Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013), Cranfield University, UK, 19th – 20th September 2013, pp 411-416

ADVANCED AUTOMATED FIBRE PLACEMENT

Christian Krombholz
Institute of Composite Structures
and Adaptive Systems
German Aerospace Center
Stade
Ottenbecker Damm 12, 21684 Stade,
GERMANY
Christian.Krombholz@dlr.de

Dominik Delisle
Institute of Composite Structures
and Adaptive Systems
German Aerospace Center
Stade
Ottenbecker Damm 12, 21684 Stade,
GERMANY
Dominik.Delisle@dlr.de

Marcus Perner
Institute of Composite Structures
and Adaptive Systems
German Aerospace Center
Brunswick
Lilienthalplatz 7, 38108 Brunswick,
GERMANY
Marcus.Perner@dlr.de

ABSTRACT

The further increase of production rates while maintaining or improving quality and lower costs demand the development of new manufacturing solutions. For this purpose, within the project GroFi® the German Aerospace Center (DLR) develops a new plant, processes and sensor systems that enable a productive, cost-reducing manufacturing with an increase in quality of large-scale composite structures. The plant concept is a novel robot-based multi-head fibre placement facility, that coordinates its up to 8 layup units working on one or more components simultaneously. For the coordination of these layup units a closed CAD-CAM simulation was developed, that generates a time and / or cost-effective manufacturing process. To increase quality and productivity additionally, a comprehensive sensor system has been developed. This development of the DLR in the field of an advanced automated fibre placement technology serves the requirements of the current aviation industry.

Keywords: Automated Fibre Placement Technology, Sensor System, CAD-CAM Simulation.

1 INTRODUCTION

Developing light structural components in the field of aerospace is at all times a fundamental aim. To increase fuel-efficiency the use of fibre reinforced plastics will be pushed more and more.

This demand of a holistic development in the fields of composites also adheres the German Aerospace Center (DLR) with the Institute of Composite Structures and Adaptive Systems which closed the interface between basic research and industrial application by the opening of the Center for Lightweight-Production-Technology (ZLP) in Stade and Augsburg in the year 2010.

To accommodate the requirements for productive and accurate production technologies especially for aeronautics, new plant concepts for the fibre placement technology have to be developed.

Therefore DLR developed in the project GroFi® (German acronym for production of extensive components in fibre placement technology) a new plant, sensor systems and simulation tools, which are represented in this manuscript.

2 STATE OF THE ART

Nowadays fibre placement machines are applied in high quality production processes especially in the field of large, low-curved aeronautical shell structures likewise fuselage sections or wings. With the utilization of pre-impregnated fibre material (prepreg) a high quality material is given. To prevent or minimize inaccuracies by the machines, the historical background of the major manufactures are high precision milling and milling machines. This resulted in gantry and portal machines with high weights and dimensions.(Evans et al. 1989)(Krombholz et al. 2011)(Krombholz et al. 2012)

The requirements for a high quality layup are given in current design rules. Especially the geometric tolerances are complied with the use of portal or gantry machines with high stiffness. The utilization of smaller and more flexible robot units was introduced by (Ahrens 1998) for the first time. Actually robot units are implemented in closed-to-productions for the aeronautic branch. The robot units are optimized for a high repeat accuracy and comply the requirements by adapted process parameters.

In order to improve the productivity of fibre placement and tape laying facilities, the employment of multiple layup units is inevitable. In industries, e.g. in automotive applications, multi-robot plants are well situated. In most cases the production units operate in separated workspaces with a fixed task allocation. Due to a lack of flexibility and redundancy of those plants, in the last few years a lot of research studies the possibilities of coordinated and cooperating robots. (Papakostas et al. 2011)

The approach of those flexible multi-robot applications presents several challenges, e.g. an optimized and collision-free path planning. With respect to the communication architecture there are two basic approaches. On the one hand there are multi agent systems with a decentralized control and cooperating units. For the GroFi®-plant a second approach is chosen. Therefore a centralized controller, referred to as master controller, is used to coordinate all production units.

