part and process deviations, estimations can be made showing part to part conflicts, shapes and gaps to be closed by the welding gun, shape and gaps before the fixture release and finally the spring-back shape after fixture release.

Realistic part deviations can come from several sources, e.g. scanning of parts in "free state", forming simulations or stored data of free state shapes of parts and sub-assemblies acquired in running production[4].

1.3 Problem description

Today, it is in practice not easy to get hold of realistic estimates of part deviation in free state. Stored SPC data only describe deviations in certain capability points captured in an over-constrained condition. Forming simulation results can be available for some details, but are still not covering the total BIW process. To feed a digital twin for estimation of the geometry outcome with realistic part deviation, the use of 3D-scanned details remains the main input.

Efficient methods and tools for acquiring point clouds are available on the market. However, tools to post-process and methods to catch the free state shape are scarcer as it involves compensation due to applied external forces such as gravity and reaction forces in the locators fixating the part.

Introducing locator force measurement devices in the measurement fixtures seem farfetched as it will make these fixtures more complex, harder to maintain and probably much more expensive.

Another solution is to position the detail to be measured in an orientation minimizing the deformation due to gravity and fixation. This can for example be done by hanging the part in a suitable hole or slot and just stop the swinging and rotation by two surface locators. It is then important to secure that these

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[1] The free state shape refers in this paper to the 3D-shape of a part or sub-assembly when not exposed to any external forces.

[2] The over-constrained shape refers in this paper to the 3D-shape of part or sub-assembly when constrained in more than six degrees of freedom.

[3] This is just a small portion of available data in the database.

[4] Morphing can be used to adapt to minor design changes.

locators apply small forces on the detail. However, this approximate solution is not suitable for all parts as its success depends upon the shape and size of the detail.

GOM has demonstrated a solution to measure a part in a “three-point setup” and estimate the shape of a part when clamped into a measurement fixture, called virtual clamping [13]. They make use of a new flexible fixture design, to secure a proper three-point setup. GOM claims that the system compensates for change in part orientation and the effects of gravity.[5] This is however a black-box solution, and thereby difficult to evaluate.

Efficient and accurate methods for estimating the free state shape, i.e. the shape when not exposed to any external forces or gravitational impact, may revolutionize the way in which non-rigid objects are measured and their tolerance allocation in the future. The control fixtures can be simplified, and the analysis improved.

The ability to estimate the shape for different over-constrained conditions and orientations in the gravity field, significantly increases the possible use of the information collected. This shape will in text below be called *estimated over-constrained shape*, see Figure 3.

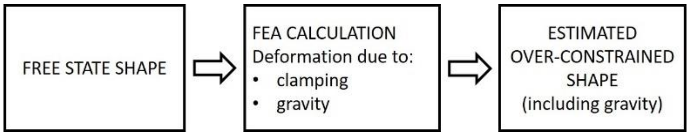

FIGURE 3: ESTIMATION OF OVER-CONSTRAINED SHAPE

Estimation of the free state shape is also a prerequisite for non-rigid variation simulation based on MIC and MCS. Especially if gravitational effects affecting the penetration state in contact modeling [14], spring-back effects after release, and fixation in different orientations (e.g. to account for form of the assembly when clamped in a measurement fixture) are to be taken into account.

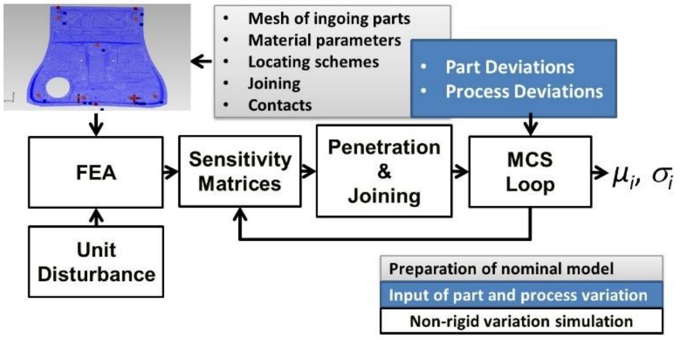

FIGURE 4: VARIATION SIMULATION OF NON-RIGID PARTS BASED ON MCS AND MIC.

