AUTOMATED APPLICATION OF LIGHTNING PROTECTION MATERIAL ON DOUBLE CURVED FUSELAGE PANELS OF CARBON FIBRE AIRCRAFTS – FROM THE IDEA TO THE APPLICATION

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Abstract
The latest generation of aircrafts, which are often in large parts made from fibre-forced-plastics, are prone due to common lightning strikes. Therefore, an extra treatment of the fuselage is necessary in order to prevent any damage. A special high conductive material (Lightning Strike Protection (LSP) material) is applied to the outermost layer of the fuselage. Currently, for double curved parts of the fuselage, this happens to be a very cost-intensive manual process. We have developed an automated solution for standard industrial robot which reduces the necessary manpower, speeds up the lay-up quantity and improves the process reproducibility. Our approach aims not only the draping process of the LSP material due to the constructed lay-up head but also the generation of the robot paths and optimised cuts of the material regarding to the curvature of the mould. The cuts are produced during the draping process directly from the material reel. Therefore our solution shortens the process chain by eliminating the pre-cutting of the material and allows to lay-up wider cuts and better utilisation of the material. The lay-up process itself is very precise, less stressful to the material and compliant to the manufacturing specifications.

1. Introduction

One of the goals of the aircraft industry is to increase the ability of the aircraft to operate at any time of the day and under any weather condition. This helps to achieve a greater payoff for the acquisition of an aircraft. Today's modern aircrafts are capable to fly through a moderate thunderstorm without suffering any damage, even if they get hit by a lightning strike. Studies [1–4] show that every commercial airplane can expect one lightning strike event a year, with only very few of them resulting in minor harm. This can be explained by the so called Faraday cage that is build by the metal fuselage of the aircraft. The electric charge carried by the lightning bolt enters the aircraft and due to the high electric conductivity of the metal fuselage is led through on the exterior hull of the airplane leaving the aircraft on different location. Another important goal for the aviation industry is to reduce the operational costs of an aircraft. One method to achieve that is to reduce the weight of a plane which improves the net weight/payload rate. One of the approaches is to use composite materials, i.e. fibre-forced plastics (FRP). The rate of FRP used in the latest generation of long-range aircrafts like Airbus A350 and Boeing 787 has reached at least 50 %. This however significantly reduces the electric conductivity of the fuselage which is not longer sufficient to create the protective Faraday cage. This bears a high safety risk in case of a direct lightning strike because the high energy of the lightning can not be lead through the fuselage and remains within the small area of the impact. This can cause critical damage to the fuselage, the electronic devices

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and endanger the safety of the passengers. There are many solutions to increase the electric conductivity of FRP-based fuselage. One of them is to apply a copper mesh, embedded within the resin matrix, as the outermost layer of the fuselage. This lightning strike protection (LSP) material can be purchased as a prepreg material containing three layers: the protective foil, the LSP material itself composed of the copper mesh and the resin and the backing paper, see Fig. 1. Currently the lay-up of the LSP-material is done manually. In case of non-cylindrical, double curved parts of the fuselage, the LSP has to be pre-cutted into special banana-like shapes in order to ensure the best possible drapery of the two dimensional cut on the three dimensional surface of the fuselage, respectively the mould. The target position of the cut is projected by means of a laser beam and provides guidance for the worker who drapes the material manually onto the surface. To ensure the electric conductivity between two adjacent cuts a defined overlap of the two cuts has to be provided.
One aim of the project AZUR [5] was to develop an end-to-end concept for automated application of LSP material on double curved surfaces with a typical size of an original single aisle aircraft fuselage. The specifications to be met were the usage of standard LSP material, cutting the material during the application, collecting the remains of the material (including foil and paper), wrinkle free results and the ability to be implemented in an industrial robot cell.

