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Data Processing for an Inline Measurement of Preforms in the CFRP-Production

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Abstract

Mass reduction of vehicles is getting increasingly important in the automotive industry. Because of their low weight, especially lightweight structures made of Carbon Fiber Reinforced Plastics (CFRP) can be seen as a key element to achieve the climate targets of cars in the future. Current especially complex shaped geometries are challenging for the serial production of CFRP. To enable the processes and to reduce scrap rates in the production process, a reliable metrology system has to be established in the early stage of preforming. In the preforming process quality critical features such as the final geometry are defined.

Previous tests have shown that laser stripe sensors offer a high potential to measure the surface of the preforms. Nevertheless there are still challenges that will be focused by the presented approach.

Due to complex 3D geometries, a combination of two laser stripe sensors has to be used to achieve an area-wide scan by reducing shadowing effects. Because of the limited depth of sharpness, the two laser stripe senor systems have to be tracked over the geometry equidistant. Furthermore, the sensor system has to be moved in a scanning mode over the preform in several paths to evaluate the whole geometry.

To generate a basis for a measurement data evaluation, the scans have to be manipulated and processed in several steps. First, a z-value correction has to be made because of the equidistant scanning. Second, a data fusion of the two laser stripe sensors to one cloud of points representing one scanned path has to be performed. Third, the different scanning paths have to be matched to one complete cloud of points. This finally can be used for further data-processing steps such as a nominal-actual comparison.

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Keywords: Metrology; Quality Control; Composites

1. Introduction and overview

The reduction of the ecological impact of individual mobility is one of the biggest challenges nowadays. To get towards a sustainable mobility fuel consumption has to be reduced [1].

Currently the automotive industrie is working on several crucial approaches to reduce the fuel consumption of cars. One possibility is mass reduction through light weight design [2] [3]. Light weight design offers the advantage that it can be used independently from the power train concept. Especially for highly stressed strucural parts, carbon fiber reinforced plastics (CFRP) with continuous fibers offer a high potential. At the moment, most of the production processes for CFRP are not yet fully automated. As a result, the cycle time is quite high and does not meet the output necessary for a high volume production. Currently, the press-based resin-transfer-molding process (RTM) offers the highest potential for realizing a volume production of continuous fiber-reinforced parts for the automotive industry. This is due to the short cycle time which can be realised in contrast to other production processes [4].

Within the process chain, the three dimensional forming operation of the semi-finished carbon textile is a crucial process step. The so called preforming process significantly influences the quality of the final cured CFRP-part. During this process, several layers of semi-finished textile are processed from a plane 2D geometry into a 3D geometry that is close to the final part's geometry [4]. Especially in complex shaped geometries, the preforming process is prone to defects [5]. This is because of the limited formability of the semi-

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finished textile. If the deformation degree is too high, defects can occure. They can be distinguished between global defects, like form accuracy and folds, and local defects, such as local deviations of the fiber orientation or gapping between the rovings [6] (Fig. 1).

Defects and imperfections can lead to a significant loss in mechanical performance of the final cured part. This is due to dry spots or resin pockets which can occure as a result of a geometry deviation from the ideal preform geometry and also because of the anisotropic properties of the fibers.

To enable the process, it is necessary to detect critical defects directly after the preforming process. This offers the possiblity that only those preforms that are within a given specification will be further processed and infiltrated with resin [7]. Due to the fact that the layers of the preform are already fixed with a thermoplast, it is not possible that a damaged layer can be replaced. Nevertheless the currently high scrap rates could be reduced.

This paper will show an approach on how especially global defects can be detected after the preforming process step. The focus is thereby on the dataprocessing of the measurement system, which consists of a three axes movement kinematics and two combined laser stripe sensors.

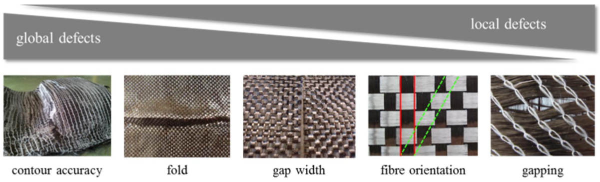

Fig. 1 Defects in carbon fiber preforms

2. Measurement principle

Defects in preforming can occure at different positions on the preform surface. So as a consequence, it is not suffice to only check single measurement points or small areas. The initial point for a detection of defects is the digitalization of the entire surface of the preform in 3D. Based on the three dimensional digitalization, further image processing and defect evaluation can be done.

