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Large-scale preforming – innovative approach in the production of rotor blades

Abstract

In order to meet the demand for shorter cycle times and higher quality demands of the growing fiber-plastic composite parts (FRP), the Institut für integrierte Produktentwicklung (BIK) of the University of Bremen, the producer of non-crimp fabrics, the SAERTEX GmbH & Co. KG and the rotor blade manufacturer AREVA Blades GmbH developed new manufacturing technologies and automation-enabled materials. Now it is possible to transform an even deposited pile of textiles to a close-to-final-contour preform with simultaneous quality control. In addition to the preform technology and the resin-injection technology an innovative process chain with low cycle times for the manufacturing of rotor blades can be completed.

1 Introduction

In recent years, two trends have been observed in the production of rotor blades for wind turbine generators (WTGs). Firstly, the systems are more powerful [2], resulting in the growing length of the blades [3]; secondly, there is demand for shorter production times with increasing quality requirements [4].

Currently, attempts are being made to satisfy these requirements with the help of automation technology. While some industrial solutions are already available for mechanical finishing processes and for painting the rotor blades, the handling process steps for the reinforcing technical textiles continue to be a topic of research. Factors that make this process more complex include taking into account the flexible characteristics of the sensitive materials when developing the handling technologies, as well as the design of the process itself.

Decisive quality criteria for the handling processes of technical textiles are positioning precision and reproducibility. These determine the structural properties of the FRP components in subsequent operation. In particular, the alignment or orientation of the technical textiles as a whole, as well as the individual fiber bundles (rovings) within the textile must – as specified by the designer – be effected taking into consideration the stresses to which the component will subsequently be subjected.

2 Basic principles and concept

A pilot plant for the production of preforms for wind turbine rotor blades has been designed and built at BIK as part of the *mapretec* joint project. This is based on a review of a comprehensive automated process chain, from storage of the textile semi-finished rolls to the completely assembled, near-net shape preform for a rotor blade segment.

“Preform” is the term for a packet of dry technical textiles before the resin infusion process. This may be maintained in the desired geometry (flat or near-net shape) using suitable binder technology or positioned in a mold or on a transport device (preform carrier).

The process flow developed for setting up and molding a preform is illustrated in Figure 1. This article will deal in particular with the mold assembly with preform carrier.

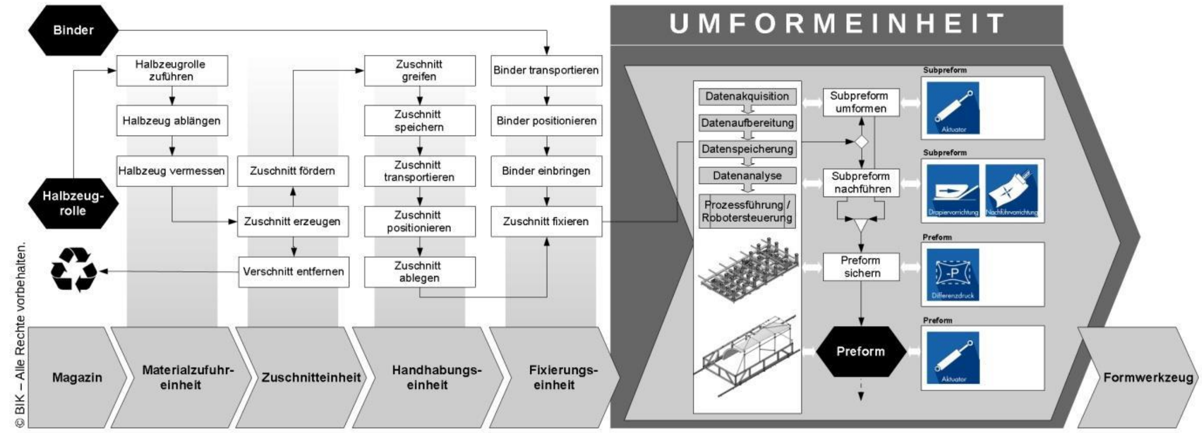

Figure 1: Process flow for setting up and forming a preform (preforming) (based on [5]), with detailed description of the processes that arise due to the mold assembly

For the process steps associated with the mold assembly, the individual technical textiles must be defined beforehand and reproducibly positioned on the flexible shaping surface.