In the aeronautic branch an inspection is submitted to ensure a high layup quality. Currently a visual inspection is carried out by a specialist after the layup of one ply or sequence. The visual inspections investigates the plies or sequences regarding material failures, intolerable layup failures (gaps/overlaps, wrinkles, crimps, bridging) and foreign bodies. Randomly there are also extensive measurement tasks, that make a qualitative statement about failures.

A sensor-based process to control and monitor the layup quality in a fibre placement production isn’t realized yet. In addition, there are quality monitoring sensors in production technologies for composite structures. However, mostly they are implemented to inspect textile preforms after draping processes. (Schmitt et al. 2009) (Schmitt et al. 2007) (Schmitt et al. 2008) Due to the poor accessibility during draping processes with optical measurement systems no inline quality control is possible. This inspection has to be done in a separate process step. An inline quality inspection that doesn’t result additional process steps isn’t realized yet.

In other robotic production branches there are implemented sensor-controlled processes for an online path correction, especially in the welding technology. (Bollig 2005)(Roebrock & Böhnke 2007)(Veryba et al. 2000)

Precision in automation systems is mainly defined through various factors. Vibration is one significant source that affects the precision. The source of excitation can be clustered into three different types: process-induced movements in case of path planning, environmental conditions likewise behaviour changes through varying temperature and controllability limits of the drive engines. A huge amount of great research studies this topic. (Economou et al. 2000) (Hu 2008) (Itoh & Yoshikawa 2003) In case of increasing demands of the production rate and the necessary part quality the vibrational behaviour of a plant becomes the most important property. Therefore, studying the proposed plant structure is a current research topic (Perner et al. 2012).

3 FIBRE PLACEMENT PLANT CONCEPT

The basis of the project GroFi® is a fibre placement research facility in Stade which was invented and co-developed by DLR. This research facility forms an ideal interface, where applied research and development can be tested at full-scale components.

Special attention is placed on the process requirements flexibility, productivity, efficiency, process stability and quality of the structural component.

The research facility comprises a mold bearing system, which supports tools with up to 20m length and 5.5m width. Around this double-sided tooling there is a rail system which is split into a production-loop and in parallel with this, a maintenance loop (see Figure 1 and Figure 2).

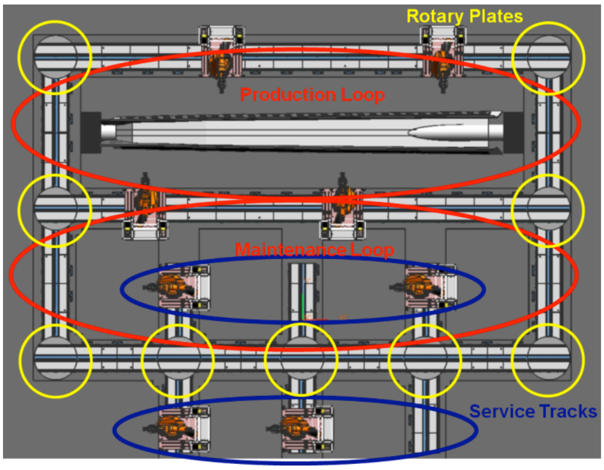

Figure 1: Top view of the GroFi®-plant with highlighting production-loop, maintenance-loop, rotary plates and service tracks

Figure 2: Photo of the automated fibre placement plant GroFi® at the Center for Lightweight-Production-Technology

On this rail system up to 8 coordinated industrial robots can produce simultaneously. This robot based multi head layup facility is equipped with both, 16 x ¼ tow fibre placement and 150mm tape laying units. For the first time it's possible to use fibre placement and tape laying technology at the same time and for the same component. Every robot unit comprises a standard industrial robot (KUKA KR500) that is controlled by a Siemens 840D-sl NC. Due to the rotary plates and the loops there is no connection to the facility among the power. Everything else is provided on the platform (e.g. vacuum, compressed air) or wireless (e.g. control data, process data).

Due to the separated maintenance and production loop the productivity of the research facility can increase significantly as the result of missing or clearly reduced dead times. Furthermore, in case of a defected layup unit, or a layup unit which has to be discharged or maintained, it's possible to delegate tasks to other available units. That ensures a flexible and redundant process.

The innovative plant concept results in improvements of flexibility, productivity, efficiency and process stability and enables a fibre placement process for aeronautic composite structures with a mass throughput of up to 150kg/h.