Widespread measurement systems for measuring and digitalizing surfaces (e.g. coordinate measurement machines, fringe projection, stereo camera, computer tomography) can not be used for measuring carbon fiber preforms. This is due to the highly reflecting properties of carbon fibers, the size of the preforms and because of the fact that preforms have to be measured contactless to avoide damages.

A coordinate measurement machine for example is working with a tactile prope that applies preasure onto the preform surface [8]. Because of the fact that the surface of a preform is not hard and flat, the probing force could lead to damage on the preform. Furthermore, it would take quite long to measure the whole preform surface point by point.

Industrial computer tomography (CT) offers a high quality measurement of carbon fiber preforms (Fig. 2). Due to the limited scanning volume and the long image acquisition time (> 1h) CT currently does not offer the potential for an inline measurement of huge preforms (up to 1m²).

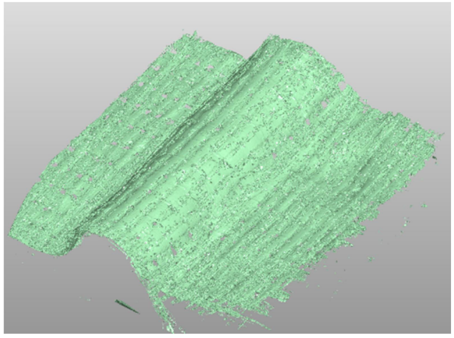

Fig. 2 CT-Scan of a carbon fiber preform

Laser stripe sensors can fulfil all the previous mentioned requirements. They work contactless and are able to scan huge parts up to aircraft components, depending on a movement kinematic. The principle of laser stripe sensors is based on triangulation. A laser generator projects a laserline onto the surface. The position of the laserline on the surface is detected by the sensor of a camera. Knowing the geometrical relation between laser and camera, or by using a calibration target, a metric profile line can be calculated. This profile line represents the surface topology at the position where the laser is projected. To get a 3D image, the whole system has to be moved with kinematics over the surface for a continuous image acquisition. The result is a cloud of points (COP) representing the surface [9].

Previous research has shown that laser stripe sensors in principle offer a high potential for digitalizing the surface of preforms made out of carbon fibers [10] [11]. The focus of this reasearch was set on evaluating huge aircraft parts with only little gradient and curvature and without complex convex/concave shape changes. Thus it was possible to track one laser stripe sensor over the surface by a robot [11].

Due to the explained measuring principle, laser stripe sensors can only measure a surface if the laser line can be projeted on the surface and the camera can always monitor the laser line. So in case of complex shaped geometries, it can happen that shadowing effects occure. In this case the surface cannot be detected [12].

Due to the mentioned shortcomings, systems with a single laser stripe sensor, as developed for the aircraft industry, cannot digitalize a complex geometry as they can be found in the automotive industry.

3. Measurement system

3.1. Objective

The discussed determining factors lead to the need for the development of a measurement system for preforms in the CFRP production process which suits the requirements for complex shaped parts [13]. As measurement principle, laser stripe sensors will be applied. The scanning operation principle of the laser stripe sensor requires a continuous movement in the x-, y- and z-direction, comparable to a coordinate measurement machine. This movement kinematics has to fulfil high requirements respective the accuracy.

The system has the aim to produce a complete cloud of points of the surface of a complex shaped preform up to 1 m² and an aspect ratio up to 400 mm. Furthermore, the system has to show the potential to be integrated into the CFRP production process as an inline measurement system.

3.2. Laser stripe sensor system

To reduce the shortcoming of shadowing effects, a combination of two laser stripe sensors (in the following named system 1 and system 2) has to be used. As mentioned, shadowing occurs if the optical axis between the camera and / or laser and the surface that has to be measured is interrupted. This can happen because of the surface geometry (Fig. 3).

To counteract the shadowing effects, system 1 and system 2 have to be tilted around two axes in opposite directions: system 1 is tilted in +x an –y direction and system 2 is tilted in –x and +y direction. Nevertheless, both systems are still measuring the same spot on the preform surface. By using this setting, the shadowing effect of system 1 is compensated by system 2 and vice versa. Through this setting, a significant reduction of shadowing effects can be expected. This leads to an improvement in the quality of the point cloud representing the preform surface.

