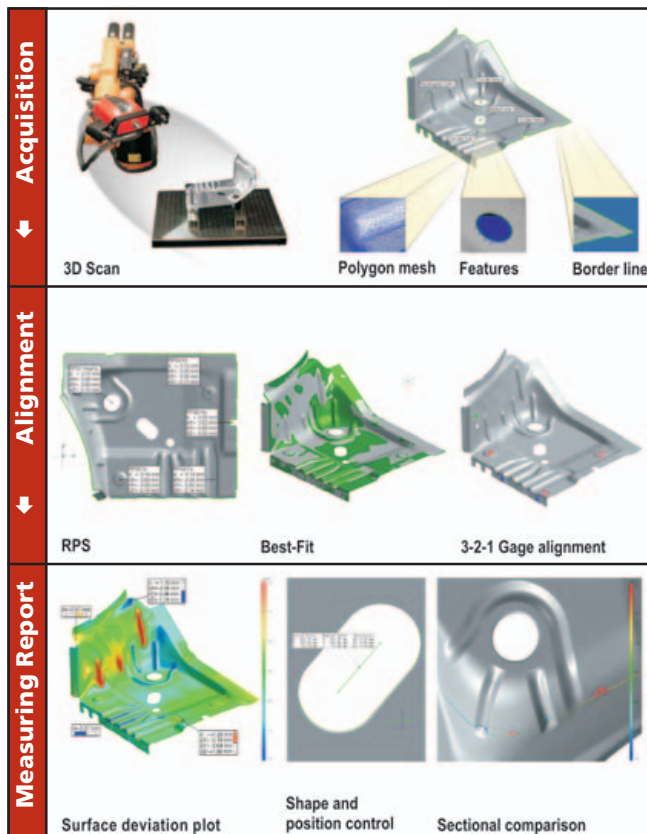


# Industrial 3D Measurement Technology



Quality Control and Inspection  
Utilizing the ATOS 3D Scanner



# Quality Control and Inspection Utilizing the ATOS 3D Scanner

Quality control has become a key component in today's manufacturing process. The ability to provide the "As Designed" geometry to meet the designers' intent and achieve the engineering dimensional requirement to deliver the intended fit and functionality is an ongoing challenge during the manufacturing process. In an effort to verify product form, fit and function, the majority of companies are applying traditional measurement techniques. These techniques have proven to be successful on prismatic types of geometries but very costly and time consuming for contoured surfaces, heavily featured geometry and product assemblies.

Optical 3D scanning, based on the principle of fringe projection, has proven to be both an accurate and cost-effective alternative delivering more dimensional information to aid in quality control and process optimization by creating more meaningful measuring reports.

## Introduction

Today, many of the industrial sectors have implemented 3D scanning technologies to address their inspection and quality assurance requirements. There are various key reasons that these companies have chosen to compliment their traditional measuring techniques with 3D scanning:

- Ability to provide full part geometry capture in a dense point cloud or mesh almost online.
- Scan data can be aligned to CAD or control points after data acquisition in contrast to having the alignment requirements addressed prior to the measurement.
- Deviations to the CAD data set and to primitives, as well as deviations in shape and position result directly from the point clouds.

- Problematic areas of the object are visualized reliably and do not need to be already known or guessed before starting the measurement.
- Measuring reports can be delivered as full color rainbow plots, Go/No-Go plots, sectional comparisons, or traditional CMM style reports.
- No set-up time for measuring object.
- Scanning system is portable so it can travel to the part or assembly, operate on the shop floor, and does not require an accurate or expensive holding device.

3D scanners provide significant measuring results that are particularly a great benefit for process analysis. 3D scanning is proving to be highly effective in the areas of first article inspection, manufacturing try-out, and root cause analysis. The images on the cover depict a typical measurement procedure utilizing the industry-accepted ATOS 3D scanning system:

Step 1 - The process of the data acquisition and storing the "As Built" part geometry in the form of a point cloud or mesh. In addition to the surface information, edges, features (holes, slots, ...) and feature lines are captured.

Step 2 - Acquired data is mathematically aligned to a defined part coordinate system to match the CAD model orientation. Here, exactly the same rules are used as for tactile measurements.

Step 3 - Comparison of the measured data to the CAD model resulting in an automatically generated "As Built" vs. "As Designed" color deviation plot. This visual deliverable gives a powerful overview of the part displaying the deviations versus the design and engineering intent.

At this point, the user has the possibility to try various alignment scenarios, create Go/No-Go color plots, pick on various surface control points and generate deviation labels, create cross-sectional deviation plots including dimensional labels, create and extract dimensional values for primitives (cylinders, spheres, cones, ...). All this information can be compiled in a measuring report.

Such a measuring report is either used in quality assurance for the assessment "good/bad" or is further processed for manufacturing control and production analysis. In addition, the data is of great importance for optimizing the production process and for product development itself.

## The Optical 3D Scanner

### Variety of Applications

The mobile ATOS 3D optical scanner has a unique capability of being user-configurable to address various measuring requirements. This is accomplished via the user's ability to change measuring volumes in minutes, in order to increase scan data resolution or increase the measuring field of view. Thanks to this flexibility, the ATOS system is able to measure objects of various sizes, from filigree die-cast components up to complete aircraft.

### Small Objects

When measuring small or highly featured objects, the ATOS SO tabletop configuration is recommended (Fig 1). Here, the object is positioned directly below the sensor head. The high-resolution measuring data allows precise measurements even of sealing rails or small snaps. Undercuts from one viewing direction are not a problem as the object is scanned from various tilt positions and the data is computed to a closed polygon mesh at the end of the measurement.