For this type of modelling, the required sensitivity matrices are established by unit disturbance of a nominal FEA model and the ingoing part deviation is coupled to the nodes in the meshes describing the stiffness of the ingoing parts, see Figure 4.

The shape deviation of a 3D-scanned object is often reported by calculating the distance between measured and nominal shape in normal direction[6] and then present the result in a color plot. However, it is important to note that this procedure only works for small deviations in relation to the shape and size of the measured detail.

Scanning of a non-rigid detail in “free state”, or just rested on three points, often results in quite large deviations, see e.g. column 1 in Table 1. Then the deviation in pure normal direction of the surface does not describe the “true” shape of the measured detail in curved areas. In addition, the deviation in pure normal direction is not continuous when studied in the axis directions of the 3D coordinate system used. A flange with nominal normal direction in x- or y-direction will show zero deviation in z even if neighboring surfaces show deviations in this direction, see Figure 5.

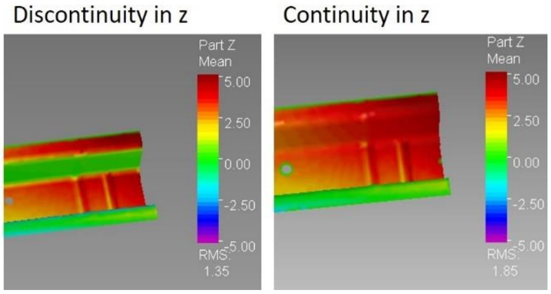

FIGURE 5: LOSS OF INFORMATION WHEN USING PURE DEVIATION IN NORMAL DIRECTION, (SCALE +/- 5 mm)

In non-rigid variation simulation, based on MIC and MCS, it is important not to miss the effect of how the nodes have moved in the plane. This aspect also needs to be considered for correct g-force and contact modeling. In order to capture the continuous deviation in all coordinate axis, morphing techniques can be used. Morphing is a well-known technique used in re-design and in other areas such as animation and medicine [15].

1.4 Scope of the paper

In this paper a method is presented, describing how both free state shape and over-constrained shape of a measured detail can be virtually estimated starting from acquired data when the detail is resting on only 3-points or spheres. The objective is to minimize the loss of spring-back information in the acquired measurement data, to preserve the shape information including in-plane deviation, to allow for a wider use of the collected measurement data, and to spare measurement resources.

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[5] Measurement system and analysis software’s from GOM have not been used or evaluated in the study presented in this paper. See section “2.3 Demonstrator setup” for description of used systems for measurement, point cloud post processing, non-rigid modeling and gravity compensation.

[6] In normal direction of nominal part

2. PROPOSED METHOD

In this section a simple 3D-scanning measurement setup is described. Then, the method used to process the collected information and the approximations on which it is based are described. Finally, the tools used for point-cloud post processing, gravity force compensation, estimation of free state shape and estimated over-constrained shape including gravity, are presented.

2.1 3D-scanning measurement setup

Essential for efficiency is simple fast rigging of the part or sub-assembly to be measured. Another aspect is ergonomics and access for the operator performing the scanning. Furthermore, the external forces deforming the measured detail must be predictable.

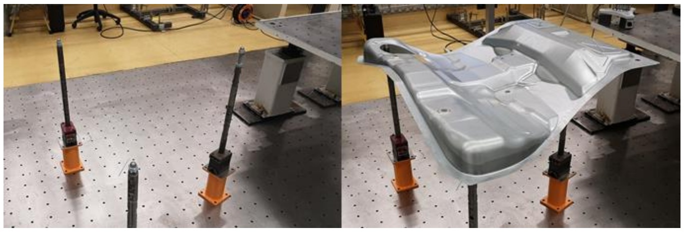

FIGURE 6: RIGGING OF PART RESTING ON THREE SPHERES

Without claiming that all the above requirements are met when measuring all types of details of different size, weight, shape and stiffness, the following simple procedure for 3D-scanning is proposed.