Using these materials, a flat preform is automatically assembled on the preform carrier with the help of the material supply unit, the cutting unit and the handling unit. When setting up the preform (which is initially flat), a binder for fixing the individual blanks to each other as well as to the flexible shaping surface is applied to areas with low relative displacement or low relative deformation. For these process steps, a fixing unit has been developed at BIK [6]; this is capable of applying an epoxy resin-based adhesive film to automatically defined regions of the preform.

After the setup is complete the mold assembly forms this stack of textiles as a whole into the near net shape preform.

This is then positioned in the mold, brought into its final shape and secured in order to begin the preparations for the resin infusion process in the next process step.

The processes/plant technologies to be developed in line with the project are to be demonstrated by applying them to the most complex geometric segment of the rotor blade. This is located between the cylindrical flange area and the aerodynamically effective area (see Fig. 2). The Gaussian curvature information for the mold, which is important for draping, is shown qualitatively in color. The Gaussian curvature is defined by the product of the two principal curvatures (k_1=1r_1⁄ and k_2=1r_2⁄) and thus by the radii in the x and y directions of the mold.

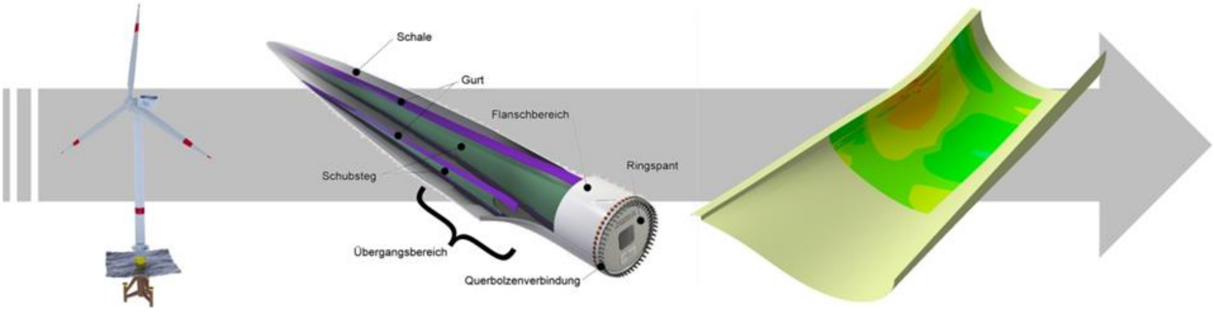

Figure 2: Schematic representation of the selected rotor blade segment at the transition zone between the cylindrical flange area and the aerodynamically effective area. Shown with Gaussian curvature

This segment has a size of approx. 18.0 m$_2$ (6.0 x 3.0 m) and has at its thickest point approx. 20 layers of technical textiles – a so-called multiaxial roving (MAR) – one above the other. It has regions with negative and positive Gaussian curvature in the range of $-4.6e_{-0.004}$ mm_{-1} to $5.8e_{-0.004}$ mm_{-1}. This geometric analysis is the starting point for the development of the process and plant technology. At the same time, the cutting and layout plans of the component are tested for automation compatibility in conjunction with the process and plant technology under development.

3 Design and textile-technology development

The design-related developments are divided into two areas. One is the development of the handling and automation technology by BIK on the basis of the process chain described in Figure 1. At the same time, Saertex will undertake textile-technology developments for technical rovings, especially for automated handling processes and large deformation paths, such as those that occur during joint near net forming. The difficulty here is ensuring good saturability at the same time.

3.1 Systems engineering

The basis of the entire process chain is the actual preforming process, which is highlighted and shown in detail in Figure 1. This process chain is being developed for flexible handling at the research facility that has been set up at BIK (see Fig. 3).

As a result of this approach, the critical path is relieved, in particular by reducing the mold occupancy times of the rotor blades. This is because the preforms are produced at the same time as – or prior to – the production process in the main mold, into which the completely assembled preforms can be inserted.

The novel issue here is that the dry, automatically assembled textile stack is formed into a single geometric dimension for rotor blades.