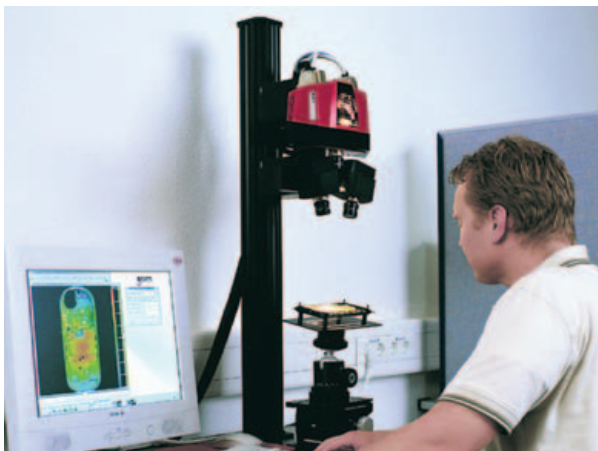


Fig. 1 Measuring small objects utilizing the ATOS SO system

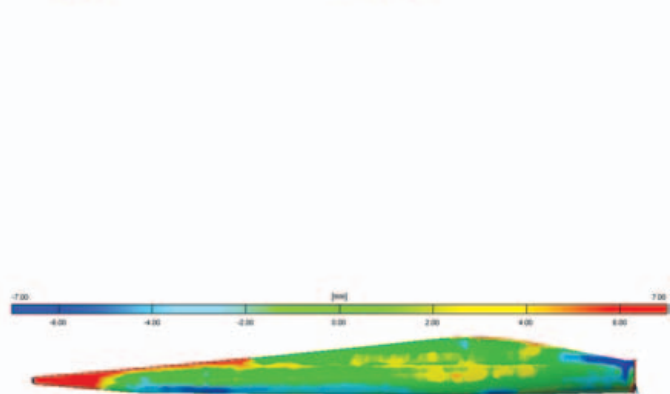
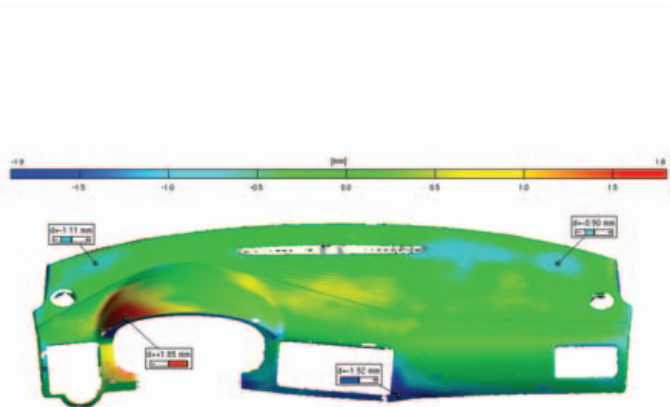
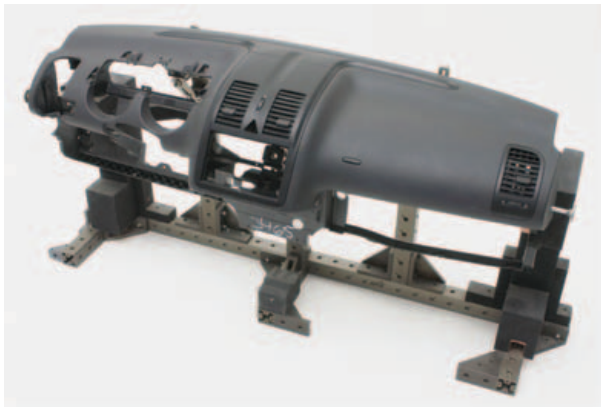
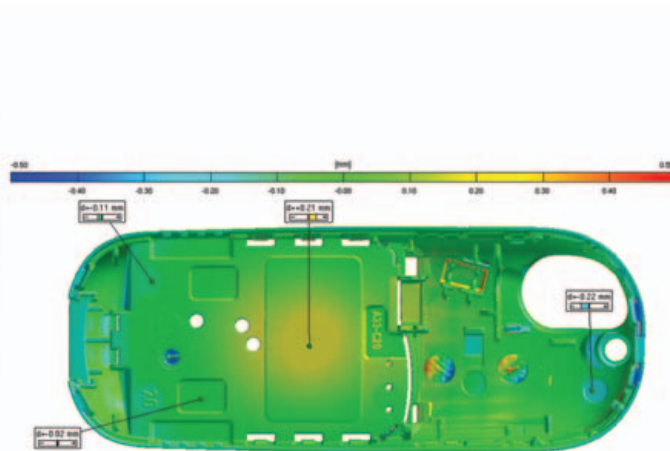


Fig. 2 Measuring medium to large objects: Vehicle instrument panel and rotor blade from a wind turbine

## Large Objects

When measuring larger objects, the ATOS sensor head is mounted on a camera stand, portable tripod or robot with the ability to be positioned flexibly in space.

Fig. 2 shows the scalability of the ATOS system in its ability to measure objects of just a few centimeters up to several ten meters. A typical vehicle instrument panel and a rotor blade of a wind turbine are displayed on the left and the colored deviation plot created by the "As Built" scan data to CAD comparison is shown on the right.

As for all measuring tasks, the measuring accuracy is an important aspect for optical scanners as well. Table 1 shows typical objects to be measured with their respective measuring accuracy and point density (measuring point distance):

Object:	Absolute Accuracy:	Measuring Point Distance:
Mobile phone cover	±0.01 mm ±0.0004 in	0.05 mm 0.002 in
Sheet metal 500 x 300 x 300 mm <sup>3</sup>	±0.03 mm ±0.0012 in	0.1 mm 0.004 in
Vehicle instrument panel	±0.05 mm ±0.002 in	0.2 mm 0.008 in
Deep-drawing die 5 x 2 x 1 m <sup>3</sup>	±0.1 mm ±0.004 in	0.2 mm 0.008 in
Car body	±0.15 mm ±0.006 in	0.4 mm 0.016 in
20 m rotor (wind turbine)	± 0.6 mm ±0.024 in	0.8 mm 0.0031 in

**Table 1:** Object sizes with typical accuracies

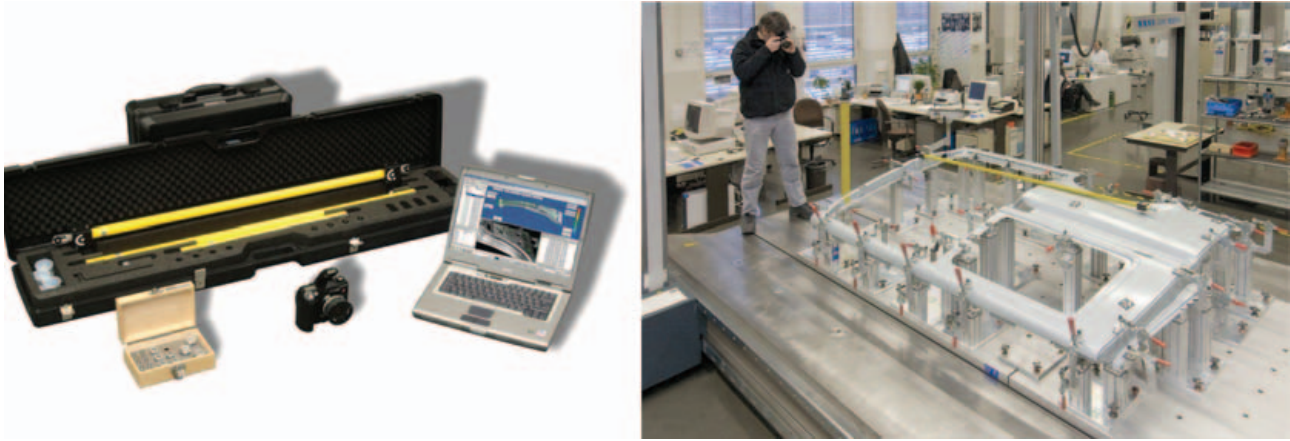
## Measuring Principle

The ATOS 3D scanner (Fig. 3) is based on the principle of triangulation. The sensor unit projects different fringe patterns onto the object to be measured. These patterns are then recorded by two cameras. Based on the optical image equations, the computer automatically calculates the 3D coordinates for each of the up to 4 million camera pixels with high precision within just a few seconds.

In order to digitize an object completely, several individual measurements from various views are required. The ATOS system utilizes a unique reference marker technique to automatically merge these various views of data. While measuring the object, the system also automatically identifies these reference markers that can be placed directly on the object, on surrounding geometry or on fixturing. All measurements are automatically merged together utilizing these reference markers, achieving a common global coordinate system. For small objects, these reference points are directly scanned with ATOS; for large objects, this is done utilizing the digital photogrammetry system TRITOP (Fig. 4).



**Fig. 3** ATOS 3D scanner designed for both metrology room and shop floor environments



**Fig. 4** TRITOP digital photogrammetry system shown measuring an automotive body part in a fixture

### Measuring Results

After scanning, the software calculates a complete high-resolution polygon mesh of the object surface, creating small triangles in curved and large triangles in flatter areas without diminishing the mesh's accuracy. Features like holes, hole patterns, slots, cutouts and edges can be identified based on their contrast to surrounding areas on the object. This information is then intersected with the polygonal mesh to obtain coordinates and dimensional data for the feature. Fig. 5 shows three different types of data.

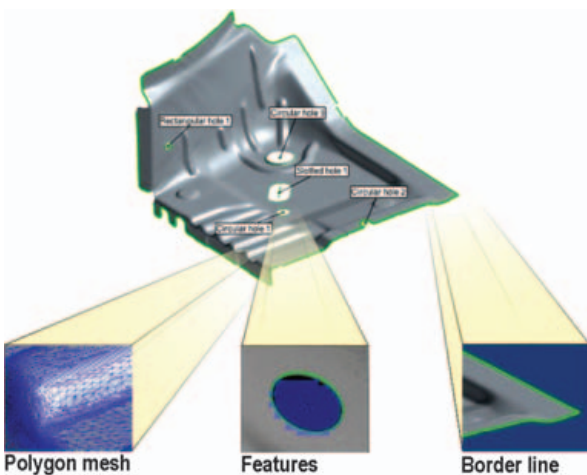
### Alignment of the Object

Upon scanning completion, the data acquired by the ATOS system is in an arbitrary global coordinate system. In order to perform the scanned "As Built" vs. CAD data comparison, the scan data is usually transformed into the CAD data coordinate position. This transformation is done analogous to mechanical measuring machines but completely by means of the computer in an offline process.