To serve the purpose of an advanced automated fibre placement facility, DLR develops additional concepts in the field of CAD-CAM simulation and quality improving sensor systems.

4 CAD-CAM SIMULATION

Typically, current fibre placement and tape laying facilities consist of single layup units. In case of the GroFi®-plant up to 8 units produce simultaneously without delimitation of the individual working areas. For this reason the DLR develops a scheduling tool which can be used for both - offline programming and online rescheduling.

Figure 3 illustrates the CAD/CAM-chain of the GroFi®-plant based on the CAD-model of the target part. This model includes not only the geometry, but also the information about the complete plybook. Regarding a single unit process, the NC-data can be generated by feeding the information from the CAD-model to a separate software-tool, referred to as GroFi®-CAM. To make these NC-data accessible for a multi-head layup process, the GroFi®-CAM tool generates a separate NC-file for each course. If there is the possibility to process a course in different directions, one file for each direction is generated. This ensures a greater flexibility for the subsequent scheduling loop.

The logistic optimization is realized by the scheduling tool. This can be either done with respect to a minimum process time or minimum costs. The scheduling tool conflates the NC-files of the different courses with respect to real-time parameters likewise the material stock of the layup units or their position into several working packages and assigns them to the available units. Simultaneously, a simulation tool carries out a collision analysis by reviewing the scheduling results.

Instead of considering the courses of each ply separately, the logistic optimization allots dependencies to the different courses. This is conducted by geometric conductions and defines the order, the course are considered for scheduling.

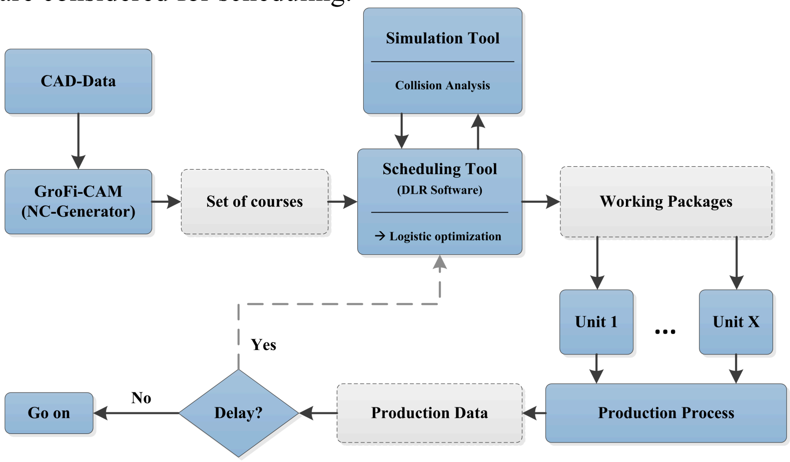

Figure 3: CAD/CAM-Chain

During the production process the layup-units return specific process parameters which are compared to the data of the offline programming. In case of a delay in the production process, e.g. based on a failure of a layup unit or material problems, an online rescheduling takes place. The algorithms of the offline programming are used for this purpose.

Due to the possibility of the online rescheduling and the consideration of course-dependencies, the CAD/CAM-system of the GroFi®-plant represents a flexible and redundant system which is able to compensate production delays automatically.

5 SENSOR CONCEPT

To precise the accuracy the dynamic behaviour of the plant components has to be taken into account. One of the key improvements in regard of the proposed AFP-production plant is the combined use of the linear unit, the industrial robot and machine tooling. Due to a comprehensive knowledge of the structural behaviour further improvements of these single components can be derived.

Industrial robots have serial kinematics, whereby elasticity of joints is summed und results in higher inaccuracies and misalignments. In addition, higher bending and torsion is induced through the compaction force of about 2kN applied by each processing robot unit. As a result of coordinated work with several robot units in one workspace the absolute accuracy of every unit can be used.

Therefore, to realize an improved production quality DLR develops a sensor system that compensates inaccuracies. The overall sensor system is divided into three categories (cf. Figure 4).