In order to be able to perform design development work on the mold assembly with preform carriers, a number of experiments [7] were necessary to ensure an understanding of the processes and materials. Subsequently, the design of the individual units of the research and demonstration facility was developed according to VDI 2221 [8].

The decisive factors for the functioning of the mold assembly can be divided into mechanical and control-related requirements. The mechanical-engineering requirements involve the hydraulic actuators, the flexible profile grid and the flexible shaping surface. For the control technology, this involves real-time control as well as the integration and evaluation of the sensors for detecting the forming geometry.

Figure 3 shows the structural design of the mold assembly (3) with 28 hydraulic actuators (5), a flexible profile grid (6), a flexible shaping surface (not shown for reasons of clarity), as well as with the mold for the rotor blade segment (4) used as an example.

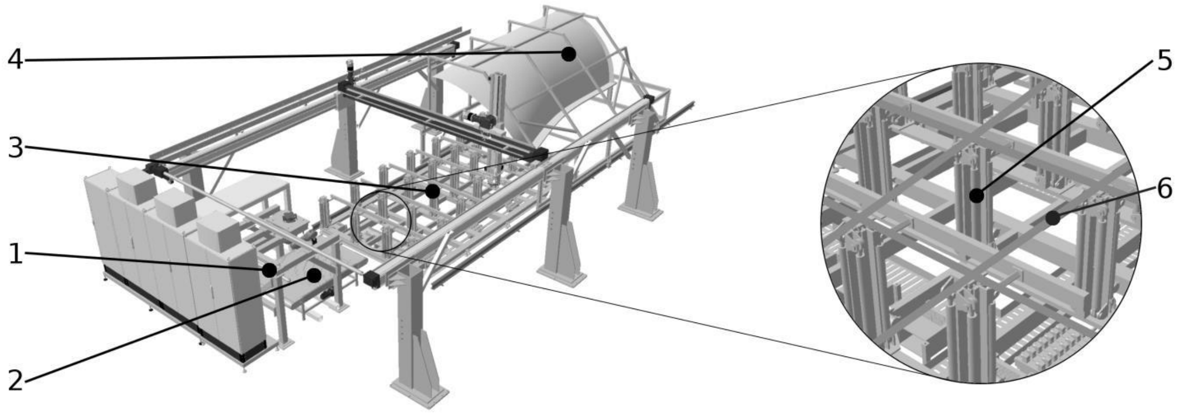

Figure 3: Structural overview. 1: material supply unit, 2: cutting unit, 3: mold assembly, 4: mold, 5: hydraulic actuator, 6: flexible profile grid

The hydraulic actuators work at an operating pressure of 7 N/mm^2. At a basic length of 750 mm, each actuator can perform a stroke of 1,700 mm. The maximum travel velocity amounts to 100 mm/s and depends on the number of hydraulic actuators that are moved simultaneously.

The flexible profile grid, made up of pultruded fiber-reinforced plastic profiles, is capable of achieving the required deformations to achieve the necessary geometry for the rotor blade range under examination by adjusting the actuators. The intersections of the profiles have a joint which has two translational and three rotational degrees of freedom. As a result, even complex shapes, such as the transition region of a rotor blade under investigation, can be implemented. A special flexible shaping surface with a floating sandwich structure, consisting of different polymer structures, serves as a support for the textile structure. This task presents a challenge for the CAE-supported design process because the high deformation properties of the material must also be taken into account.

3.2 Textile technology

Comprehensive expertise is required for the textile-related development of a multiaxial roving that is capable of high degrees of draping and that simultaneously permits complex three-dimensional forming without wrinkling, guarantees good saturation with the matrix material and meets the requirements of automated handling.

In addition, the textile-engineering development is subject to strict basic conditions due to the rotor blade design and the permit-related criteria.

The initial point is a triaxial semi-finished product with an orientation of ±45° glass fiber and 0° carbon fiber rovings, a defined total surface weight of the textile semi-finished product, and the weight and material of the roving to be used.

Based on the rovings previously used in rotor blade production, comparative studies of the saturation and drapability are required. To determine the degree of drapability, a drape test is used, with which it is possible to quantitatively and qualitatively represent the drapability of a technical textile (see Fig. 4).

