AUTOMATED APPLICATION OF SEALANT TAPE: FROM A BASIC MECHANICAL SYSTEM TO A ROBOTIC SOLUTION

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ABSTRACT

Automation in composites manufacturing leads to a significant increase of quality assurance and efficiency. Nevertheless vacuum bagging for infusion technology and especially the air-tight application of sealant tape still involves a high amount of manual work. This paper presents an approach on the robotic application of sealant tape using a mechanical application system. Starting with a test of the basic functionalities on a CNC based 3-axis gantry system, the motion sequence has been transferred to an offline CAD model and thereby optimized for robot path planning. Finally, the tape application has been validated on a full-scale demonstrator of an A350 rear pressure bulkhead.

1. INTRODUCTION

In state of the art airplane manufacturing and predictively also in future airplane designs, carbon fiber reinforced polymers (CFRP) play an increasingly important role for primary structures and sub-components. With regards to higher production rates, airplane manufacturer focus on cost efficient and more flexible production technologies. Targeting these challenges, innovative production systems and processes are developed in the context of Industry 4.0 (European definition) and smart manufacturing (American definition). Therefore, robot-based systems for material treatment, such as handling devices for carbon fiber materials have been investigated. Nevertheless, in flexible production, communication systems and data management allow new ways of process optimization and organization [1, 2].

Open-mold vacuum infusion technology based on dry fiber preforming is a well-established manufacturing process for large primary structures with a three dimensional shape regarding cost efficiency and part quality. For example, this technology is used to manufacture the Airbus A350 rear pressure bulkhead (RPB) at Premium Aerotec GmbH, Augsburg [3]. In an internal research project at the Center for Lightweight Production Technology, Augsburg, of the German Aerospace Center (DLR), automated production technologies for a full-scale A350 RPB have been investigated. In this context, an automated production line alongside the process chain has been developed. This process chain includes material cutting and transportation, dry fiber preforming, vacuum bagging, high temperature vacuum infusion and curing with epoxy resin (HexFlow RTM6, Hexcel). Merging all of these process steps, handling technologies, data management and control units have been set up and validated.

This paper focuses on the vacuum bagging process and especially on the application of sealant tape. A standard setup for vacuum assisted processes (VAP) is illustrated in Fig. 1.

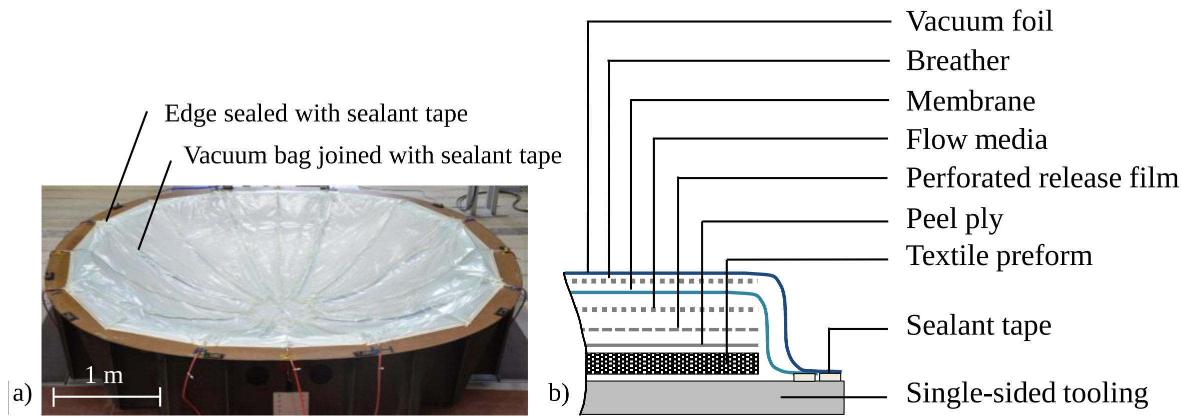

Fig. 1: a) Demonstrator of rear pressure bulkhead (RPB) with sealed vacuum bag;
b) Standard setup for a vacuum assisted process (VAP)

Several layers of auxiliary materials, such as peel ply, release film and flow media are applied on a preform out of dry fibers. The main functionality of a vacuum bag on top of a preform is creating a closed cavity for resin infusion. The following criteria to assure the quality of the sealed vacuum bag have to be considered:

- position of the auxiliary materials (gaps and overlaps),
- position of pleats in membrane and vacuum foil,
- coverage of the 3D geometry without bridging,
- leak tightness of the vacuum bag.