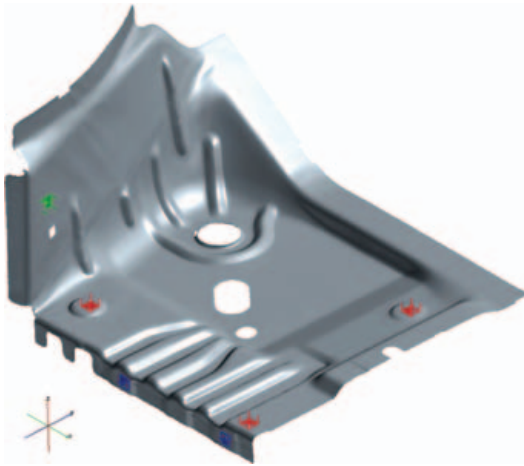
### 3-2-1 Transformation

The 3-2-1 method requires six coordinates for alignment. In case of, for example, a ZZZ-YY-X alignment, three Z coordinates are entered to define the Z plane, two Y coordinates to define the direction of the Y axis (and thus of the X axis as well) and one X coordinate to define the origin. To increase the reliability of the alignment process, additional coordinates may be entered, thus defining e.g. the plane using four coordinates. In this case, the system averages over four points.

3-2-1 transformation is used, among others, if the component is mounted on a gage. The alignment diameters or surfaces are scanned and transformed to the corresponding target values together with the data set. In Fig. 6, the surfaces used for 3-2-1 transformation are displayed in color. Here, the alignment was made directly via the surfaces of the component, thus simulating the fixture points mathematically.



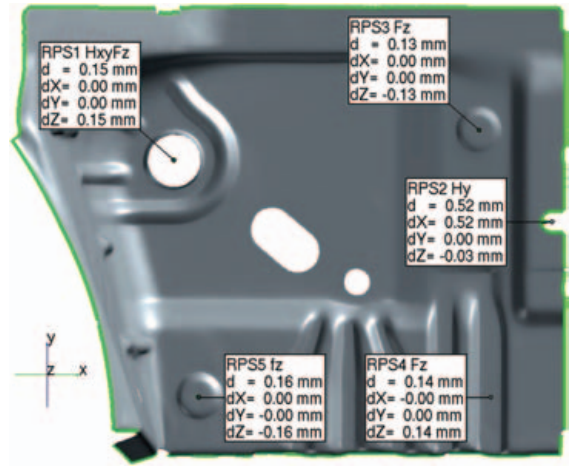
**Fig. 5** Measuring data types of the ATOS scanner



**Fig. 6** 3-2-1 transformation (gauge alignment)

### RPS Registration

Alignment according to the RPS method (Reference Point System) is based on characteristic features. For this purpose, geometries of the part (circular holes, slotted holes, cylinders, planes, ...) are used. The coordinates of the predefined reference points are assigned to these features and their direction of action is determined. Based on this information, the software defines the corresponding RPS registration. As for the 3-2-1 transformation, at least six coordinates determining all three axes have to be defined. In case of redundant identification, the coordinate value is averaged among the corresponding number of points. In Fig. 7, reference point RPS1 defines all three coordinates; it is called the master reference point. Reference point RPS2, taking effect in Y-direction, prevents torsion. The remaining reference points RPS3, RPS4 and RPS5 take effect in Z. Therefore, these four points overdetermine the Z plane and the discrepancy is distributed among these points. The RPS method is commonly utilized in the automotive industry.

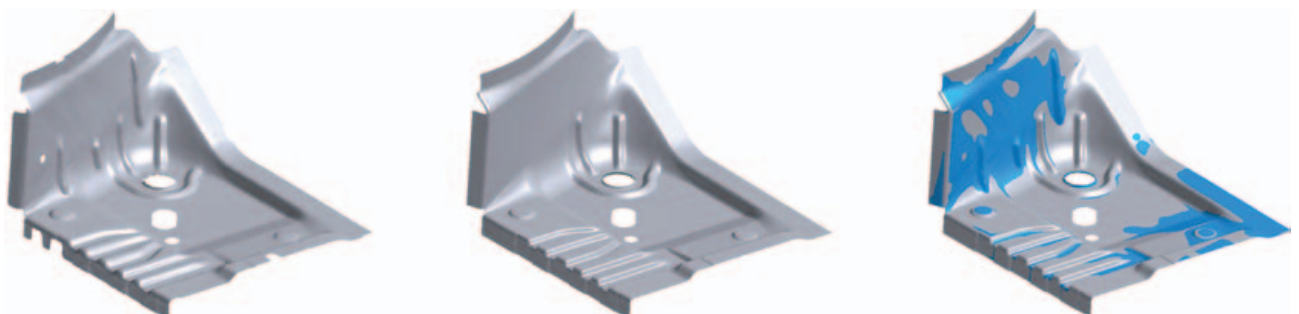


**Fig. 7** RPS registration

### Best-Fit Registration

In case of best-fit registration, the entire surface or selected areas of the measured surface is aligned with the CAD data such that the average deviation of both surfaces is minimized. Thus, optimum alignment of both the measured and CAD data is achieved (Fig. 8). With the help of best-fit registration it is possible to identify deviations of an object and to decide whether the measuring results are valid. Best-fit registration will factor out a bad RPS definition or fixturing error affecting the alignment. However, deviations in the part geometry directly affect the outcome of a best-fit registration, preventing a true direct data comparison. Therefore, best-fit registration is often used as an intermediate step during problem analysis. To obtain final results, the valid alignment specifications for the object must be observed, which in most cases is not the "best-fit" method.

Fig. 8 shows digitized data on the left, CAD data in the middle, and the visible surfaces of both measured data (blue) and CAD data (gray) on the right. It is immediately visible in the middle picture that the ribs in the CAD data sets are missing, and the deviation of the data sets in the right picture is obvious as well.



**Fig. 8** Best-fit registration of the digitized data to the CAD data

### Alignment as Metrological Problem

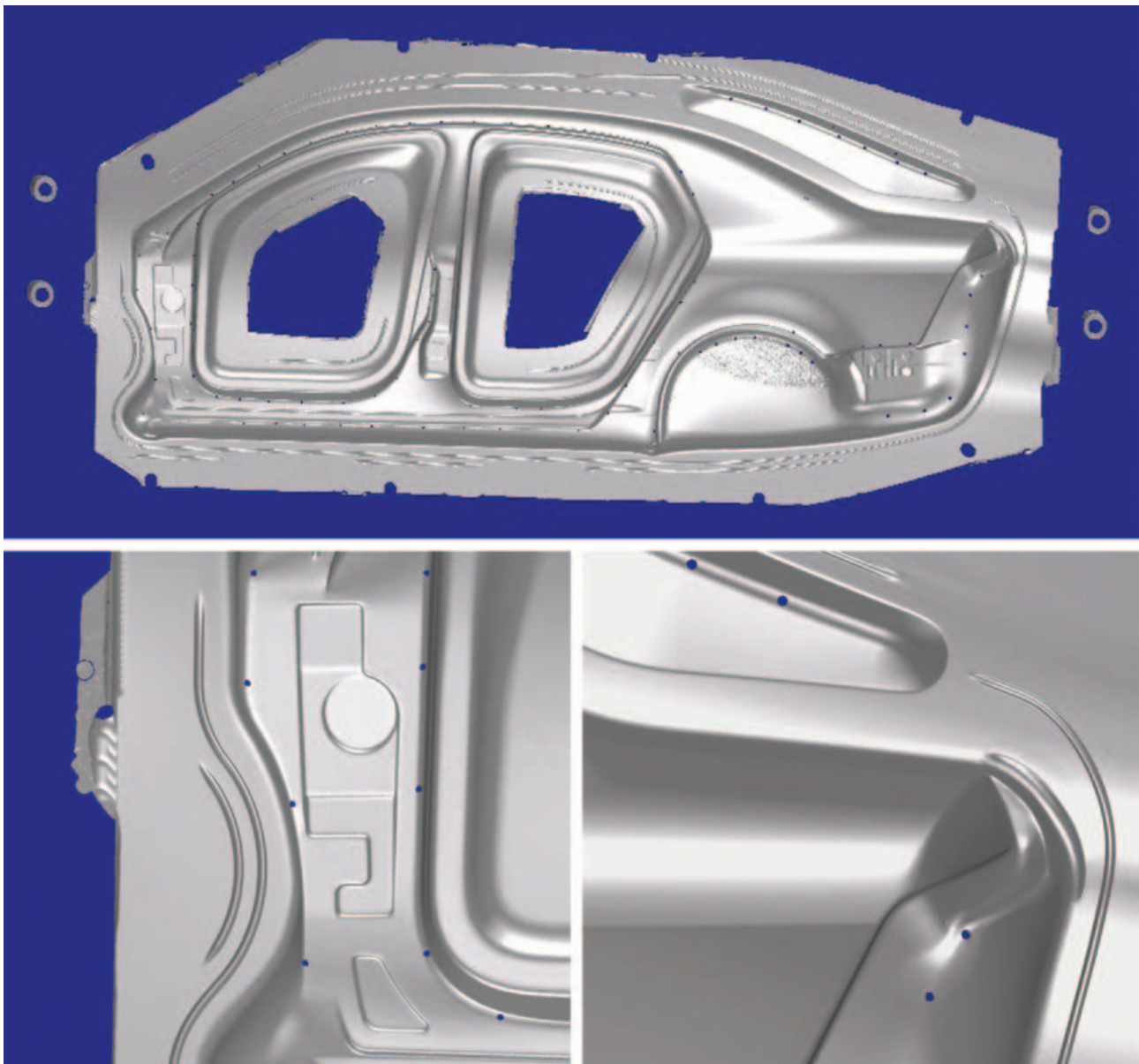
Faults in alignment are a frequent source of error in tactile 3D measuring. Typically, the alignment is carried out using one of the above mentioned processes. The measuring points are captured in the coordinate system defined by this alignment. If a mistake was made when aligning the component, all measuring points will show this alignment fault.