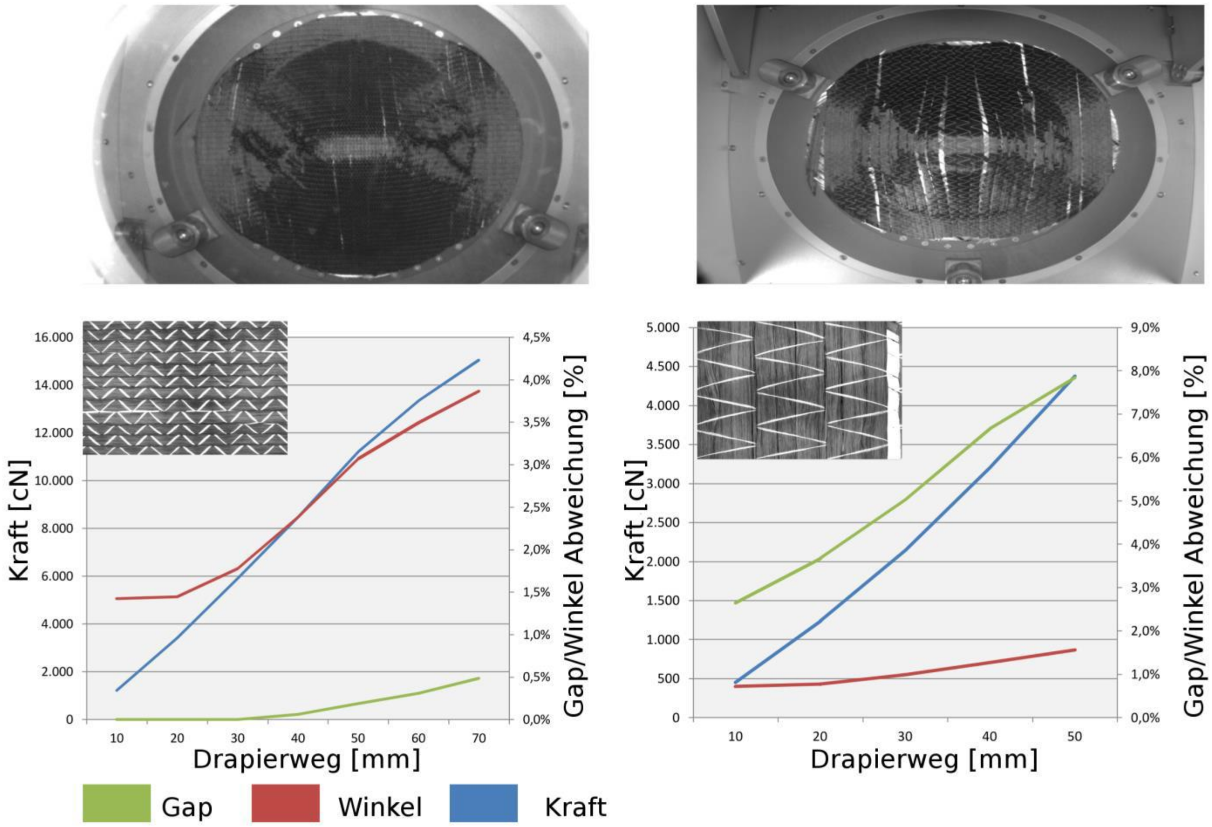

Figure 4: Material characterization using the drape test (ZIM research project: Messsysteme zur Charakterisierung der Drapierbarkeit von Multiaxialgelegen [Measuring systems for characterizing the drapability of multiaxial rovings], 03/2010 - 12/2011); left: original material; right: newly developed material with high drapability.

Here, a technical textile is deformed by a conical punch. At the same time, the angular deviations (gaps) between the fibers/fiber bundles that are displaced as a result of deformation are measured. The combination of the required force and these angular deviations, applied using the deformation/draping path of the punch, provides information about the drapability.
The draping of multiaxial rovings depends on, among other things, the type of stitching and the roving type or material used (glass or carbon). Using several iterations, a new MAG has been developed which, in contrast to the original highly restricted drapability, allows optimum adaptation to the complex 3D structure. Thus, the automated manufacturing process described above is optimally supported on the textile side.