1. Rig three height adjustable supports with spheres on the top on a horizontal measurement base plate. The supports should be adjusted and positioned to allow the part to rest on spread and close to parallel surfaces with clearance from sharp radiuses. See Figure 6 and cases presented in Table 1.
2. Lay the part on the three well defined supports.
3. Scan the part acquiring its shape when resting on the three spheres.
4. Take away the part, then scan the three spheres (Sp1, Sp2 and Sp3) and a small portion of the base plate in the same alignment as in step 3 above.

The above procedure provides the following information.

A. Point cloud describing shape of part resting on the three spheres.
B. Point cloud describing the three spheres.
C. Point cloud describing the plane perpendicular to the gravity field.

Note that all point clouds shall be collected in the same coordinate system, also called alignment using measurement terminology.

2.2 Estimate of free state and over-constrained shapes

In this section a method is presented for estimation of the free state shape and the over-constrained shape using the collected data resulting from the measurement procedure described by the four steps presented above. The method is based on the following assumptions.

- The friction forces in the *three points*[7] in contact with the measured part are assumed to be low, when the part is resting on the three spheres.
- These in plane forces are assumed to generate a negligible contribution in relation to gravity and resulting reaction forces in normal direction, reshaping the detail.
- That there are no major differences in stiffness between nominal and measured part.

The method is applicable for measurement of details that are stiff enough to be placed on three points, without any plastic deformation[8]. Furthermore, when modelling and estimating the over-constrained shape, the following delimitations apply:

- The measurement fixture is considered fault free, stiff enough to force the part to nominal position in all locating points.
- Play in pin reference, positioning hole or slot, is not considered. Furthermore, eventual drawer effect is neglected. The pin is assumed to properly enter the hole or slot.
- Friction in non-steering direction is not considered for locators acting on surfaces.
- Clamping sequence is omitted.
- The measured detail is not considered to be deformed in the plastic regime by the fixture.

The geometric requirement set on a typical BIW sheet metal detail is in the range of 2 mm. In general mating surfaces, hole and slot positions have a tolerance of +/- 1 mm. Keeping this in mind, the hypothesis is as follow.

> *With input from 3D-scanning of a typical BIW sheet metal detail resting on three spheres, its over-constrained shape can be estimated with enough accuracy to judge if inside tolerance or not, despite made simplifications listed above.*

With the assumptions and delimitations listed above, the estimation of the free state shape can be made following the below described procedure. The procedure is also depicted in Figure 7 below.

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[7] The three points in contact with the measured detail, will in the following be named P1, P2 and P3.

[8] Single sheet metal details and sub-assemblies of moderate size, not to heavy.

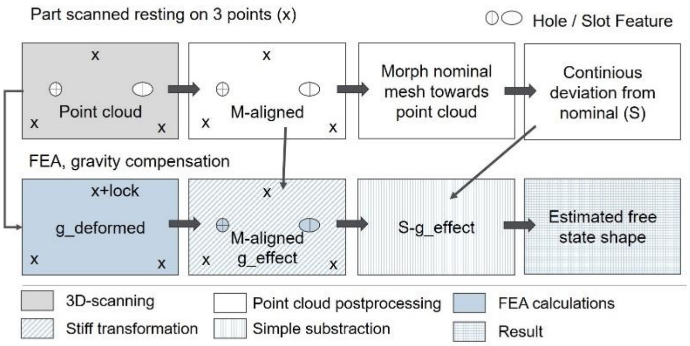


FIGURE 7: FREE STATE SHAPE MODEL

1. Align the point clouds (A, B and C), towards nominal model describing measured detail, so that:
    a. sphere centers (Sp1, Sp2 and Sp3) are distanced equal to their radiuses from the nominal detail´s surfaces in their normal direction.
    b. the additional degrees of freedom in rotation and translation are locked by two easily identified[9] and well spread features, e.g. a hole and a slot, selected so that the locating system becomes close to a 3-2-1 system.