The evaluation of scanned data provides a safe procedure: First, a best-fit registration is performed, then the colored deviation plots are evaluated to check for any major discrepancies. Next, an alignment is performed according to the specifications called out for this particular part and the deviations are compared to best-fit analysis. If there was a large discrepancy between the best-fit

and the RPS inspection, the RPS alignment would need to be investigated. Figures 9, 10 and 11 illustrate such a scenario.

Fig. 9 shows the shaded digitized data of a body side panel tool. Both close-up data images show the quality and resolution of the data acquired by the ATOS scanner, reflecting the tool's "As Built" configuration.

Fig. 10 shows the comparison with the CAD data according to an RPS alignment. The result is high deviations in the areas of high curvature, visible via the full color plot as well as with the inspection labels. The potential fix to this tool could be re-machining, grinding, or the welding of additional material for re-machining which constitutes a high amount of work and may influence the quality of the tool.



**Fig. 9** Measuring data of a side panel tool

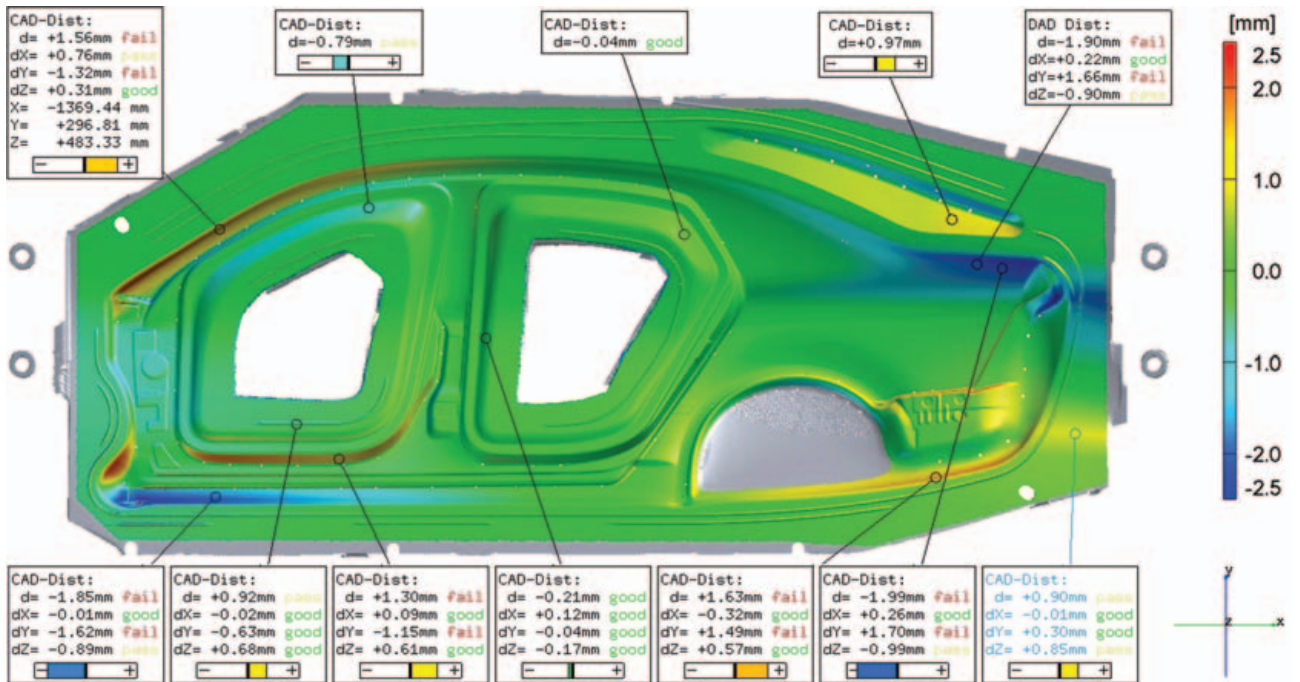


Fig. 10 Deviation of the digitized data versus nominal data after RPS registration

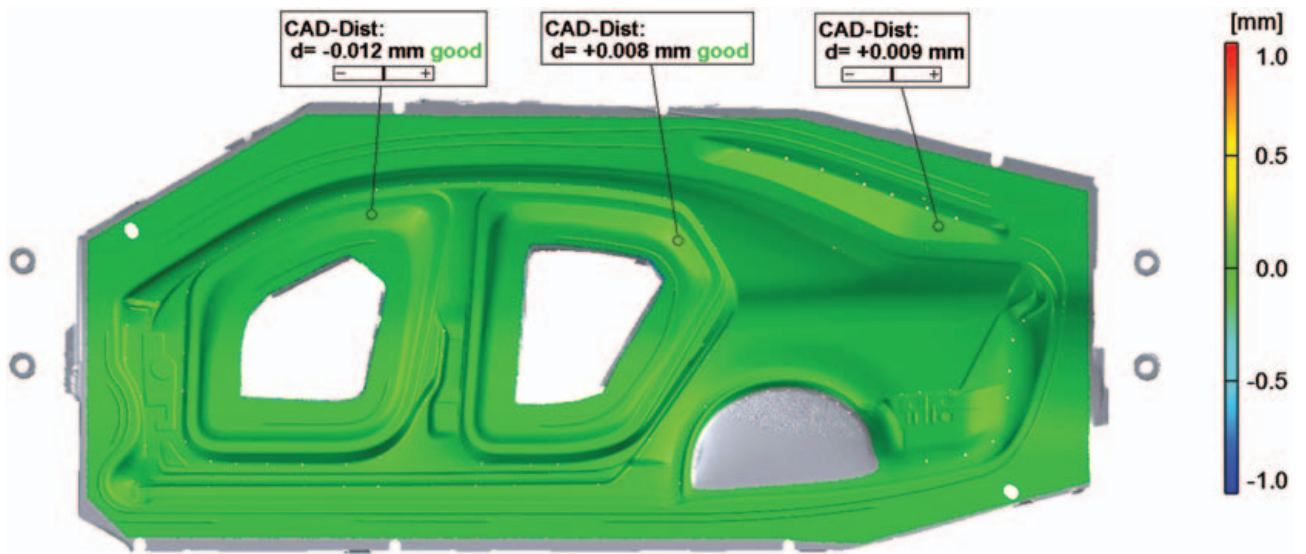


Fig. 11 Deviations utilizing best-fit registration eliminating incorrect RPS control point values

Fig. 11 shows a remarkable effect: The digitized data was realigned to the CAD data utilizing best-fit methods. The deviations in the previous out-of-tolerance areas are now insignificant. An incorrect RPS value skewed the analysis shown in Fig. 10. The quickly acquired best-fit analysis proved itself as a useful data check. It is very difficult to identify such faulty alignments when using traditional procedures of aligning first then measuring second.

## Evaluation of the Measuring Result

### Full Color Deviation Plots and Labels

After the measured scan data has been transformed into the targeted coordinate position, the distance of each scan data point to the CAD surface is automatically calculated. For visualization purposes, a color is assigned to each discrete distance. This process creates an easy to interpret color map conveying the dimensional accuracy of the "As Built" condition vs. CAD. For example, reddish areas on the plot indicate an area that is oversized or above the CAD model surface. Conversely, the blue areas are undersized or below the CAD surface. The multicolor deviation scale is automatically created based on the calculated deviations.