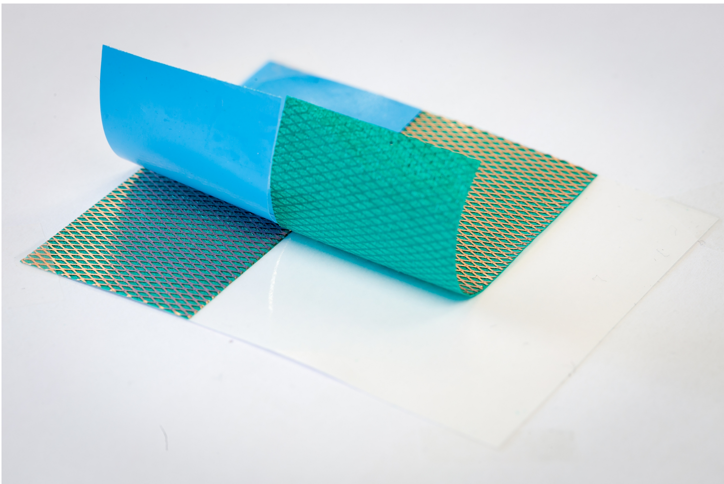

Figure 1. Buildup of the LSP-Material for concave process: blue: protective foil, green: copper mesh and resin marix, white: backing paper.

2. Concepts

At the beginning the manual process was analysed in order to identify every single step and the crucial parameters regarding to their influence on the required quality of the lay-up. The consequential process for the automated approach was developed, see Fig. 2. The process starts with manual loading of a full material roll and leading of the three material layers along their travel paths. Now, the automated process begins: the LSP material is front-cutted and guided to the separation point of the prepreg and the backing paper. Meanwhile the sides of the prepreg are cutted into desired shape. The prepreg is guided to the pressure roller while the foil storage is filled. Then the pressure roller establishes contact with the mould surface and the lay-up process begins. The material is applied while it's sides are trimmed and the remains of the material (foil, LSP material and backing paper) are collected. At the end of the path the final cut is produced and the LSP material for the end of the path is applied while the foil storage is emptied. Now the process can start over for the following path. If the material roll doesn't contain enough material for the following cut, the process stops, the remains have to be cleared. After that the process starts at the beginning with the loading of a new material roll.

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In order to estimate the maximum force that can be applied to the material without any significant

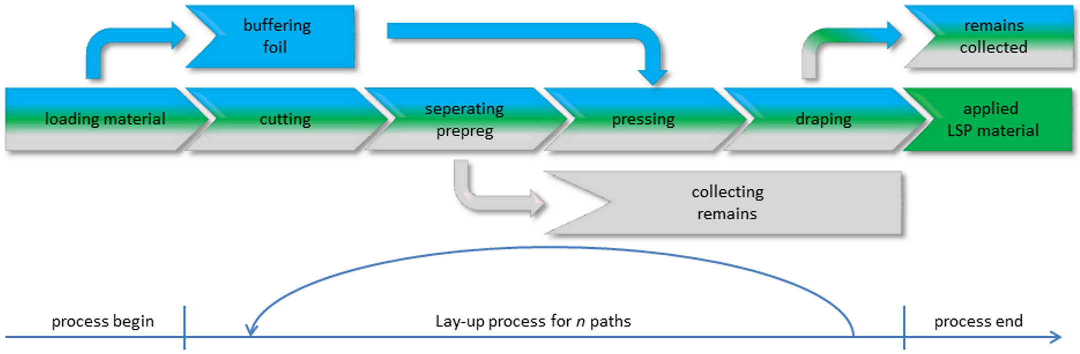

Figure 2. Developed process for automated application of the lightning strike protection material. Blue stands for the protective foil, green for the prepreg material with copper mash and grey for the backing paper.

alteration of it's mechanical and electrical properties and the minimal forces that are required for some process steps (i.e. separating the protective foil from the tacky prepreg) tests have been carried out on the material. Only with the knowledge of these boundary conditions the concepts for the drives and applicable engine torques could be developed.