The sensor of the 3D camera offers a high resolution of 2048*2048 pixels. So with an observed laser line width of 100 mm a resolution of approximately 50 µm can be achieved.

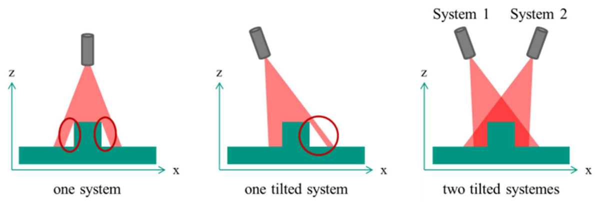

Fig. 3 Laser stripe sensors and shadowing effects

3.3. Set-up of the measurement machine

The set-up of the measurement machine is determined by the measuring principle as well as by the preforms and their geometry.

The measurement machine should offer the possibility to measure typical multiple curved geometries of automobile parts with high aspect ratio up to 400mm (z-direction) and external dimensions of at least 1000mm*1000mm (x-,y-direction). Derived from these requirements, a x-, y-, z-motion kinematics with the working space of 1300mm*1300mm*400mm was designed to move the laser stripe sensor systems, mounted at the tool center point (TCP), over the preform surface (Fig. 4). To reduce the linear thermal expension, which can occure through temperature changes in the production environment, the structure parts of the movement kinematics are build out of stone.

The movement speed of the axes is chosen high enough so that the limiting component will be on the side of the laser stripe sensors' readout time. The achieved positioning accuracy will be 50 µm. This high accuracy is necessary to qualify the measuring principle for a future implementation in the automotive industry.

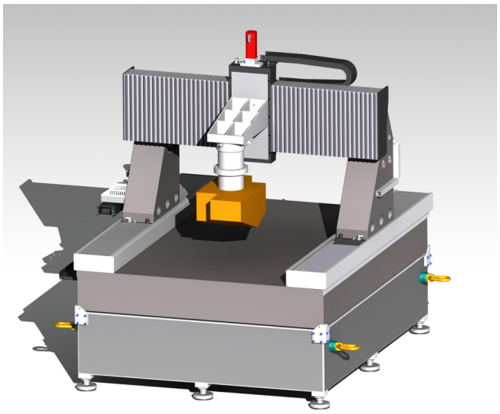
Fig. 4 CAD-model of a measurement machine for preforms

The used laser stripe sensor systems have a limited depth of sharpness (a few mm). As a consequence, it is necessary to move the sensor system over the surface with a constant offset (Fig5).

To perform an area wide scan, the sensor system has to scan the part in several paths. This is due to the limited horizontal detection width. The path width has to be < 100 mm, so that a smal overlapping of the scanned paths is achieved (Fig. 6).

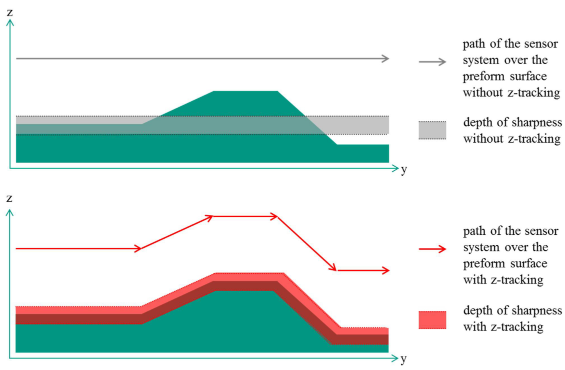

Fig. 5 Equidistant movement of the sensor system over the surface

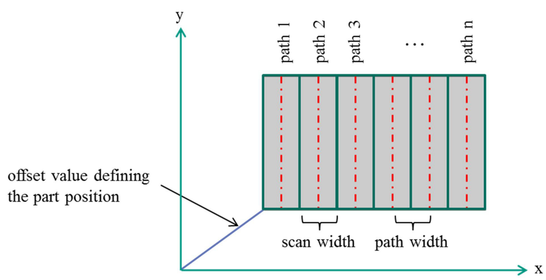

Fig. 6 Segmentation of the preform geometry into scanning paths

4. Data processing for the inline measurement machine

The data processing for the described measurement machine is essential. It affects different aspects and includes the path generation, the movement controller, the sensor integration and the sensor data processing. All these parts have an influence on the meausrement uncertainty of the measurement system.