In state of the art composites manufacturing, most of these criteria have been met using manual processes. Faber and Schmidt-Eisenlohr evaluated rigid and flexible robotic application systems either for single-curved or three-dimensional part geometries [4, 5]. In further works the application of near net shape tailored semi-permeable membranes or vacuum foils have been investigated. Thereby, the position of pleats and the coverage of the 3D geometry on the part directly referred to the manufacturing accuracy of the tailored materials. As a result, a significant reduction of lead time and labor costs has been concluded. In this context it was demonstrated, that it is highly beneficial for economic purposes to apply tailored materials on large molds. The authors summarize, that this optimization can be easily implemented in industrial production [6].

An aspect, that has not been addressed and investigated so far, is the assurance of leak tightness of the vacuum bag during the application of sealant tape. In current composite manufacturing processes, leakage detection and leak sealing is the most time consuming step during evacuation. Improvement can be given by applying a constant contact pressure to minimize wrinkles and air entrapment in the sealant tape. These requirements have been addressed in the adhesive tape application. In this context, automated application systems are already distributed (e.g. Vulkan Technic GmbH, Germany). In addition, automated application of sealant tape has been investigated and industrialized in window production industry. Therefore, Lemuth GmbH, Germany, developed a gantry system (Gasket insertion machine - DAW100) equipped with a sealant applicator for 2D applications. Nevertheless, sealant tape application systems for 3D geometries (e.g. CFRP structures) have not been realized yet [7].

The present research project focuses on three topics. First, the optimization of an adhesive tape application system for sealant tapes will be explained. In a second step, robotic motions and the robotic path will be developed. Finally, the application concept will be validated on a full-scale RPB mold.

2. EXPERIMENTAL SETUP

In the current research project, a near net shape tailored semi-permeable membrane and vacuum foil are applied and sealed on the outer edge of a composite tooling. Therefore, a ductile high-temperature resistant sealing tape (GS 43-MR, Aero-Consultants AG, Switzerland) with a paper covering layer is used. The following investigations describe a method for robotic sealant tape application.

2.1 Sealant tape application system

A pneumatic application system for adhesive tapes by *Vulkan Technic, Germany* has been optimized for sealant tape application. The mechanical setup of the system after optimization is shown in Fig**.** 2.

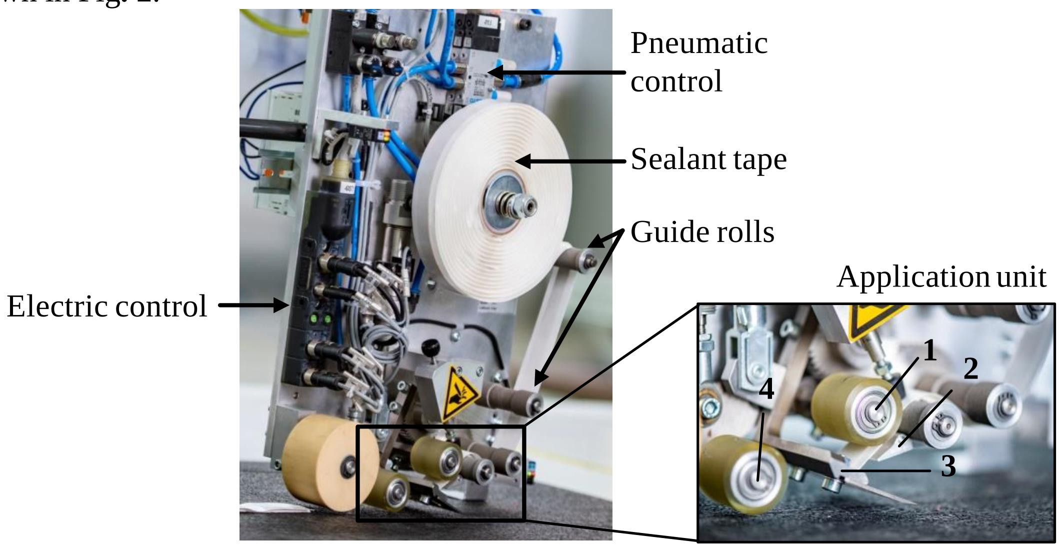

Fig. 2: Mechanical setup of the sealant tape applicator

The sealant tape is fixed on a retarded roll as material stock. For material guidance, deflection rolls with non-sticky coating are mounted to ensure loose feeding to the application unit. A detailed view on the application unit is given in Fig. 2. The sealant tape is fed through the gap between feeding roll (1) and a pressure prism (2). Ensuring suitable tension by pressure prism and guiding rolls, the cutting unit (3) allows precise cutting of both tape and covering layer. When applying the tape on a rigid surface, the pressure roll (4) can be used to adjust the compaction pressure. Feeding roll and pressure roll have a rubber coating to apply friction between roll and covering layer. This allows constant tension on the sealant tape and thereby leads to a smooth and non-crimped application. All adjustable units (feeding roll, cutting unit and pressure roll) are activated by a pneumatic control (Festo valve terminal) which is triggered by an electric control unit. Robotic control of the tape applicator is realized by a Beckhoff industrial PC connected to the KUKA control system via EtherCAT bridge terminal.