4 CAE interface

An interface between the plant control system and the CAD system has proven useful for programming the automated forming process. This interface was developed within the framework of the project (see Fig. 5). For this purpose, the surface of the mold was first measured using a 3D laser scanner and imported into the Catia V5 3D CAD system. These geometry data are the basis for further analysis of the forming process.
The analysis is performed with the aid of a parametric model. This allows the most advantageous positions of the hydraulic actuators on the flexibly adjustable base support ($x_{i,t}$, $y_{i,t}$) as well as the subsequently required extension lengths ($z_{i,t}$) to be determined. The various combinations are

evaluated by comparing the ideal geometry (final contour) and the geometry that was actually achieved.

The determined optimum positions are transferred as a geometry dataset (matrix) directly into the real-time control of the hydraulic actuators by the developed interface.

A program was created for this interface using the mathematical programming language MATLAB. Other parameters, such as the travel velocity ($v_{i,t}$) and acceleration ($a_{i,t}$) of the actuators, as well as the forming strategy, can be adjusted via this interface. The output format consists of generating the PLC code for the actual forming process.

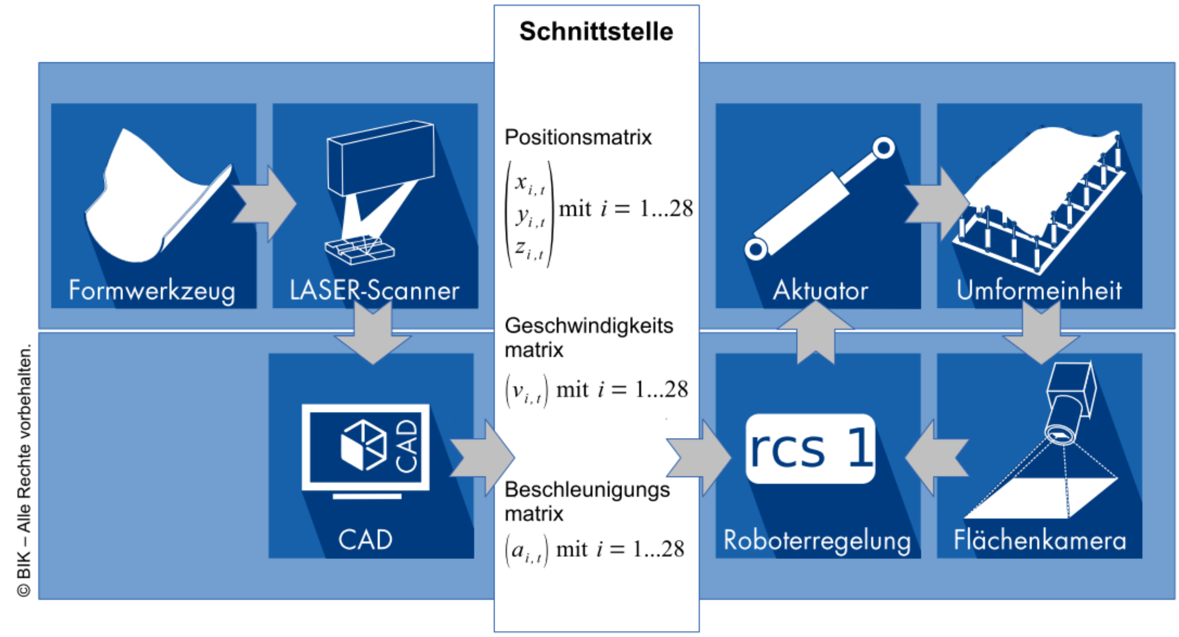

Figure 5: Interface between the 3D CAD system and the control system of the mold assembly