2.1. Material guiding and drive engineering

The concept of the material guidance had to consider the way of every single layer of the material. For the cutting and trimming of the material, the protective foil had to be separated from the prepreg and backing paper but merged together again while draping. This was required due to manufacturing specifications where the pressing roll is not allowed to have direct contact to the certified prepreg for the reasons of possible contamination of the LSP material. The prepreg and the backing paper had also be separated directly before the prepreg reaches the pressing roll without being exposed to the process forces in the absence of the much stiffer backing paper. The material guiding is presented in figure 3(a). The transport of the material is accomplished by three drives D1, D2 and D3, whereas D1 and coupled D2+D3 are torque driven in so called "static state", where the material is held in tension but not moved at all. Only if the pressing roll is rolling over a surface, and therefore additional forces are delivered due to the friction of the prepreg on the surface, the material is unspooled with the speed of the tool. This allows to eliminate any differences of the speed between the material and the tool which would inevitably result in wrinkles or material damage. The two other drives of the cutting unit (D4 and D5) are moving the knives along a linear guide. They are directly linked to the robot drives which allows full position synchronised movements of the industrial robot and the cutting unit. This ensures correct side-trimming which highly depends on the position of the tool on the mould surface [6].

2.2. Test trolley

Based on the developed concepts a test trolley was built [6]. It's design has implemented the material guidance as well as the control of the rolls. The required moments of force for the "static state" were generated by weights hanging on wires which were wound on the axes of the rolls. The trolley also contained the cutting unit and pressing roll to demonstrate the proof of concept. The forward movement along the rails on the ground was provided by an electric cable winch. The trolley was used to preform many pre-tests and validations for every module of the designed lay-up head on a double curved surface,

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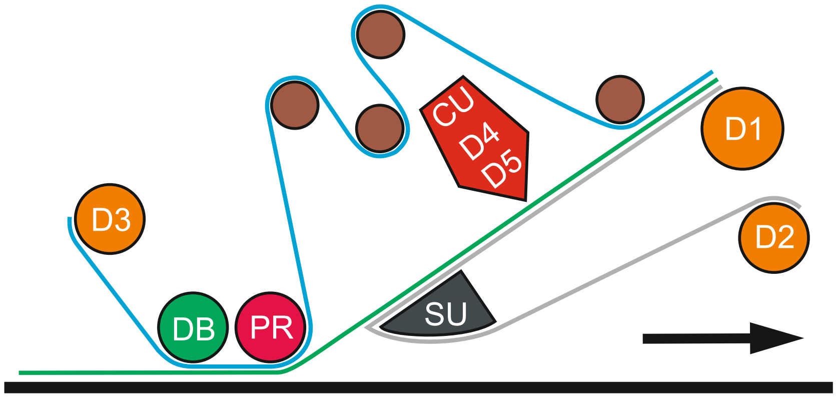
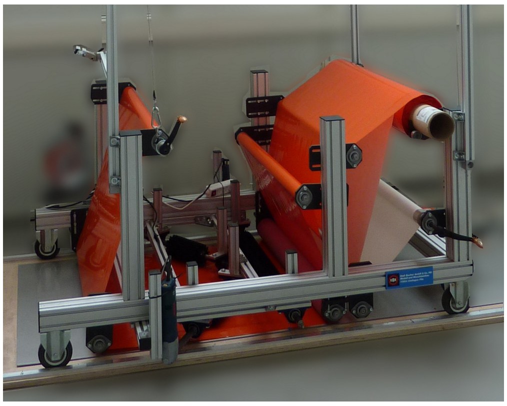
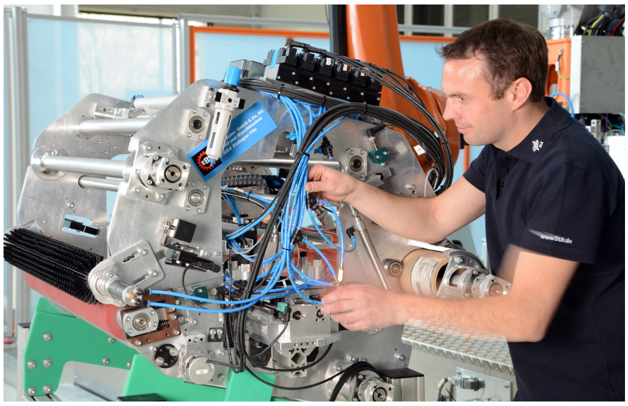
including the best designs for the draping unit and pressing roll, see Fig. 3(b). To save the very expensive LSP material, for the majority of the preformed tests, the much cheaper fiberglass prepreg was used. Taking into account the gained experience a prototype of the robot based lay-up head was finally designed and built by project partner Emil Bucher GmbH, see Fig. 3(c).