2.2 Functionality of the application system

The application of the sealant tape can be divided into six separate process steps. The process flow is visualized in Fig. 3. First, the applicator has to be initialized and moved to the starting position (Fig. 3a). During this period, the tape is fed into the application unit and the cutting unit is activated while the feeding roll and the pressure roll are both deactivated. After exact positioning the feeding roll is activated while the cutting unit is deactivated. This results in a precise positioning of the beginning of the tape on the application surface (Fig. 3b). In order to apply the tape on the mold the applicator has to be moved in x-direction (Fig. 3c). All passive rolls start rolling due to the movement of the applicator. Additionally, the pressure roll is activated, when the sealing tape is underneath. Once the applicator reaches the end of a defined path, the sealant tape is cut. Therefore, the cutting unit is activated and the feeding roll is deactivated (Fig. 3d). After cutting, the press roll is deactivated, thus the applicator returns to its initial state. For the removal of the covering layer, a metal scoop has been installed on the back-side of the applicator. Fig. 3e) shows the removal by the tip of the scoop, which therefor has to be placed precisely between sealing tape and covering layer. Finally, the removed part of the covering layer is bent over (Fig. 3f) and thereby fixed. This allows an overlap between the already applied tape and the next tape line. After bending, the applicator is lifted up and transferred to the next starting position.

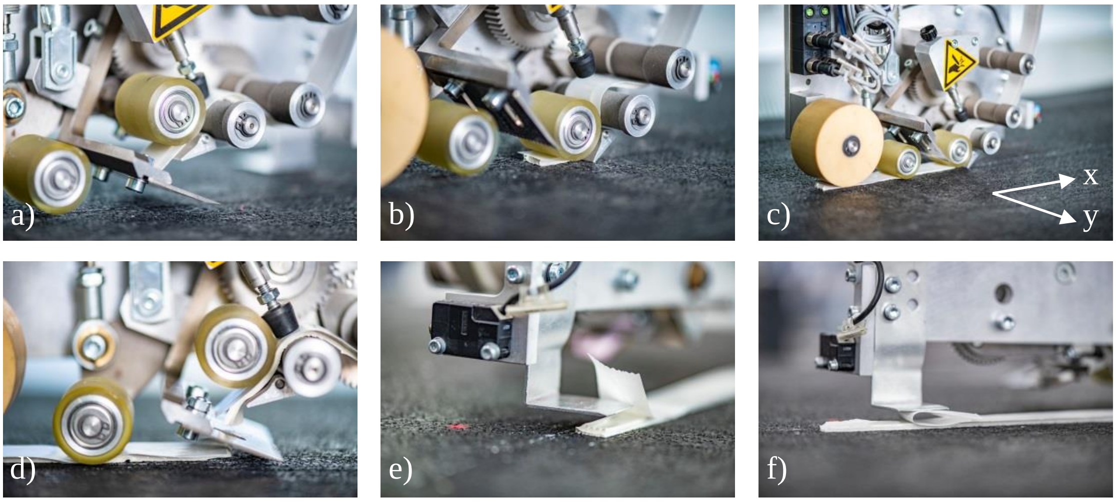

Fig. 3: Process flow of the sealant tape application: a) Initialization and positioning of the applicator; b) Positioning of tape; c) Continuous tape application; d) Cutting; e) Separation of the covering layer; f) Folding of the covering layer

3. ROBOTIC MOTION AND PATH PLANNING

The evaluation process of the sealant tape applicator can be divided into five development steps. Following Fig. 4, the applicator first has to be adjusted and functionalized for sealant tape application. Especially the coating of the rollers, the gaps between the rollers and the stresses in the material need to be determined. During the second development step, the system has been calibrated and the basic functionalities have been tested on a static test rig. It was found, that tilting the applicator up to 10° negatively around the y-axis helps to position the beginning of the tape. Also pressure distribution can be improved. Due to the small height of the tape of approx. 3 mm, high precision is necessary, when peeling of the covering layer. The next development steps will be described in the following paragraphs.