This scale can also be fine-tuned or adjusted by the user. The color legend correlates with the calculated deviations on the part and will aid in the determination if the part is within tolerance. This same legend can be displayed with discrete colors

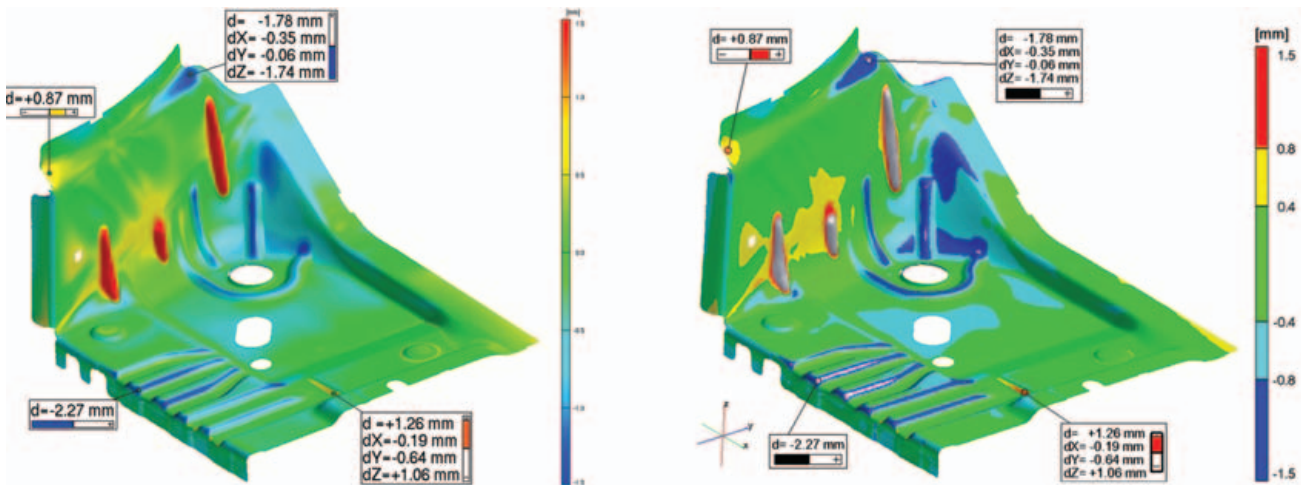
or can be modified to a Go/No-Go scenario to show individual tolerances. Deviations of individual measuring points (Fig. 12) are displayed as numerical values together with the respective color in the tolerance field. These surface control points can either be defined manually or loaded as points of comparison. The layout and the content of the labels can be adapted individually.



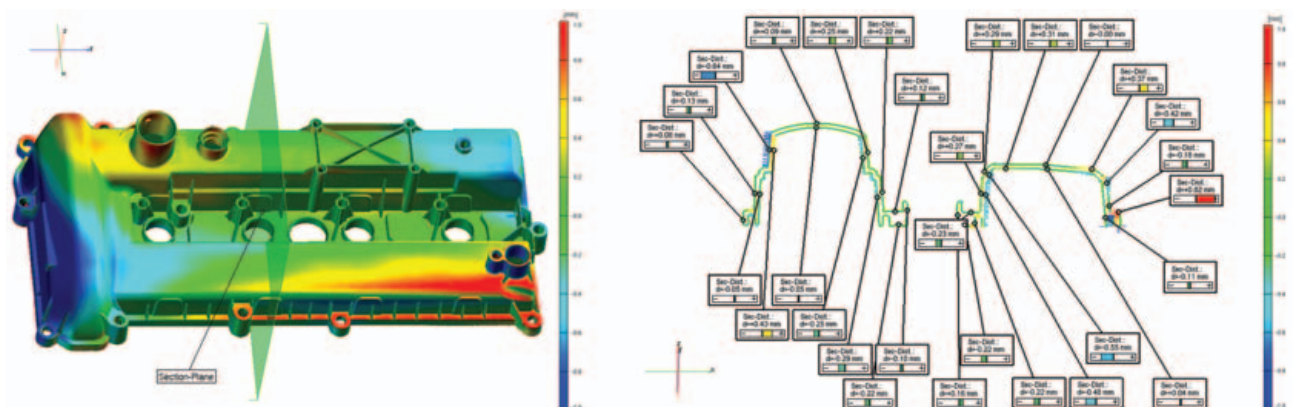
**Fig. 12** Dimensioned and colored presentation of deviation values

### Evaluation along Sections

Another possibility to visualize deviations in shape or deformations is the calculation and representation along sections. From a point cloud, 2D section lines are created and compared with the CAD data.



**Fig. 13** Deviations in the shape of a sheet metal with respect to the CAD data, customer-specific representation, left: continuous color transitions; right: discrete color coding



**Fig. 14** Inspection by cross-sectional data analysis showing full color tolerance results along with discrete point information

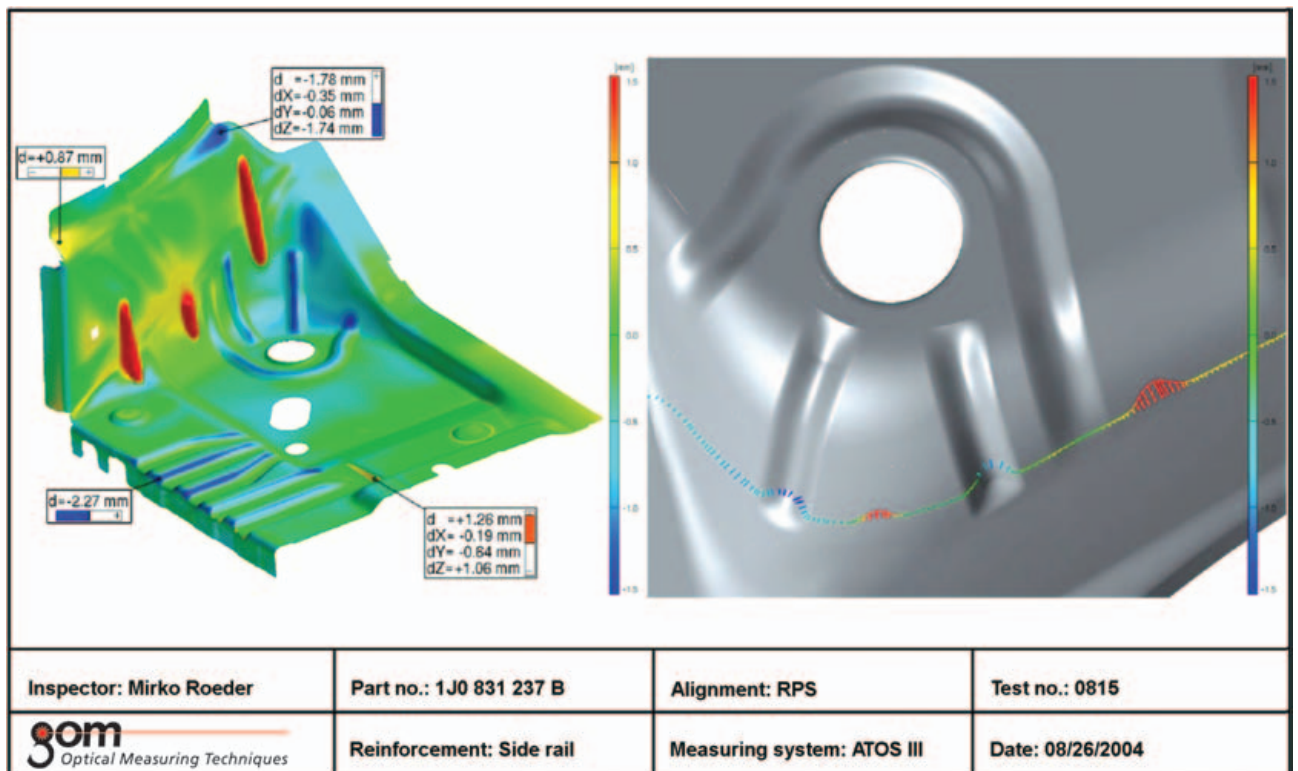


Fig. 15 Example of a measuring report

Fig. 14 shows the data of a digitized cylinder head cover compared with the respective CAD data set. Within seconds, the computer calculates a section representation from the full color plot. Now, the deviations can be further analyzed. Measuring reports are created for documentation purposes and as a basis for subsequent editing. These reports integrate snapshots of the above mentioned evaluations. Templates provide for inserting supplementary information like part number, inspector, date, ....