4.1 Path generation

As mentioned, the sensor system has to be moved over the preform surface with a constant distance to keep the depth of sharpness. The operation system thereby depends on the tilt angle of the system. Furthermore several paths have to be scanned.

To avoide inaccuracies, this path planning is derived from the CAD data file of the preform geometry. For this step a G code generator is used as known from machine tools. Here, the height offset and the path width is set. The G code generator calculates interpolation points that represent the path of the sensor system equidistent to the surface (Fig. 5). The interpolation increment of the path planning has to be smaller than the distance between the measurements so that the interpolation is not influencing the measurement accuracy.

Before the measurment machine can move the sensor system along the generated paths, it is necessary to define the position of the part in the machine coordinate system (x,y,z-value).

4.2 Movement controller and sensor integration

To have an ideal basis for the image processing, it is the best if the generated cloud of points has the same distance between the points in the x- and y-direction. The distance in x-direction is defined through the resolution of the camera sensor and the width of the detected laser line. The distance in the y-direction is defined through the interval in which the laser stripe sensor acquires a profile line. Because of this, the movement controller of the measurement machine has to send a trigger signal in a predefined metric interval.

To ensure that the trigger signal is given at the right position, it is derived from the glass scale of the axes and not from the time.

The TCP position (x,y,z) at the moment of trigger's signal, are written in a data file for later use.

4.3 Sensor data processing

The sensor system of the measurement machines for CFRP preforms consists of two separate laser stripe sensors, to reduce the shadow effects. To obtain a single global cloud of points of the geometry for the later analysis, several data processing steps have to be conducted.

First of all, the two laser stripe sensors have to make a calibration run. In this process the measuring machine moves the sensor system over a known calibration target. After this, the aquired 3D data of system 1 and system 2 can be calibrated and have one common coordinate system.

When measuring a geometry system 1 and 2 are moved equidistant over the surface, following the contour of the previous generated paths. This leads to a falsification of the generated cloud of points. The COP does not any more represent the real geometry. Instead it ideally gives an even surface (Fig. 7). This makes it necessary to conduct a correction of the z-values of the COP of system 1 and 2. At this point the data of the two laser stripe sensor systems have to be matched with the TCP position data at the time of the respective trigger signal.

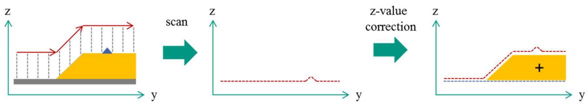

Fig. 7 Z-value correction of the COP

The trigger signal with its position equates to the profile number the sensor has generated. After this z-value-correction, the COP of system 1 (COP_1) and the COP of system 2 (COP_2) again represent the real preform geometry. At this stage the two COPs are fused to one COP representing the point cloud of system 1 and 2, acquired for on path of the geometry (COP_{Path_1}). This process is executed for each path of the part.