(a) Guiding of the material. Every of the three layers (blue - protective foil, green - copper mash and resin, grey - backing paper) is shown on its distinctive path. Drives D1 to D3 are responsible for the material transport, D4 and D5 for the position of the knives within the width of the material and implemented within cutting unit (CU). DB stands for drape unit, PR for pressure roll and SU for separation unit. The lay-up head moves in the direction of the arrow onto the mould surface (thick black line).



(b) The test trolley used for pre-tests.



(c) The prototype of the lay-up head built by Emil Bucher GmbH and used for the validation.

Figure 3. Pictures above illustrate the development phases of the robot based lay-up head.

3. Commissioning process and validation

3.1. Sensors and robot control

The commissioning and the succeeding validation took place within project RoCk [7]. The prototype was equipped with a wide array of sensors. Some of them were monitoring the condition of the lay-up head, i.e. the position of the knifes, the filling level of the foil storage or the quantity of the material left on D1. The others were used for monitoring the lay-up process itself: the position of the edges of the material, the quantity of applied material or the force of the pressing roll onto the surface. The sensors can be used to operate the process within defined boundary conditions. However the validation, see chapters 4 and 5, reveals that the process is very robust and stable and a rigorous monitoring is not necessary.

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The programs for the control of the robot carrying the lay-up head and for the drives of the cutting module were generated via offline programming using software tools like CATIA, DELIMA and FAST SURF as well as proprietary tools. One of these tools calculates the robotic path of the lay-up head onto the mould surface by means of in-house developed algorithm which took the curvature of the mould into the calculation. The second tool completes the robot program by adding the paths of both ultrasonic knifes and the necessary process steps. As a result, an integrated robot program for a single material cut was provided which can be loaded directly into the robotic cell.
The developed path generation also allows wider cuts (up to whole width of the material roll, 90 cm) and thus better utilisation of the material (see Fig. 4) and lesser strain while draping the material onto the mould compared to the manual process [6, 8, 9].

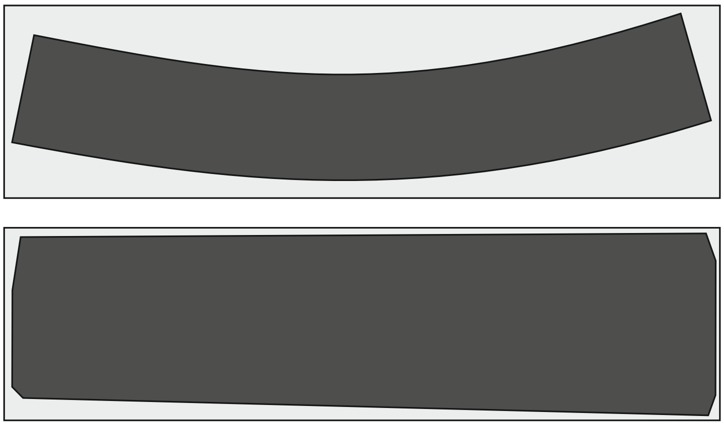

Figure 4. Sketch for the comparison of the utilisation of the material for current manual process (top) to the new approach with optimised paths (bottom). Dark grey area is the applied material, light grey the width of the material roll (0.90 m).