### Inspection against the CAD Model or Drawing: Measuring and Comparing with Primitives

If dimensions of drawings have to be checked during inspection, extensive measuring tools of the ATOS software are used. To check geometrical elements like cylinder, sphere, cone, plane and circle, the respective elements are fitted into the measuring data. Due to the high measuring point density this is done with a very high statistical confidence. After the fitting process, the position of these elements and their deviation with respect to the nominal values can be displayed in the 3D object window by means of labels.

As an example, Fig. 16 shows the representation of a slotted hole which was defined in ATOS.

Fig. 17 illustrates a water pump and visualizes the verification of the flatness of a joining surface and the cylindricity of an element. In order to check the shape of the elements, a surface deviation plot is created, visualizing the deviations between the fitted element and the measuring data. Here as well, the deviations are displayed with labels.

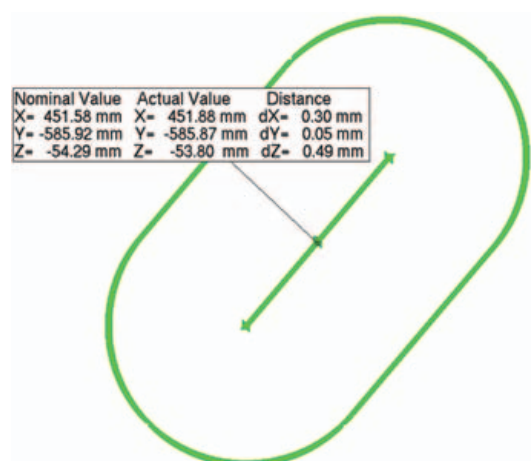
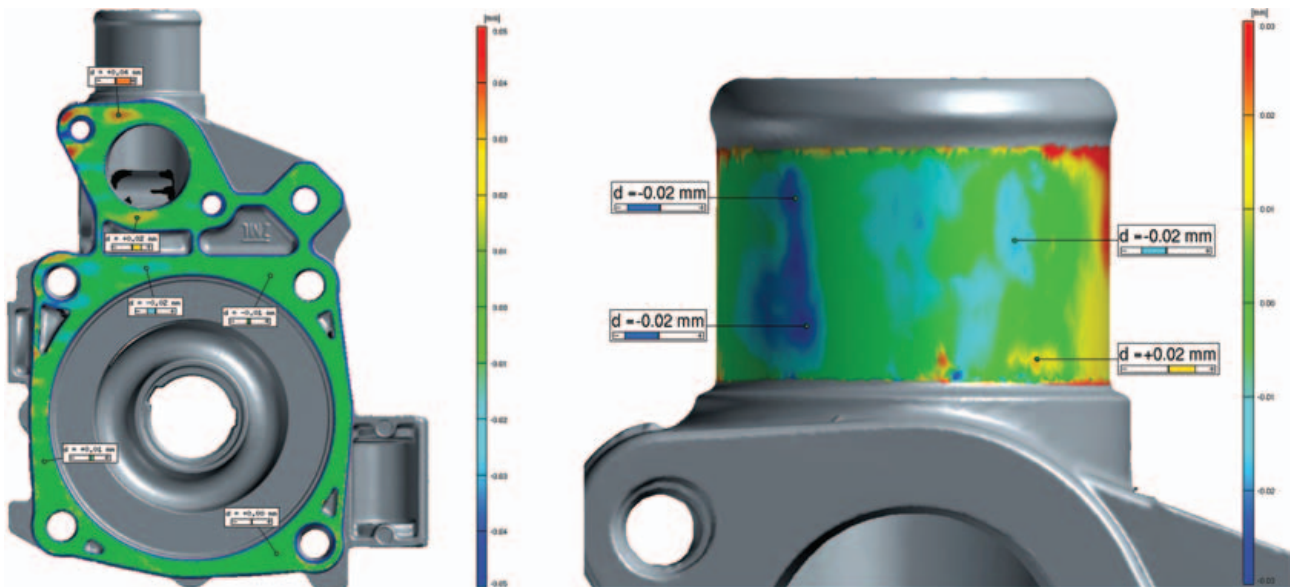
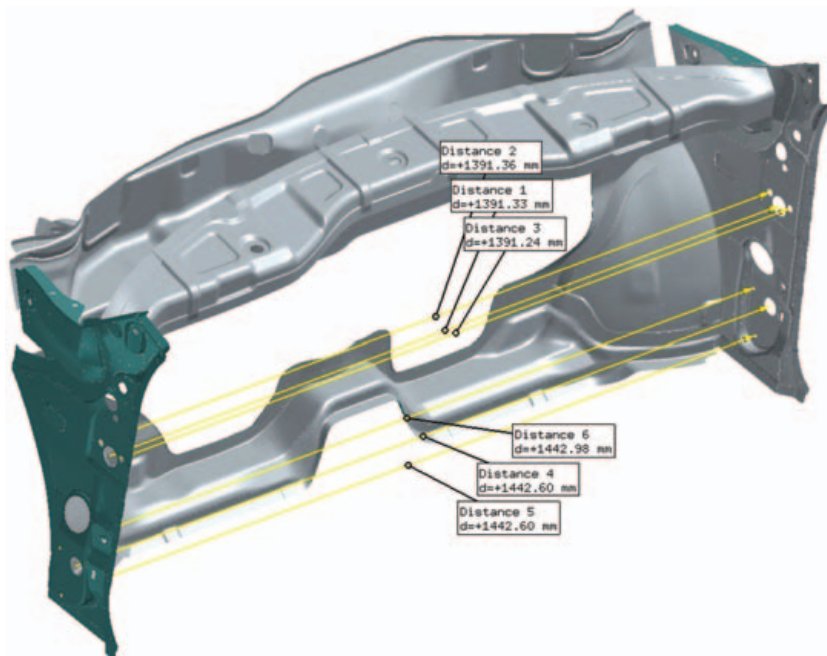


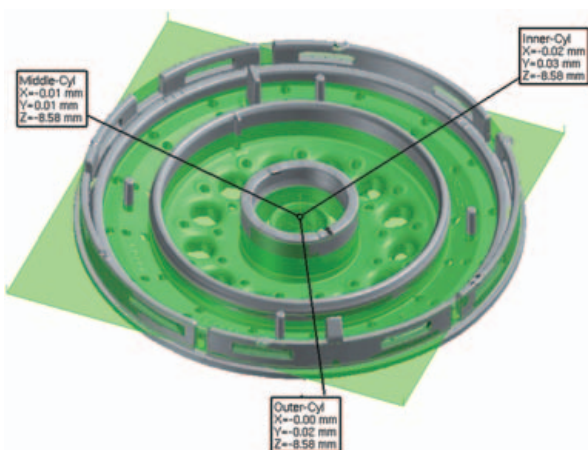
Fig. 16 Representation of the measuring values of a slotted hole



**Fig. 17** Representation of the flatness deviation of a joining surface and of the cylinder deviation of the mounting flange