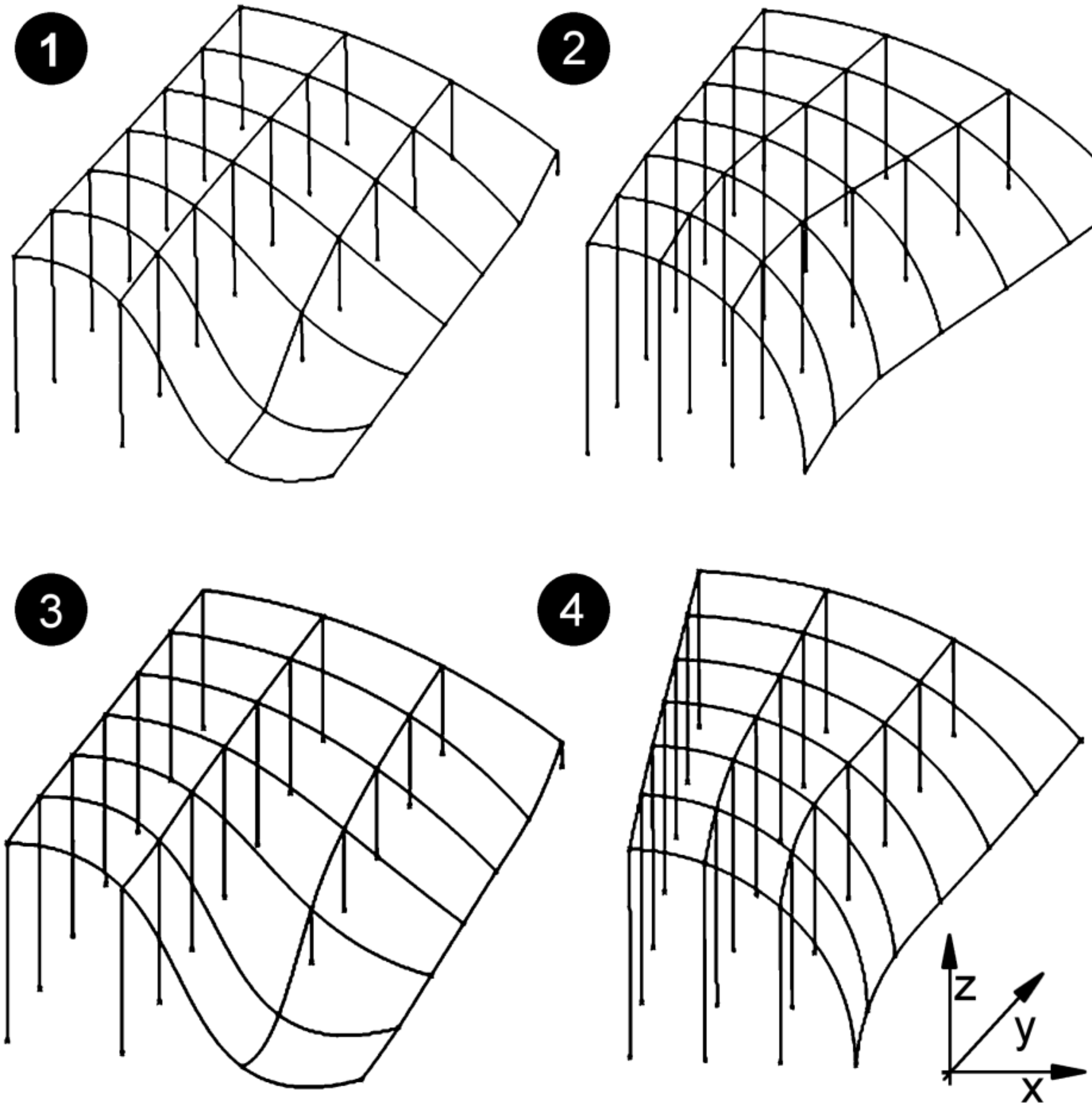

Figure 6 shows examples of the geometry analysis of different positions and extension lengths of the hydraulic actuators using the Catia V5 3D CAD system. Figure 6 also shows studies of two different versions of the profile grid (spline, linear function defined section-by-section) in the x axis.

Figure 6: 1: version in which the supports are at the same distance and a series of supports (y axis) is respectively connected to a spline. The supports are connected in the x axis using a polygonal line; 2: same principle as in 1, but in this case the distances between the supports are optimized in terms of geometry; 3: the polygonal lines give way to further splines with the same support spacing; finally, 4 shows another variant in which only splines can be seen at different column spacings – this exhibits the best result, although its design is the most elaborate

Figure 7 shows the hydraulic actuators assembled on the rotor blade segment under examination in the x, y and z axes.