    Call this alignment, M_aligned.
2. In the alignment created above, calculate the sphere contact points (P1, P2 and P3) *touching* the nominal model describing the measured detail.
3. In the same alignment, morph nominal mesh onto measured shape of the detail (point cloud A) and calculate the part deviation in each node, capturing also the in-plane deviations. Call this shape S.[10]
4. Perform FEA-calculation, estimating the deformation of a nominal part resting on the three points P1, P2 and P3, applying the gravity field defined by the normal of the plane measured on the base plate, aligned in the coordinate system established under step 1 above. In the FEA-calculation P1, P2 and P3 are constrained in their nominal normal direction in these points and the remaining free rotation and translation degrees of freedom is locked locally either in P1, P2 or P3. Let us call this shape g_deformed.
5. Position the g_deformed part in alignment M_aligned to calculate the effect from gravity, g_effect.
6. Finally, calculate the free state shape by extracting the gravity effect from the morphed shape.
   Free_state = S – g_effect.

The estimated free state shape can be used as input for variation simulation of non-rigid assemblies, but also to virtually estimate the shape of the detail if it is clamped into a measurement fixture, see Figure 3 and cases presented below.

2.3 Demonstrator setup

The tool setup used to demonstrate the proposed method is as follows:

- The point cloud was acquired using a 7-axis manual CMM arm, MCAx, equipped with a laser scanner, ModelMaker MMDX, of brand Nikon.
- The Inspector- and Modeler modules in Polyworks [16], has been used during measurement and for post-processing of the point cloud, including morphing.
- The virtual fixture has been modeled using the CAT-tool RD&T [8]. In this tool the gravity effects on the non-rigid part are estimated, free-state shape is calculated and finally the shape of an over-constrained detail in the control fixture is estimated.

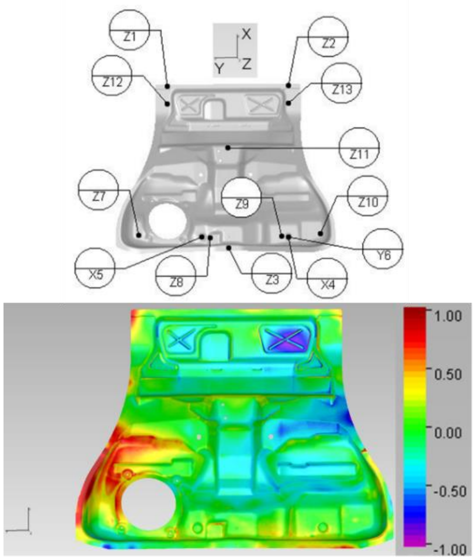
3. RESULTS AND DISCUSSION

In this section the studied case is presented followed by a discussion about lessons learned and what conclusions we can draw from the studied case.

3.1 Case studies

A weak and quite large automobile sheet metal part was chosen to test the presented method in practice. This mild steel part has the size 970x1280x200 mm, thickness 0,6 mm and weight about 5,3 kg.

The part was placed in a measurement fixture and scanned in that over-constrained condition. The used locating system and color plot showing its shape are depicted in Figure 8. This measurement was used as reference, towards which the below presented estimated over-constrained shapes were compared.