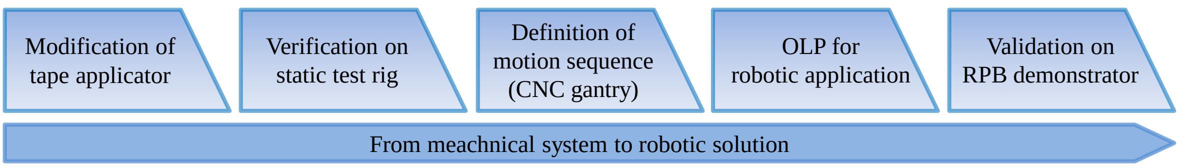

Fig. 4: Road map for development of motion sequence

3.1 Motion sequence for tape applicator

After a first verification on a static test rig, the performance of the applicator during continuous tape application has been evaluated. Therefore, the applicator has been mounted on a CNC based 3-axis gantry (FlatCom, ISEL Germany AG). This system allows precise in-plane (xy-plane) and out-of-plane (z-direction) movement using Cartesian coordinates. The motion sequence of the sealant tape applicator can be described by two characteristic movement sequences.

Sequence one defines the linear application from the starting point to the endpoint. When applying the tape on a flat surface, variations in z-direction are only needed when overlapping the previously applied tape. This change in z-direction prevents the unwanted cutting and penetration of the lower tape.

Sequence two defines the movement to peel-off and bend the covering layer. The tip of the scoop is positioned underneath the covering layer and then stepwise moved forward and lifted up to ensure a careful peel-off. This process step affords high precision in positioning the tip of the scoop of ±1 mm in z-direction. Once the covering layer is peeled-off from the full width of the tape, the scoop will be moved alongside the tape removing the covering layer to a defined length to ensure overlap of two tape lines. Finally, the scoop is used to bend and fix the removed part of the covering layer by applying pressure.

In addition to the motion sequence, the maximum process velocities have been determined. The maximum speed of the gantry system of 150 mm/sec can be reached without loss of reproducibility during linear movement. For removal of the covering layer with the metal scoop perpendicular to the application direction, the velocity needs to be decreased to maximum 10 mm/sec. In order to create a bubble-free overlap between two lines of sealant tape, additional tests focusing on the angle between the two lines have been conducted. It was found that the application system allows application angles α (Fig. 5) varying from 90 to 135 degree. Smaller or larger angles would cause penetration of the cutting unit into the lower tape line.

The CNC-code including all movement data (e.g. coordinates and velocity information) can be stored and exported as text file. This allows direct exchange of the motion sequences to any other CNC-based machines, robotic systems or offline programming tools.

3.2 Offline path planning for robotic tape application

To generate the robot program for the motion sequence, CATIA V5 with the FASTSURF workbench has been used. Therefore, a model of the robot cell with the RPB mold positioned accordingly to manufacturing has been loaded. The contour to cover the RPB with sealant tape consists of 16 straight lines on the edge of the mold. These lines are adjusted in length to ensure the reproducibility of the movement defined in section 3.1. Regarding the high accuracy that is needed, the lines are split into eight segments consisting of two lines each. Every segment is close to a calibration plate of the mold. This allows the definition of robot bases with the origin as close as possible to each segment which improves the accuracy of the robot motion. Following the definition of the contour, the reachability of the system has been analyzed. It shows that minor changes to the system from the CNC gantry system need to be done to ensure the accessibility. To reduce interfering contour at the robot flange, the system has been set on a frame which tilts the system by 45 degrees and adds some distance to the flange (Fig. 5). The frame has also been used for the storage of the Beckhoff industrial PC for the robot to system communication. With this setup we have realized the reachability for robot movement with minimal axis movement. The finished offline motion planning model is shown in Fig. 5.