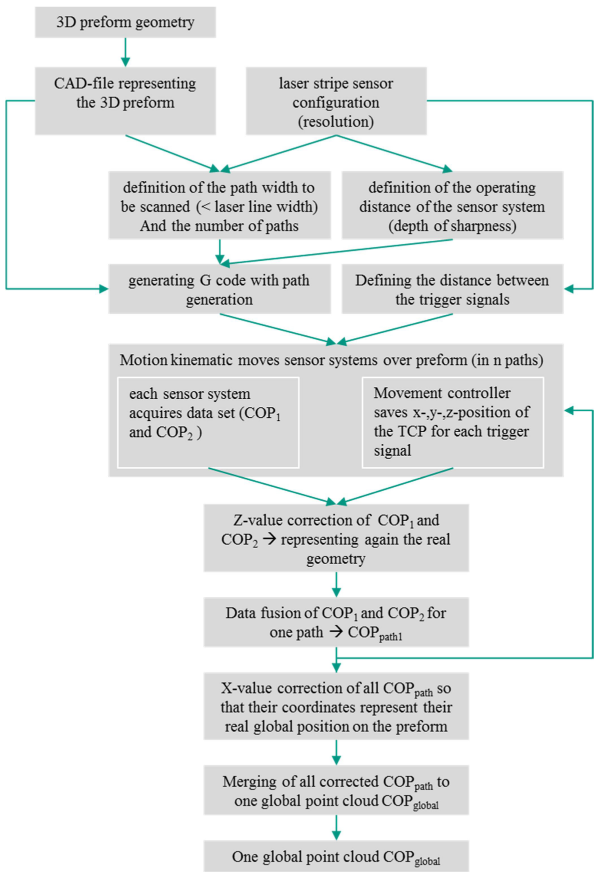

Fig. 8 Overview of the data processing for the inline measurement machine

To get towards one global point cloud (COP_{global}), which represents the entire preform geometry, all the COP_{path} have to be merged. Therefore, it is necessary to correct the x values of all COP_{path} depending on their related shift. This shift is the same as the path width which is preset. This value also can be taken from the TCP information.

After the x-value correction all COP_{path} can be merged to one COP_{global} which represents the entire geometry of the preform including all its imperfections and defects. Fig. 8 shows the described data processing in an overview.

5. Image evaluation

The generated COP_{global} with its 3D information is the basis for the image evaluation. To find defects such as folds or form deviations on the preform surface the aquired data of COP_{global} have to be used for a nominal-actual comparison with the CAD-data of the preform. Here it is important to consider the thickening towards the CAD-model caused by the several layers of semi finished textile. The thickness of n-layers of semi finished textile lead to a formdeviation which is represented by the thickening.

The nominal-actual comparision leads to a 2D disparity map showing the deviations from the CAD-model. The deviations are given point by point in metric units. Hence the 3D information still exists in the 2D image. The height value is coded in the grey value. In a next step, the deviations can be evaluated using tolerance limits which offer an easy decision making if the preform is good or bad. These tolerance limits have to be derived from the part design as well as simulations. They can be seen as a given input and are not part of the conducted research.

If a more detailed analysis of the preform surface and its defects is needed, an extraction of the defects has to be performed. Therefore it first has to be defined which value on a form deviation can be seen as a defect. This value can be set as a limit value. Knowing that all values that are higher than the limit value are defects, the image can be transferred into a binary image. In the binary image, the pixel value does only indicate, if the height value of the pixel is above or below the limit value represented by black and white pixels.

After this computation step the aim is to extract defects. For the extraction, the loose accumulation of pixels in the same area has to be transferred into a continuous area. This step is known as image segmentation. The segmentation offers the advantage for an easier possibility to analyze the image.

Due to the highly reflecting surface of the carbon fiber preform, the acquired point cloud is prone to noise. This results in single points which do not belong to a defect. To eliminate these points a previous median filter can be applied to COP_1 and COP_2 before the nominal-actual comparison is made. It is also possible to remove these points in the binary image by performing an erosion.

The erosion process does not only reduce isolated pixels. It also reduces the size of the real defects. Because of this, after the erosion step a dilation with the same size has to be performed on the image. The dilation process can also be of importance to close areas where no signal could be aquired by the sensor system. This can happen due to the fact that the orientation of the fibers influence the quality of the image acquisition and can lead to a lack of information.

After the discussed image preparation steps, the final feature extraction can be conducted on the modified binary disparity map. Therefore, the so called blob detection can be used. A blob obtains an area in an image with neighboring pixels which have the same grey value.

The generated blobs represent the defects on the preform surface. An analysis of their shape and their position on the preform surface can lead to a further classification of the detected defects. For the classification, several criteria can be defined such as their area or the diameter. One approach for comparable information can be for example the ratio of width to height of the blob that can be transferred to the definition of an eccentricity of an ellipse.

6. Conclusion and outlook

CFRP are getting more and more important as light weight construction material for the automotive industry. To get towards a volume production of these parts, the process has to be further automated. Especially the quality assurance after the form generating preforming process has to be developed. Imperfections and defects that occure in this stage of the production process, significantly influence the performance of the final CFRP part.

Due to the fact that existing measurement systems do not meet the requirements for a measurement of carbon fiber preforms, the paper shows the development of a suitable measuring system focusing on an inline application.

As discussed, the data processing and computation of the movement controller, the sensor data as well as the image evaluation are strongly linked with each other. Only through such a comprehensive approach, a reliable integration as an inline measurement system can be achieved.

Future work will focus on tests with the new preform measurement system and the accuracy that can be achieved in practice.

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