4. Validation - convex mould

The first validation test took place on convex mould (male geometry) build-up from a part of the tail section of an Airbus A350. The aim was to demonstrate the functionality of the drive controls for the material and the ultrasonic knives, the cutting module and the quality of the drapery. Also the precision of the positioning of the cuts was confirmed by lay-up of two adjacent cuts with defined overlap. The result meets the requirements for the manufacturing of an original panel, see Fig. 5. The robot programs for the paths of the lay-up head on the surface were created offline by using the developed tools as described above. The material used for the validation was the SURFACE MASTER 905 for male process from Cytec.

5. Validation - concave mould

After the successful validation of the lay-up on convex mould, preparations for the necessary hardware modifications to enable a female process (concave mould) has started. The design had to be adapted because of the mirrored female LSP material (the order of the copper mesh and resin matrix is reversed) and thus the material guiding had to be changed. The biggest modification was carried out by modifying the pressure roller. This was necessary because of the change of the drape mechanics on concave surfaces.

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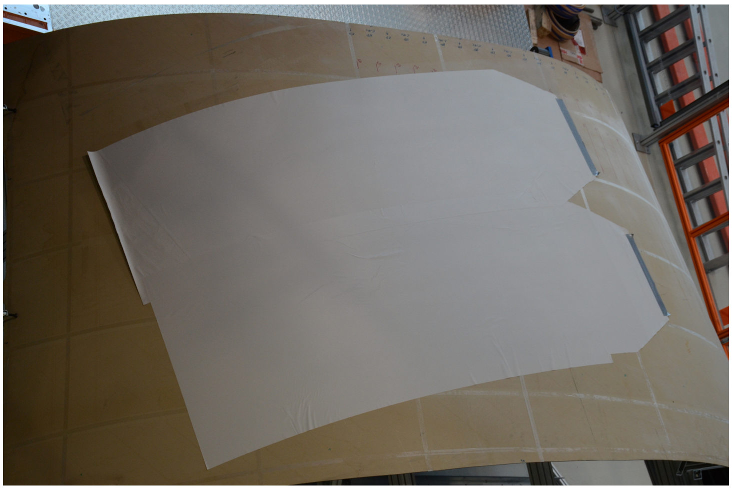

Figure 5. Result of the automated application of two adjacent cuts of LSP material onto convex mould with defined overlap. The overall lay-up quality is good and meets the requirements for the manufacturing of an original panel.

While draping on a convex mould there is only one distinctive contact point, so the emerging wrinkles can be lead to both sides and get carried away. On a concave mould, having a straight pressure roller, two contact points occur. Any wrinkles that may accrue are led to the midpoint and pressed on, building non compliant folds. Therefore the pressure roller had to be shaped similar to the mould profile with even stronger curvature so that in the midpoint of the roller only one contact point with the mould can be established. The bend of the pressure roller had to be adjusted within several millimetres for different radii corresponding to the several different cuts covering the whole surface of the panel.
The aim was a gapless coverage of a defined area on the mould with defined overlap between each cut, see Fig. 6(a). The defined area was restricted between two boundaries: the EEOP (Engineering Edge of Part) and MEOP (Manufacturing Edge Of Part). The former is embedding the area, where gapless lay-up in certified quality is required, the latter restricts the start and the end of the cut, where the quality is not crucial. This approach represents typical manufacturing practice, where the part (panel) is finished along the EEOP in post-processing. The first two cuts were covering the most critical spot with the highest curvature, see Fig. 6(a).
Automated lay-up was achieved for three adjacent single cuts layed up separately to diminish the influence of the pre-layed cut on the following one. All three cuts showed good lay-up quality with no critical wrinkles or bridging, covering the EEOP area and without crossing the MEOP boundary. The process was carried out without interruptions and in one step with the original LSP material AF535XD FT .056WT for female process from 3M.
In the second step, we have researched the impact of the already applied cut on the quality of following cuts and the interaction in the overlap area. There were no indications on any kind of interaction problems and the overlap remains constant and within the given specifications regarding to the quality and the required overlap space, see Fig. 7.