**Fig. 18** Key location dimensions within a front end assembly

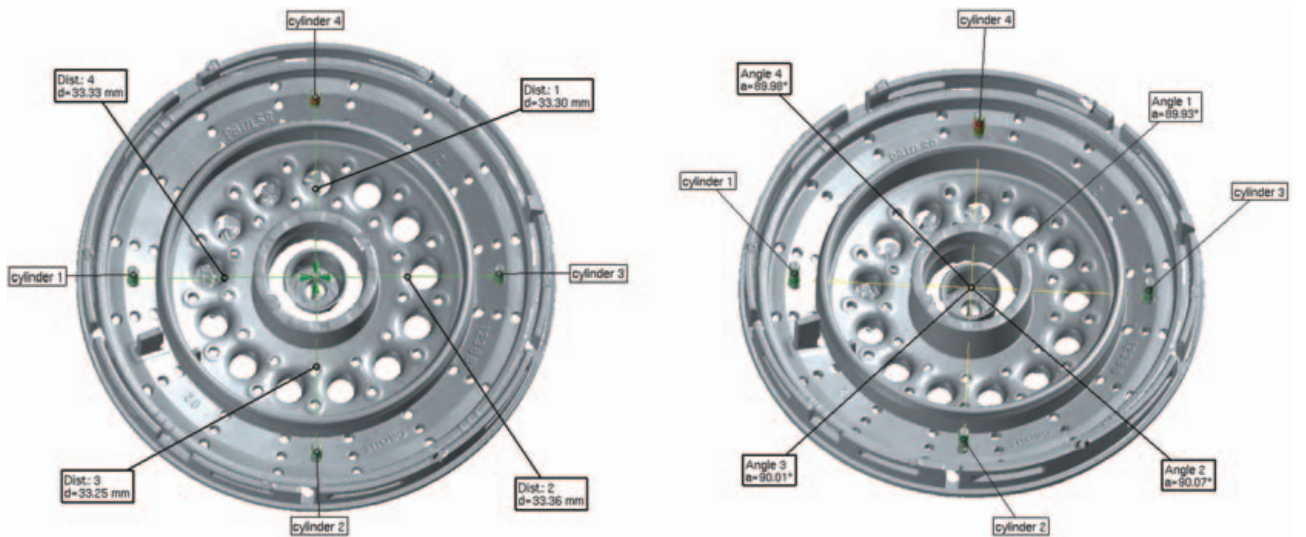


**Fig. 19** Various diameters concentricity analysis of a shower head component

### Angles and Distances

In the ATOS software, angles and distances are either derived from primitives or calculated directly from points of the polygon mesh. Fig. 18 shows the measurement of a front end element in which certain inside dimensions were directly determined from the point cloud.

For the shower head in Fig. 19, first the eccentricity of three cylinders was determined for assembly. It is apparent that the axis coordinates of the inner, the middle and the outer cylinder are barely different. In a next step, the distance and the angles of four pins lying on one radius were checked.



**Fig. 20** Distance and angularity of four pins of a shower head

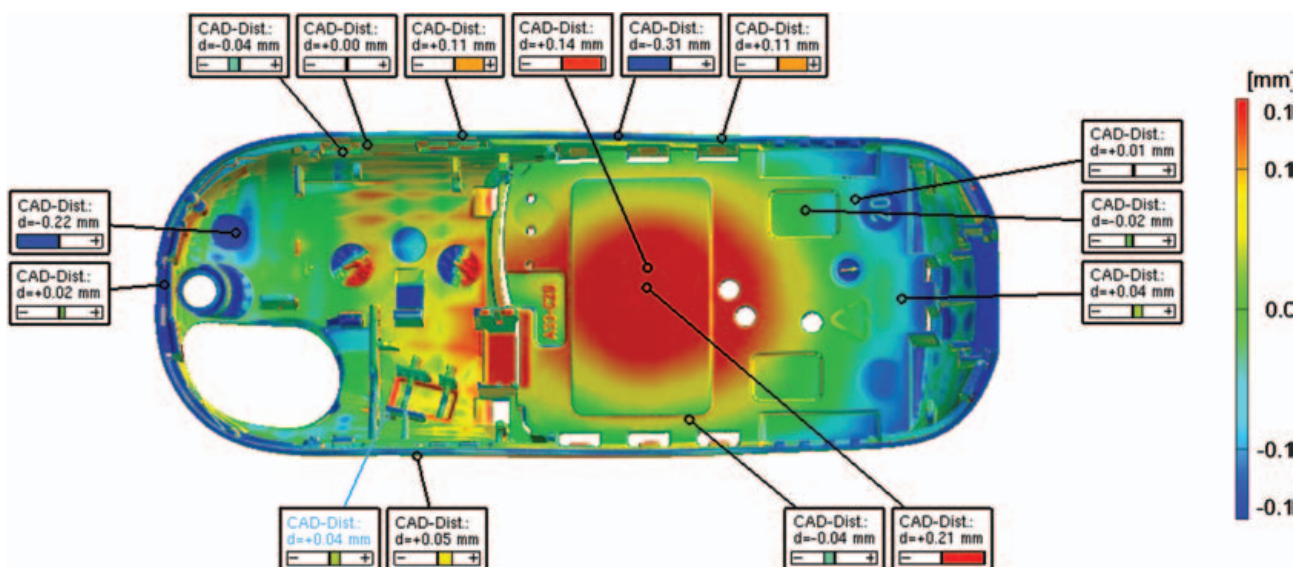
## Use in First Article Inspection

Traditionally, in a first article inspection, an inspection plan is created based on the CAD data. This plan defines the features to be measured and their corresponding tolerances. For complex parts, several hundred features may need to be measured. The task of measuring these features can be cumbersome and time-consuming with a tactile measuring device. Even after the measuring is complete and the report is generated it is still difficult to identify the problematic areas and determine corrective action due to the lack of full part information.

Today, a new procedure without creating and completing a test plan is being embraced at a many companies in a wide range of industries. The

first article inspection process is being expedited via the use of full-field scanning and utilizing full color plot images.

Fig. 21 depicts the “As Built” vs. CAD inspection analysis of a cell phone housing and the resultant full part color map analysis that is a great benefit derived from the ATOS dense data acquisition system. Via the ATOS software, the user can analyze the full part and key location deviations in detail, apply different alignment scenarios, identify, display and report problematic areas quickly and reliably. For this purpose, the most important elements like primitives, distances and angles are directly measured in the point cloud.



**Fig. 21** First article inspection of a cell phone housing

## Application - Car Body Measurement

Sheet metal parts, subassemblies, Body in Whites, and full sheet metal vehicle verifications are a premier application for the ATOS system. In addition to measuring the surface information, the ability to measure edges, trims and features (holes, slots, ...) are of particular importance. The system's ruggedness, flexibility and mobility are also key characteristics when measuring is to occur in a lab, on the shop floor or off-site and are clear advantages of the ATOS system.

Fig. 22 is an example of a car body measurement. Such measurements are utilized to evaluate, for example, flushness of components, feature locations, gaps between edges, and key control point values. This body inspection quantifies that an adjustment of the welding jig is necessary to minimize certain deviations. Companies are also measuring components prior to and after welding them into an assembly to measure the deformation of the individual component or entire assembly.