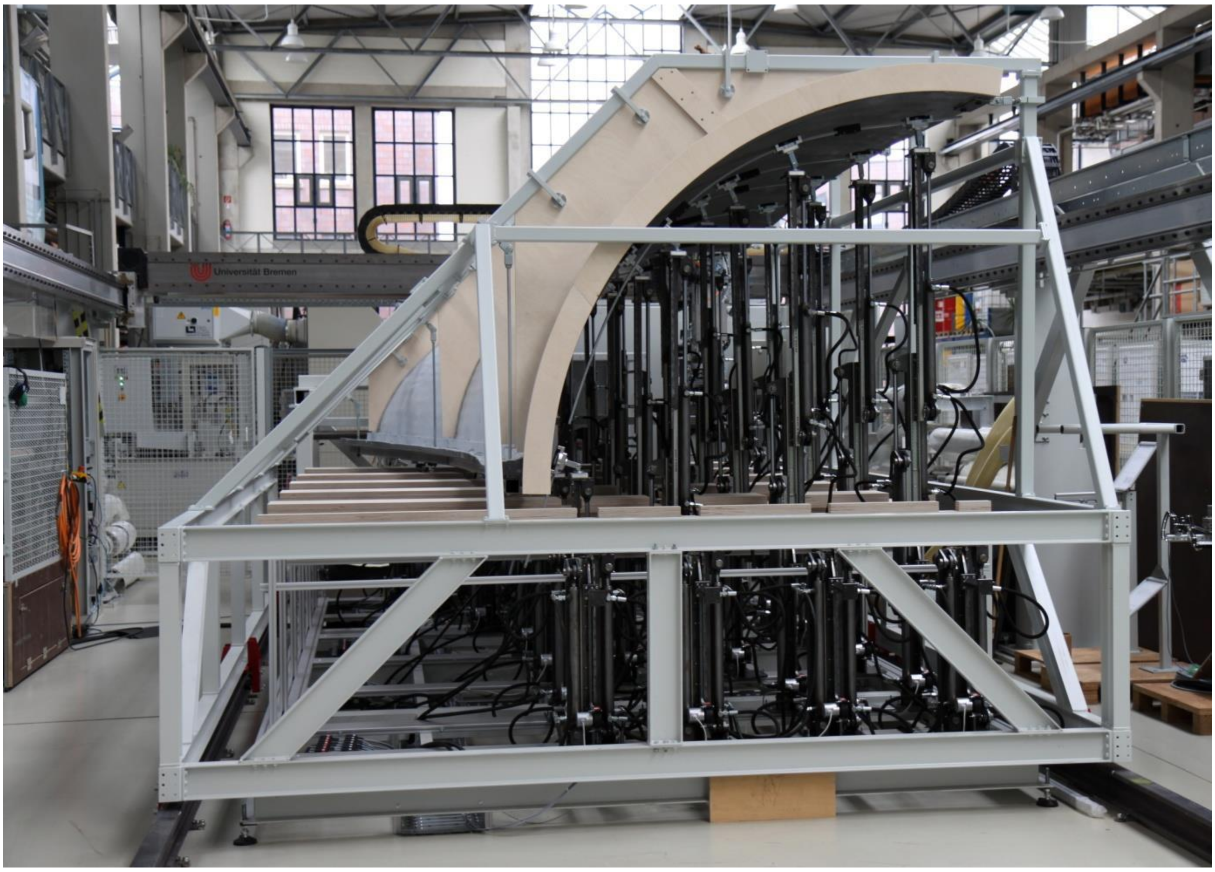

Figure 7: Hydraulic actuators assembled on the rotor blade segment under examination in the x, y and z axes

5 Process technology

Following the smaller scale (1:9) [9] experimental studies and simulations of the forming process, which were carried out before development of the facility, experimental investigations of the forming process are currently taking place at the institute. The focus of these investigations is on the forming strategy. The following three strategies for forming serve as examples:

- In the first version, an intermediate step is carried out during the forming process. Here, the actuators are jointly moved to a position of medium height. Then movement into the near-net shape position takes place. Some of the actuators are further extended while others are retracted.
- In the second version the textile layer stack is formed by lowering the hydraulic actuators. First, all actuators are moved to an upper position; some are subsequently lowered, thus resulting in the near-net shape position.
- In the third version, the actuators are moved in a controlled manner from the planar position to the near-net shape geometry.