+/-1mm

FIGURE 8: LOCATING SYSTEM AND SCANNED SHAPE

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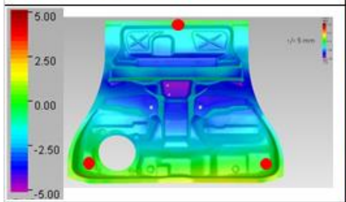
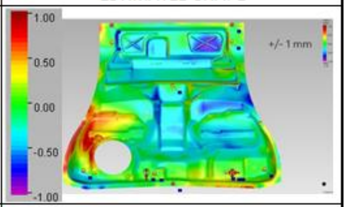
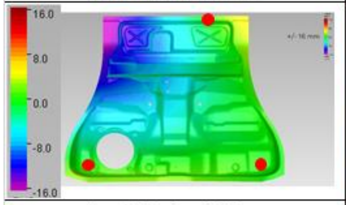
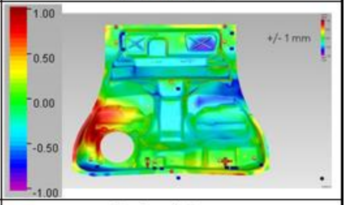
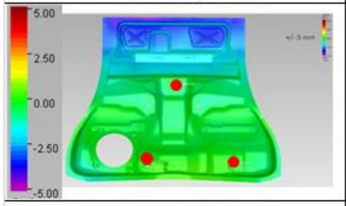
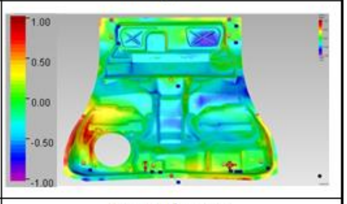
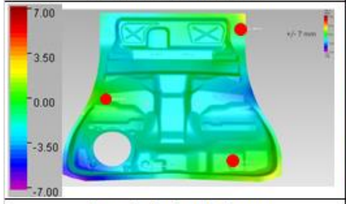
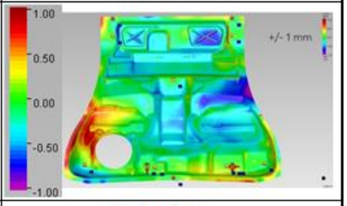
[9] Both in point cloud A and in nominal model describing the measured detail.

[10] For simplicity and available space of this paper the morphing process is not penetrated in detail.

Four different 3-point setups were tested. The part was positioned just laying free on 3 supports, whilst scanned. Color plots of the by gravity deformed parts are shown in column one in Table 1. The red dots in these pictures mark the different 3-point setups studied. The color plots in column two show the estimated over-constrained shape, corresponding to if the detail would have been positioned in the measurement fixture.

TABLE 1: 3-POINT SETUPS AND ESTIMATED OVER-CONSTRAINED SHAPES

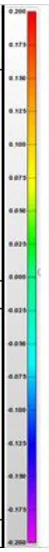
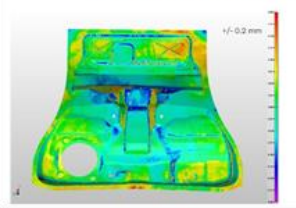
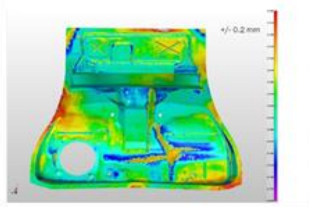
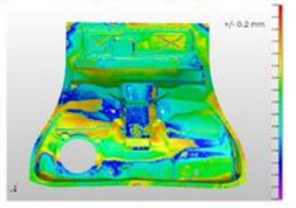
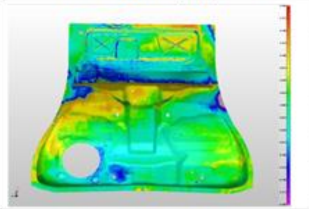
MEASURED SHAPE	ESTIMATED SHAPE
	
Case1: Scale +/- 5mm	Scale +/- 1 mm
	
Case 2: Scale +/- 16mm	Scale +/- 1 mm
	
Case 3: Scale +/- 5mm	Scale +/- 1 mm
	
Case 4: Scale +/- 7mm	Scale +/- 1 mm

The 3-point setup in Case 1 was chosen considering the placement of the part references, see Figure 8, and to have a large spread between the three points. In Case 2 the support on the "top" was moved to avoid any symmetry effects. The setup in the next case was chosen as another possible rigging solution as we want the part to rest on "almost" parallel surfaces and to get another deformation. Finally, in Case 4, we decided to use a bad setup by purpose. Here, the two supports closest to the top were located on weak areas of the part.