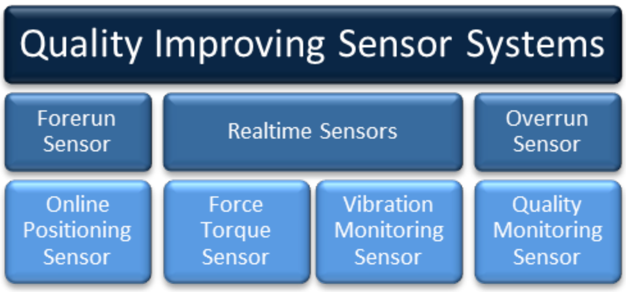

Figure 4: Quality improving sensor systems for the fibre placement process

The online positioning sensor detects in the forerun of the compaction roller the edge position of a neighbour material and is able to start a robot path correction to control material gaps and overlaps. The sensor is a laser light section sensor. Hereby, a laser light section is projected on the measurement surface. The reflexions of the laser line are acquired by an optical sensor, mostly a CMOS sensor. By means of triangulation a topographic 3D-measurement can be realized and geometrical steps like material edges can be detected metrically. The online positioning sensor is integrated into a real-time evaluation unit which is directly embedded into the NC-control. If the position of the material edges is way beyond defined tolerances, the online positioning system realizes an online path correction of the robot unit. (Krombholz et al. 2011)(Krombholz et al. 2012)

The real-time sensor system consists of a force-torque and a vibration monitoring sensor.The layup quality of prepreg or dry fibre material is especially influenced by several process parameters. Next to the material temperature, air humidity and feedrate, the compaction force is an important factor to minimize air pores, bridging effects and increase tack characteristics between tool and first ply as well as interlaminar. A control of the compaction force and torque along the compaction area is necessary. Therefore all layup units in GroFi® have a force torque sensor next to the compaction roller that measures the values online. A realtime unit processes this values as a function of the current robot pose and communicates with the robot NC-control. The NC-control is able to initiate corrections of the compaction force by means of pressure or robot position corrections. On the one hand side this enables an online control of the compaction force and on the other hand an homogenous force distribution along the roller. Additionally, a material optimized production, e.g. of pressure-sensitive materials such as sandwich cores, is given.

As an essential criterion in engineering the dynamical behaviour of the performing structure beginning at the platform up to the last active robot axis is studied. The last active axis means the last controllable axis on which the lay-up head is mounted. As one first step to overcome vibrational issues affecting the lay-up performance a dynamic study was established in (Perner et al. 2012). The results were considered for the optimization of the coupled drive control of the linear unit. Actually, these studies has to be made during the installation phase.

Vibration can be observed during the layup using accelerometers. These sensors are available with different specifications by means of frequency range and sensitivity, for instances. Since the robot structure itself is heavy weight, the influence of the sensor's mass on the response of the structure can be neglected through signal analysis. The filter device for signal condition separates disturbances from the target acceleration. In the case that the oscillations during the layup process exceed the defined limits, a compensation movement is initialled. Unfortunately, the dynamic behaviour of the drive engines is not capable to compensate for deviations through frequencies higher than about 40Hz. Therefore, the online monitoring of vibration by likewise accelerometers forms the input signal for a compensation which is part of future investigations.

Beside of the sensor systems to increase the layup quality, e.g. by online path corrections, an online quality monitoring is necessary. Nowadays, experts control the laminate ply by ply or sequence by sequence. This results in dead times of the production facility by an average of 15min per ply in case of the fuselage production. An overall dead time for quality inspections in the production of large scale aeronautic parts is estimated to 4-6 hours. To realize a highly productive fibre placement facility the inspection time has to be minimized. As a consequence, the DLR develops an online quality monitoring system. The sensor system is mounted in the overrun of the layup head and performs the visual inspection fully automated and within the layup process. In this way the manual inspection is substituted or minimized by localising incorrect areas for a detailed manual inspection.

The quality monitoring sensor is based on a laser light section sensor with a much higher resolution optical sensor. The scan width represents the full material width of 16 x ¼" tows. The major task of the sensor system is the detection and survey of material gaps and overlaps, misalignments and foreign bodies. To realize a real-time solution, the optical sensor uses a real-time processing unit that is directly connected with the NC-control. Based on the measurement results, corrections can be initiated within the process. Moreover, the measured edge contour can be used as the base for the forerun online positioning sensor to detect neighbour material courses.