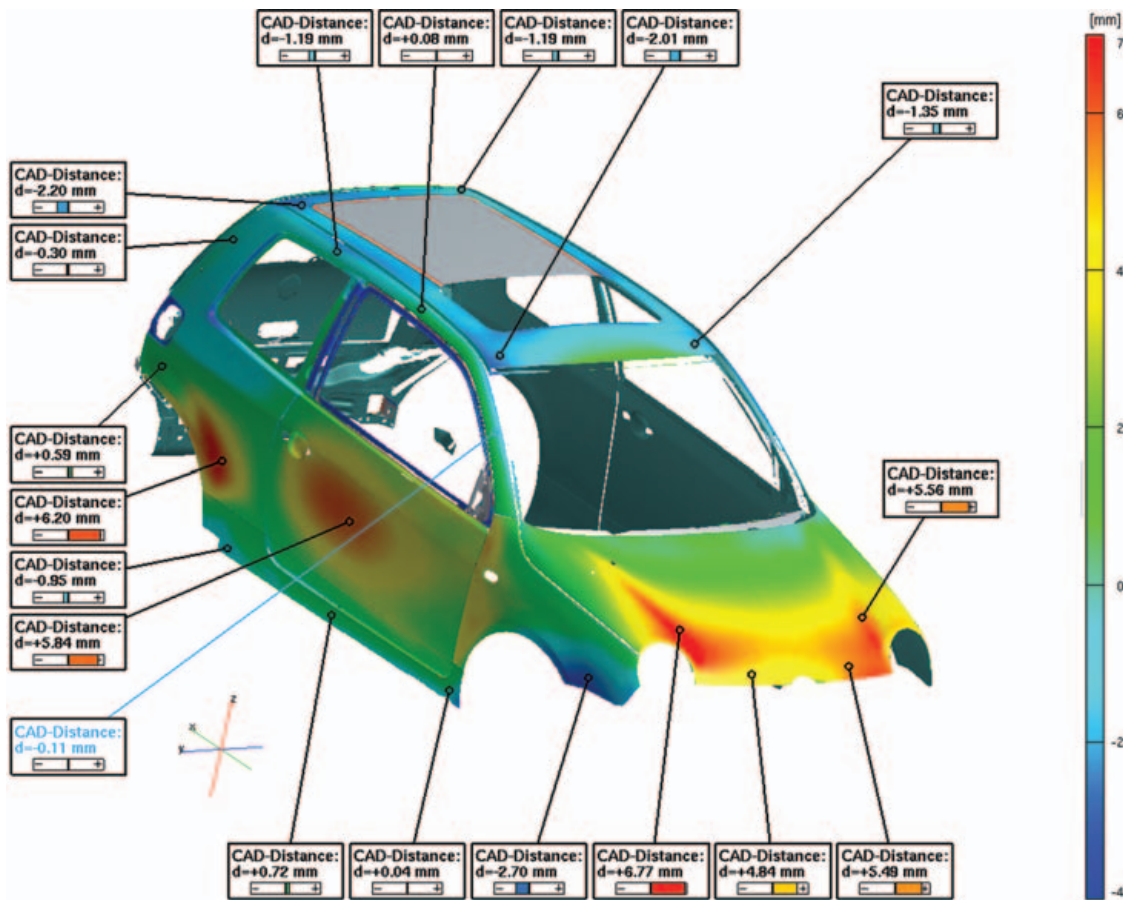


Fig. 22 Deviation of a sheet metal car body from the nominal data

## Automation

In order to measure, assess and document the inspection of numerous identical parts during sampling checks, production ramp-up and for production control, two additional components are required:

- A handling device for the sensor or the component (rotation table, robot)
- A macro recorder in the software for the automation of measurements, STL generation, data evaluation, protocol generation and output.

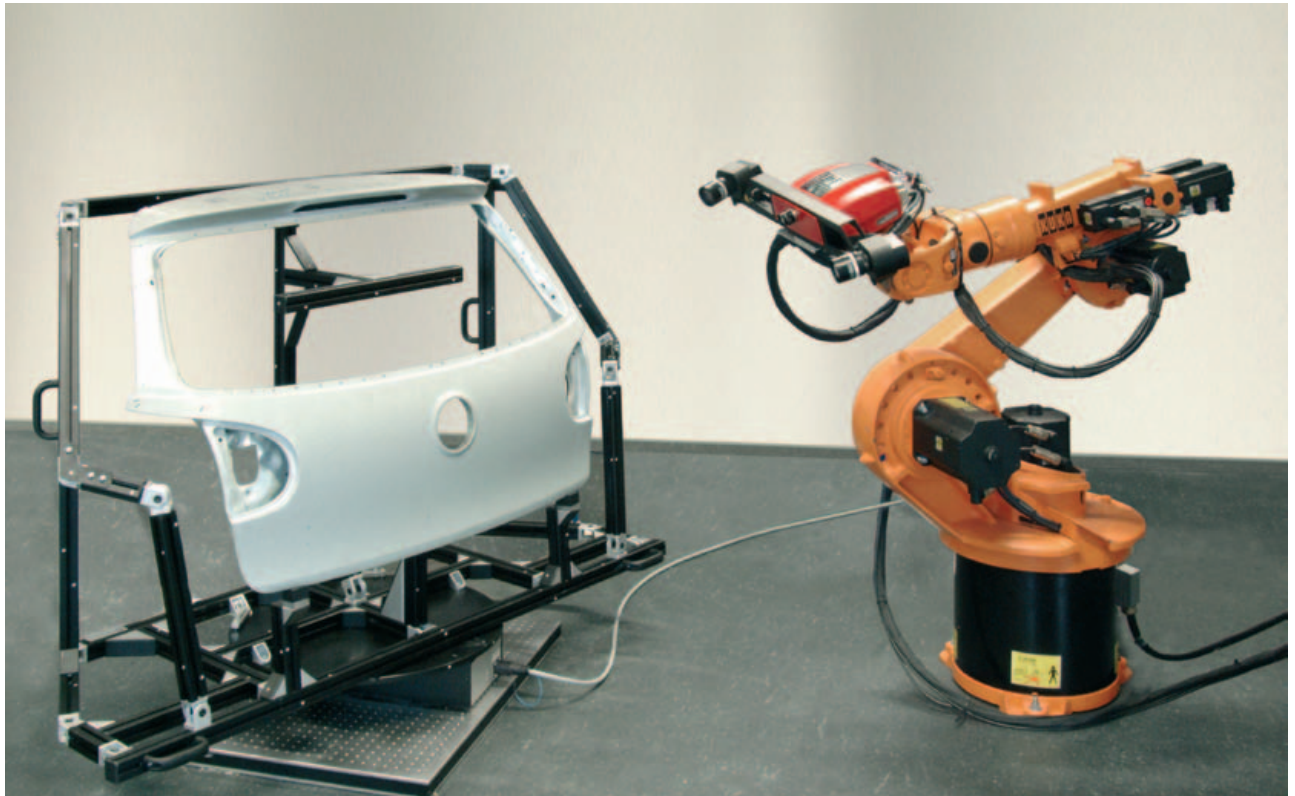
The rotation table is suitable for small to medium-size parts. It supports the configuration of a fully automated measuring and inspection station with minimal effort. The operator loads the part, initiates the macro and reviews the finished resultant report to determine pass or fail of the part.

For the inspection of complex or larger parts a robot can be utilized with a rotation table, if necessary. Normally, in such a measuring cell, the

sensor head is mounted to the robot and the part is held in a reference marker applied fixture for that specific part. The complete scanning, data interrogation, evaluation and measurement reporting process can be fully automated for this measuring cell. This considerably reduces the inspection process time and allows the operation to be performed by less qualified staff.

To program (teach) the measurement cell, the robot's control unit is used to move the sensor to

the desired measuring locations for that specific part. The ATOS software records all these moves to drive the robot in future measurements. In addition, post scanning operations such as: data alignment, sectioning, color plots, dimensional analysis, and printing of reports are saved in the same manner. Now, additional inspections on those same part number parts are repeated automatically by invoking the measurement macro.



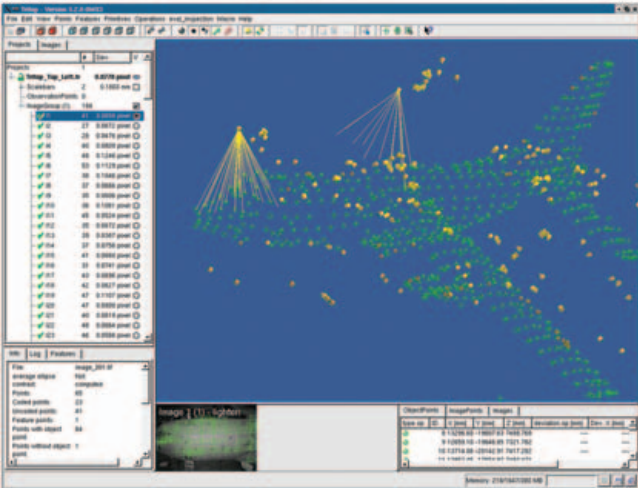
**Fig. 23** Flexible and automatic measurement of a component using a rotation table and a robot

## Measuring Large Objects

The mobile ATOS system also facilitates inspection of extra large objects like aircraft, ships and power generation systems. On these types of projects, the TRITOP Digital Photogrammetry system is utilized to compliment the ATOS scanner by pre-measuring the reference points.

The top image of Fig. 24 shows an aircraft with the markers applied. Images will be taken from multiple views to encompass the complete aircraft. The bottom left image shows the automatically calculated 3D coordinates of the reference markers and

various camera positions from the TRITOP measuring session. Also shown is the shaded ATOS-generated triangular mesh, which describes the full-scale aircraft in exact detail and shape.



**Fig. 24** Digitizing of a C130 aircraft

## Summary

More than 10 years ago, the automotive industry was the driving force for the development of full-field digitizing systems. These systems were utilized to capture form information from physical models to generate a CAD model via the reverse engineering process. Meanwhile, these measuring systems are accepted for many industrial measuring applications as well. Examples in both the automotive and aerospace sector are inspection, root cause analysis and quality assurance of sheet metal stampings, machined and formed parts, composite lay-ups, assemblies, interiors and entire vehicles and aircraft. Other high return on investment areas are prototyping, moldmaking, tool making, injection molding, die-casting, precision casting, and blow molding applications.

Reasons for using ATOS high-precision digitizing systems in quality assurance and inspection are:

- Good data quality and high data density
- Good graphical illustration and easy interpretable results
- High measuring speed
- Flexibility for various applications
- Mobility







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