During the scanning of the part when placed in the measurement fixture, a small play was detected in the hole/pin and slot/pin combination. Furthermore, when looking closer at the scanning data describing the hole and slot used for alignment of the four cases, the accuracy of these were questioned. Hole and slot accuracies are dependent upon used scanning equipment and used point cloud post-processing system. In our case the accuracy would have been increased if boundary point cloud was stored whilst scanning the details surface. Unfortunately, it was not.

To assess how well the shape has been estimated in each case, color plots showing the error in shape after a best-fit alignment, of estimated over-constrained shape towards scanned shape in measurement fixture, are shown in Table 2. Best-fit alignment was chosen to eliminate eventual translation and rotational effects stemming from the uncertainty of hole and slot measurement. As can be seen, the differences are less than 0,2 mm in most areas.

TABLE 2: ERROR IN SHAPE ESTIMATION[11]

SHAPE DIFFERENCES COMPARING SHAPE SCANNED IN FIXTURE AND ESTIMATED OVER-CONSTRAINED SHAPE AFTER BEST-FIT		
		
Case 1: Scale +/- 0,2 mm	Case 2: Scale +/- 0,2 mm	
		
Case 3: Scale +/- 0,2 mm	Case 4: Scale +/- 0,2 mm	

3.1.1 Study of the gravitational effects

The gravitational effects are compensated for by modelling how the nominal detail is deformed in this force field. Faults such as e.g. material thinning, softening of radiuses and residual forces after stamping are neglected as these effects are not present or easily captured in the acquired data. Moreover, are these effects and their variation believed to add a negligible contribution when measuring the shape of a typical BIW sheet metal part in practice.

In the presented case, a shell mesh consisting of 47236 nodes and 47970 elements[12] with average length of 5 mm has been used in the FEA-calculations. A shell mesh was chosen as the modeled detail is very thin in relation to its size. In this situation a shell element is known to model bending well.

In the FEA calculation of how the detail bends in the g-force field, at least 6 degrees of freedom must be locked. Obviously, a correct locating scheme that reflects reality must be chosen. Assuming the friction forces are low and because they are unknown at each point, the above rotation and translation are

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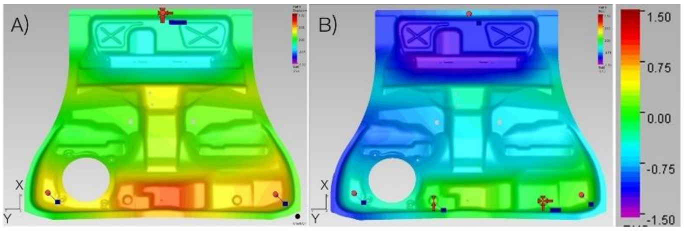
[11] Linear color plot scale +/- 0,2 mm

[12] 95% four node elements and 5% triangle elements

instead locked in one of the 3-points on which the detail rests, see locating scheme depicted in A) in Figure 9. The calculated displacement of each node in all three coordinate directions, in this paper called g_deformed, is then aligned with the coordinate system used when scanning the detail using a stiff transform. The stiff alignment is here called M-alignment and the resulting deviation from nominal g_effect. See B) in Figure 9.



Scale +/- 1.5 mm in both color plots.

FIGURE 9: COLOR PLOT SHOWING NODE MOVEMENT IN X-DERICTION FOR A) G_DEFORMED AND B) G_EFFECT.

To put all the friction in one of the 3 points on which the detail rests obviously does not match reality. But what effect does this simplification have on the calculated gravitational deformation?

In Table 3 the differences in estimated gravitational effect depending on which of the 3-points is selected to also lock rotation and translation[13] are reported. Rx_max, Ry_max and Rz_max describe the maximum difference in estimated deformation in each coordinate direction of calculated displacement in all nodes. R_max indicates the maximum root square deviation found in any of the 47236 nodes in the nominal mesh.