The quality improving sensor system, based on forerun, real-time and overrun sensor systems, meets the requirements for a high precision and productive fibre placement process. The result for the industry will be the development of a layup technology with at least the same quality for a more flexible and cost efficient production of composite structures.

6 SUMMARY AND CONCLUSIONS

Within this manuscript, tasks of the DLR project GroFi® were introduced. At first, a novel robot based fibre placement facility was demonstrated that consists of up to 8 coordinated layup units. These layup units are equipped with fibre placement or tape laying heads on a rail system. In addition, a new CAD-CAM simulation was presented to schedule these units to achieve an efficient production process. Despite the usage of standard industrial robot units a sensor concept was demonstrated that increase the quality of the composite structures.

It was shown that the requirements of the actual aviation industry could be addressed successfully.

Further studies will show up new theoretical and practical knowledge of the advanced automated fibre placement process, especially in the fields of coordinated multi-head facilities and simulations but also in the interaction of different sensor systems.

REFERENCES

Ahrens, M., 1998. Fibre placement offers cheaper composites. *Reinforced Plastics*, 42(6), p.25.

Bollig, A., 2005. Einsatz optischer Technologien zur Regelung des Laserstrahlschweissens. *Automatisierungstechnik*, 53, pp.513–521.

Economou, D. et al., 2000. Robust vibration suppression in flexible payloads carried by robot manipulators using digital filtering of joint trajectories. *Symposium on Robotics*, (November), pp.244–249.

Evans, D.O., Vaniglia, M.M. & Hopkins, P.C., 1989. Fiber placement process study. In *International SAMPE Symposium and Exhibition (Proceedings)*. Reno, NV, USA: Publ by SAMPE, Covina, CA, United States, pp. 1822–1833.

Hu, Q., 2008. Input shaping and variable structure control for simultaneous precision positioning and vibration reduction of flexible spacecraft with saturation compensation. *Journal of Sound and Vibration*, 318(1-2), pp.18–35.

Itoh, M. & Yoshikawa, H., 2003. Vibration suppression control for an articulated robot: Effects of model-based control applied to a waist axis. *INTERNATIONAL JOURNAL OF CONTROL, AUTOMATION and SYSTEMS*, 1(3), pp.263–270.

Krombholz, C. et al., 2012. Improving the Production Quality of the Advanced Automated Fiber Placement Process by Means of Online Path Correction. In *28th Congress of the International Council of the Aaeronautical Sciences*. Brisbane.

Krombholz, C. et al., 2011. Online Bahnkorrektur eines Industrieroboters mittels optischer Sensoren für den Einsatz im Fiber-Placement-Prozess. In *Deutscher Luft- und Raumfahrtkongress 2011*.

Papakostas, N. et al., 2011. Industrial applications with cooperating robots for the flexible assembly. *International Journal of Computer Integrated Manufacturing*, 24(7), pp.650–660.

Perner, M. et al., 2012. Clarifying vibrational issues of an advanced automated fiber placement production plant. In *Advanced Intelligent Mechatronics (AIM), 2012 IEEE/ASME International Conference on*. pp. 111–116.

Roebrock, P. & Böhnke, K., 2007. Offline path correction system for industrial robots. *Proceedings of the 9th WSEAS International*, pp.276–280.

Schmitt, R. et al., 2008. A method for the automated positioning and alignment of fibre-reinforced plastic structures based on machine vision. *CIRP Annals - Manufacturing Technology*, 57(1), pp.501–504.

Schmitt, R., Niggemann, C. & Mersmann, C., 2009. Laser light-section sensor automating the production of textile-reinforced composites. *Proceedings of SPIE*, 7356, p.73560P–73560P–12.

Schmitt, R., Orth, Alexandre & Niggemann, Christian, 2007. A method for edge detection of textile preforms using a light-section sensor for the automated manufacturing of fibre-reinforced plastics. *Proceedings of SPIE*, 6616, pp.661609–661609–12.

Veryba, Y. et al., 2000. Method and system for robot end effector path correction using 3-D ultrasound sensors. *Intelligent Control and Automation, 2000. Proceedings of the 3rd World Congress on*, 2, pp.1240–1243 vol.2.