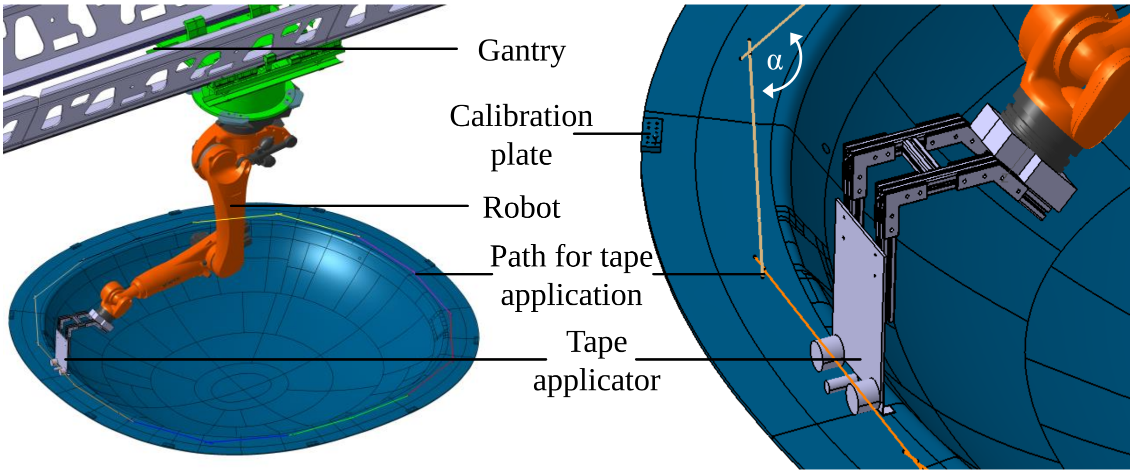

Fig. 5: CAD model for offline motion planning

To recreate the motion designed on the CNC gantry system several steps are necessary. First, with the help of the offline motion planning model, we have generated the robot programs for the simple movement along each line. In the following, digital inputs and outputs (I/O) have been set to control the components in the system at distinct positions in the robot program. Also the offsets in z-direction to cover already applied tapes have been added for each line separately since every line is different. The complex part of the motion with cutting and peel-off is the same for each line and therefore we have used a sub-program. The sub-program contains the relative movements and controls for the components as defined for the CNC portal. This sub program has to be called at the end of each line in the respective robot program. The actual robot position can be used to calculate the relative movement in the sub-program. To finish the robot programs, a start motion and an end motion has been added to ensure collision free movement from line to line.

3.3 Concept validation

With the help of the reachability analysis the final endeffector has been build and added to the robot cell. For the control of the tape applicator via KUKA control panel, the Beckhoff industrial PC has been integrated. The measured tool center point (TCP) has been set in the robot controls. Furthermore, each base on the tooling has been calibrated to the robot controls. To ensure the functionality of the setup, a simplified robot program has been used. This program tests the Beckhoff communication, the correct setting of the I/O and the functionality of the system like correct cutting and application of the tape. Finally, after system calibration, the sealant tape has been applied automatically for each line.

4. RESULTS AND DISCUSSION

After applying the sealant tape onto the manufacturing mold the functionality of the system and the quality of the applied tape have to be discussed. The transition from the static rig over the CNC gantry system onto the robot cell has been demonstrated successfully. The motion sequence developed on the CNC gantry system is usable for the robotic movement. For this work the NC code has been translated manually into a KUKA robot program and then optimized by offline programming. However, time optimization of the code translation could be reached by using commercially available solutions for direct import of NC code. For direct replication of the motion sequence developed on the CNC gantry system, communication between application system (Beckhoff PC) and KUKA control has been implemented.

Regarding the quality of the applied tape the accuracy of the robotic cell and the calibration of tooling to robot caused problems. The first applied segment of two lines showed satisfying results in position of the tape, adhesion to the tooling and peeling of the covering layer from the tape. However the next segment wasn't applicable due to major offsets in calibration and robot program. This results from the imprecise transfer of the offline programed robot program to the real mold. The CAD model refers to an ideal shape of the tooling. This differs from the deposition geometry on the tooling basing on the calibration plates. Especially on the border of the tooling the differences between CAD and the real mold are high by up to 5 mm. Regarding the needed precision of the system less than 1 mm, this causes major issues. Although the TCP has been measured and calibrated, there are slight measurable differences. For future applications the tooling and the calibration plates need to be measured with e.g. laser scanners. The reconstructed surface out of the point cloud would be much more precise then the original CAD-model. Alternatively, distance sensors on the application system could help to control the distance between mold surface and application unit.

Further optimization could be done on the deposition contour of the tape. The actual layout with 16 lines is used for manual application. For automation purposes one long oval line would be much better due to less cutting, easier robot motions and less movement. The achievable movement speed, accuracy and reproducibility would justify the automation of the process. This approach would just be limited by the stiffness of the covering layer leading to minimum applicable radii of approx. 1 m.

Nevertheless, the described concept shows high potential for an automated application of sealant tapes. Especially on three dimensional mold geometries with limited access for manual work, this increases flexibility and deposition reproducibility. In addition, the robotic application system could also be used to directly apply sealant tape on the membrane or vacuum foil. Especially time and labor costs during tailoring and joining of complex near net shape membranes would be significantly reduced.

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