Using a track system, the mold is positioned above the forming installation before the forming process takes place (see Fig. 3). In a real manufacturing process, hydraulic folding devices would be used (e.g. by [10]).

The mold of the experimental apparatus is equipped with a differential pressure device that uses a vacuum foil to press the near net preform upside down into the mold in the final contour and to hold and secure it. Subsequently, the resin infusion and curing processes can be carried out; in the last step, the final FRP component can be removed.

6 Quality assurance

Before the forming process takes place, a surface analysis of the assembled planar textile stack is performed. For this purpose, a newly developed effector with an image acquisition system is used. This allows both 2D and 3D images of the textile surface to be created.
Figure 8 shows the image acquisition system that has been developed; during its development, the focus was placed on the weight to stiffness ratio. This is necessary because of the permissible payload of the articulated-arm robot that is used to position the camera system and the need to obtain a high degree of vibration attenuation in order to achieve a steady and sharp image. For this purpose, an aluminum-carbon design with a structure similar to that used in bionic approaches was used.

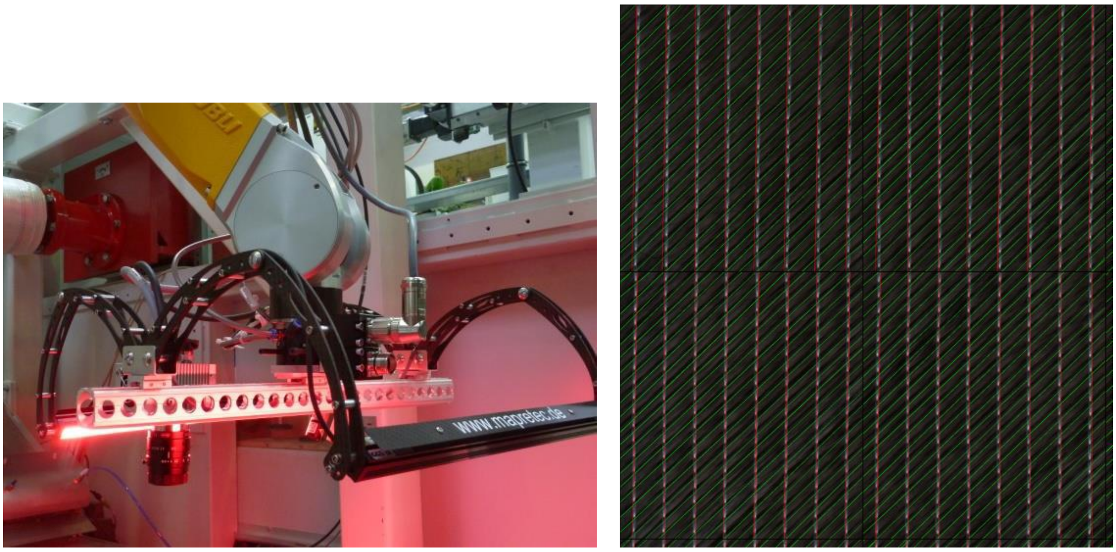

Figure 8: a) Quality assurance unit (OCQU); located on the left, on the 6-axis articulated-arm robot for recording textile surface defects after deposition; right: examples of an imaged textile surface of a multiaxial carbon fabric with the evaluated fiber orientations (red: sewing threads; green: gaps)

Using this imaging system and the subsequent analysis routines as set forth in [7], the real roving orientations can be captured and output as mathematical functions. This also makes it possible to detect permissible and impermissible formations of gaps and angular deviations (see Figure 8).

7 Conclusions

By undertaking research and development in the area of plant and process technology for large-scale preforming, we have managed to prove the viability of this approach in rotor blade production with the help of forming technology.

Using this type of plant and process technology, major innovations in automated handling and textile technology can be achieved in rotor blade production. Automation technology provides the ability to develop and make use of new types of non-crimp-fabrics that are not suitable for conventional manual procedures.

By combining automation, innovative textile technology, preforming technology, and resin infusion technology, low cycle times can be achieved with high reproducibility. With the ever-rising sizes of rotor blades and increasing quality requirements, this will become more and more important in future.

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