TABLE 3: SENSITIVITY OF CHOSEN POINT TO LOCK

RANGE GRAVITY EFFECT IN 3-POINT SETUP				
(mm)	Rx_max	Ry_max	Rz_max	R_max
Case 1	0,05	0,04	0,13	0,14
Case 2	0,08	0,06	0,16	0,19
Case 3	0,07	0,08	0,24	0,24
Case 4	0,33	0,28	1,50	1,56

The deviations in Table 3 provide a measure of sensitivity affecting the estimated free state shapes. These shapes can also be studied in the over-constrained condition. Then a measure of its impact on the estimated over-constrained shape in the control fixture is obtained. The size of this effect is shown in Table 4 below. Note that the 3-point rigging in Case 4 was chosen to see the effects of placement on weak areas. Furthermore, the sensitivity of chosen 3-point setup can be evaluated virtually before the actual measurement take place and thereby secures a proper choice.

TABLE 4: EFFECT ON OVER-CONSTRAINED SHAPE

SENSITIVY OVER-CONSTRAINED SHAPE				
(mm)	Rx_max	Ry_max	Rz_max	R_max
Case 1	0,03	0,02	0,05	0,05
Case 2	0,04	0,04	0,08	0,08
Case 3	0,05	0,03	0,10	0,10
Case 4	0,21	0,27	0,45	0,45

3.1.2 Estimation of hole and slot features

It is not only the shape that is of interest. Features such as holes, slots and edges are also to be judged if inside tolerance or not[14]. To evaluate hole and slot accuracies the part was rescanned in over-constrained position and a new 3-point setup. Now storing the boundary point cloud whilst scanning the details surface to increase hole and slot measurement accuracy.

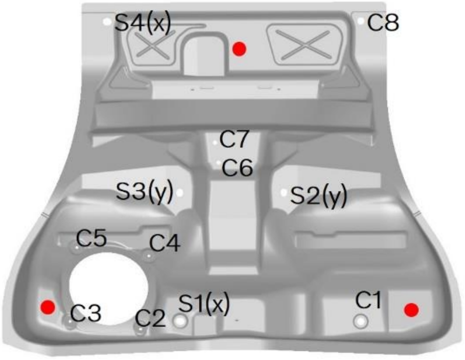


FIGURE 10: NAMING (ID) OF MEASURED FEATURES

The measured center values of holes and slots are used in the morphing process, deforming the nominal mesh to fit with the measured center points. Thus, contributing to node displacement also in planes perpendicular to the normal direction of the scanned surfaces.

The studied detail has eight holes (C1-C8) and four slots (S1-S4, whose steering directions is indicated in parentheses). In Table 5, column 2-4, the deviations of these features measured whilst scanned in measurement fixture and the estimated values are shown. The position of the hole and slot features are depicted in Figure 10.

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[13] One degree of rotational freedom and two in translation.

[14] The used morphing functionality in this study, does not have the ability to anchor and constrain the outer boundary of the part.

TABLE 5: MEASURED VERSUS ESTIMATED FEATURES

(mm)	MEAS. - ESTIMATED			COMPENSATED		
ID	dx	dy	dz	dx	dy	dz
C1	0,00	0,00	-0,11	0,00	0,00	0,04
C2	-0,19	-0,01	0,01	-0,15	0,00	0,05
C3	-0,05	0,09	0,06	-0,02	0,09	0,03
C4	-0,13	0,02	-0,11	-0,07	0,01	0,06
C5	-0,09	-0,01	-0,02	-0,03	-0,03	0,07
C6	-0,09	-0,06	-0,23	-0,05	-0,08	-0,02
C7	-0,07	-0,04	-0,24	-0,03	-0,06	-0,03
C8	-0,27	0,02	0,03	-0,17	0,00	0,02
S1(x)	0,00	-0,05	-0,09	0,00	-0,03	0,01
S2(y)	-0,15	-0,01	-0,22	-0,11	-0,02	0,01
S3(y)	-0,13	0,07	-0,19	-0,08	0,00	-0,01
S4(x)	-0,16	0,04	0,02	-0,04	0,02	0,01

The estimated values are calculated assuming that the measurement fixture is nominal. However, a close study of the measurement data collected when the part was fixated, does show deviation from nominal in the steering direction of the used locating system. The found deviations from nominal for each MLP and additional support points are shown in respective columns 1-2 and columns 3-4 in Table 6. The names (ID) are depicted in Figure 8.