6. Conclusion

In conclusion we have developed an automated solution for robot driven lay-up of lightning strike protection material directly from the reel that meets the up to date manufacturing requirements for production of large double curved aircraft fuselage panels. The lay-up head is applicable for both of the two com-

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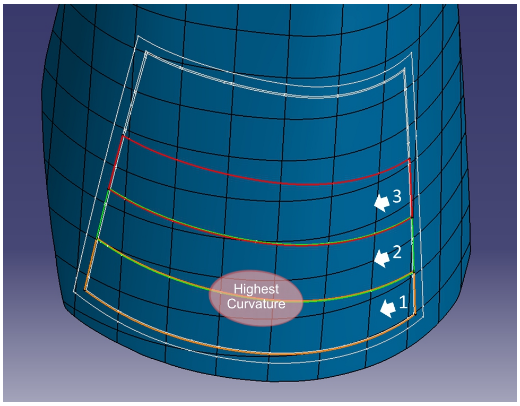
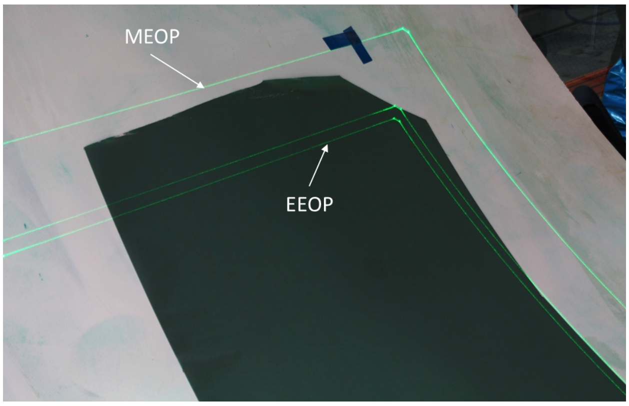


(a) CAD data of three adjacent paths/cuts as seen in the DELMIA software during the generation of the robot program. The area of the highest curvature of the mould is marked and represents the most difficult spot regarding to the drape process.



(b) The beginning of a LSP material cut within the projection of EEOP and MEOP boundaries for first path.

Figure 6. Position of the first three cuts respectively the cut shape and quality of the first path between the defined boundaries.

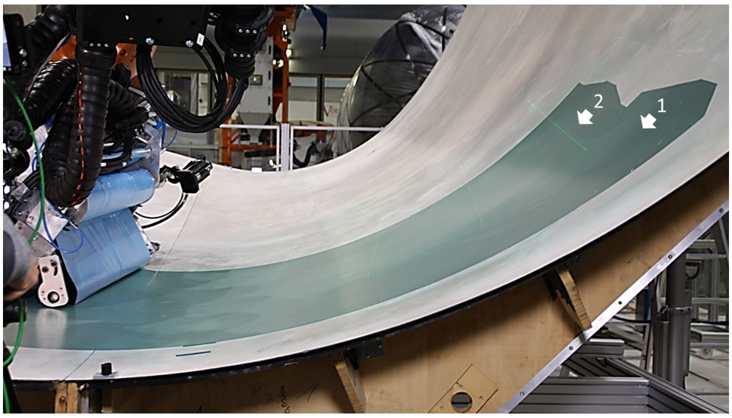


Figure 7. Result of the automated application of two adjacent cuts of LSP material onto concave mould with defined overlap.

mon manufacturing principles: male and female process on convex respectively concave moulds. The lay-up tool brings together all steps into one continuous process: the material delivery, the cutting of the geometry, the draping of the LSP material on double curved surface and the collection of the remains of the material. This allows to speed up the lay-up process dramatically and to deliver more material in shorter time compared to the current manual process. The developed approach for generating robot paths and programs for optimised cuts allows better alignment of the material to mould curvature which results in better utilisation of the material and lesser strain to the material itself. The position of the applied cuts is precise and reproducible and thus allows very small margins for the overlap. Layups with almost full reel material width can be applied, reducing the total number of overlap margins. In result the presented method can reduce the needed weight on the LSP material, making the aircraft lighter. The automated lay-up process provides a quality as good as in manual processes and and and in addition it is reproducible.

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