TABLE 6: DEVIATION IN CONSTRAINED DIRECTION

ID	DEV. (mm)	ID	DEV (mm)
Z1	0,08	Z7	-0,06
Z2	0,03	Z8	0,15
Z3	-0,06	Z9	0,16
X4	0,00	Z10	0,16
X5	0,00	Z11	0,22
Y6	0,00	Z12	-0,04
		Z13	-0,01

In the FEA calculations these fixture faults can be compensated for, by adding offsets, slightly changing the position of the locating scheme that distort the free-state shape into the over-constrained condition. The deviations between measured and estimated values after this compensation are shown in column 5-7 in Table 5, above.

3.3 Discussion

The described method seems to work well for the case presented above and it has performed well when tested on other details as well. In the presented case the estimated over-constrained shapes deviate in the order of +/-0,2 mm, when compared to scan data of the detail positioned in the measurement fixture. After compensating for the existing fixture faults, deviations of the same order of magnitude were detected in the study of hole- and slot center positions. Given that the measurement system used has an accuracy of +/-0,1 mm, better resemblance cannot be expected.

A slightly larger deviation in shape is obtained for the 4th 3-point arrangement. This is reflected in the differences obtained depending on which of the three points that has been chosen to be locked in one rotation and two translation degrees of freedom in addition to the pure surface steering in normal direction. However, it is important to note that the assessment of this sensitivity is calculated based on the nominal model. Thus, it is possible to determine whether the selected 3-point layout is appropriate or not before scanning begins. In addition, the average of the three calculated locking options can be used as a better guess of the deformation due to gravity and thus improve the accuracy.

In order to capture angular errors in flanges, or other clamped surfaces, and their influence on the shape when details are forced into the measurement fixture, it is important that the contact area of the locator is included in the FEA model describing the control fixture. The FEA model can also be extended to describe fixation of sub-assemblies. Then the FEA-model must also include joining and contact modelling.

Care must be taken when the over-constrained estimated shape is compared to measurement of the part clamped into a control fixture. The real fixture has also its deviation from the intended requirement setting. Locators deviate from nominal, clamping sequences, lock of part in non-steering directions and not enough stiffness of fixture are all examples of not intended factors in the tolerancing of the parts. All these factors are present in practice and are influencing the measurement result. Therefore, it is not an easy straight forward task to judge if an estimated over-constrained shape is right or wrong.

When scanning the detail, placed on three points, it is important that the chosen measurement method or tool can acquire the hole- and slot centers with high accuracy. Otherwise, problems may arise during the morphing process, which affect the deviation of the nodes from their nominal position in the plane.

A method to handle outer boundary measurements is missing in the used tool for point cloud post-processing. Better tools for boundary detection and incorporation of it in the morphing need to be developed to catch the important edge features.

Post-processing of the point cloud is often the most time-consuming activity. Better methods for quick preparation of the point cloud before morphing need to be developed. Today, it often requires a lot of manual *cleaning*. For efficiency, that needs to be more automated.

Finally, note that shape estimation can be done in whatever defined over-constrained situation and orientation in relation to gravity force when free-state shape is established. This increase the usability of the collected data.

4. CONCLUSION

The paper presents a method for virtual fixturing. The results from the presented industrial case show that the estimated over-constrained shape shows good resemblance with measurements acquired when the part is over-constrained in its measurement fixture.

The geometric requirement set on a typical BIW sheet metal detail is in the range of 2 mm. In general mating surfaces, hole and slot positions have a tolerance of +/- 1 mm. Keeping this in mind, the suggested method is judged to be useful. It has the potential to minimize the loss of spring-back information in the acquired measurement data, to preserve the shape information including in plane deviation, to allow for a wider use of the collected measurement data, and to spare measurement resources.

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