# INCREASING THE ROBUSTNESS AND RELIABILITY OF CFRP PRODUCTION PROCESSES THROUGH SYSTEMATIC ANALYSIS AND PROCESS MONITORING

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**Process Modeling and Analysis**

The presented work focuses on increasing the robustness of various serial manufacturing processes for CFRP parts for aeronautic applications. Therefore, a universally applicable approach to model and analyze serial production processes has been developed. The approach is illustrated in figure 1.

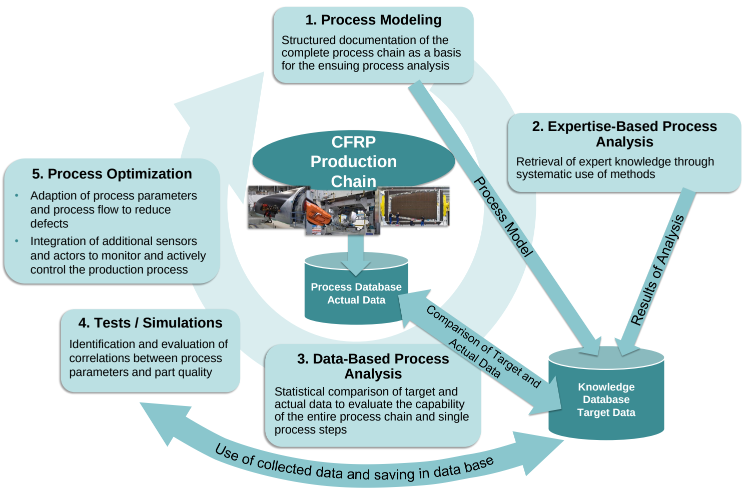


**Figure 1:** *Methodical approach to model, analyze and optimize CFRP production processes*

In the first step of the methodical approach, the process modeling, a system to hierarchically structure the production process in four layers has been defined. To visualize the process structure a specially designed swim lane diagram is used. In combination with other tools, this diagram serves as the basis for the second step, the expertise-based process analysis. In this step, the expertise of people familiar with the considered production chain is used to identify possible interactions and challenges. By using a consistent data base with the help of user interfaces to collect information, it is possible to create a data base of target values that can be compared to the actual data created by the manufacturing processes (Step 3).
However, the analysis of several manufacturing processes reveals that the data base generated during manufacturing is limited. Especially for production chains with a high percentage of manual processes the collection of unbiased data is difficult. As a fourth step, it is therefore often necessary to conduct experiments or simulations in order to evaluate assumed interactions and, as a last step, derive optimization measures.

**Process Monitoring using Time Domain Reflectometry (TDR)**
Using the above described methodical approach, vacuum infusion processes for several serial parts have been analyzed. It was observed that the infusion process is a critical step within the production chain as it is affected by several previous processes such as the lay-up of the preform and the auxiliary materials. This increases the risk of process deviations. Furthermore, a proper infusion is essential for a good part quality. One way to reduce costs while implementing new processes is the use of resin flow monitoring sensors. These support the establishing of stable and robust processes with a reduced number of qualification parts. A variety of sensor concepts based on optics [1], ultrasound [2] or pressure [3] has been presented in literature.
Time domain reflectometry (TDR) has been identified as a promising sensor concept to develop CFRP infusion processes, because such a sensor can be incorporated into a layup with only little influence on the laminate. The sensor consists of a two wire transmission line into which a voltage step pulse is sent. An oscilloscope is used to record the reflection of the signal created by impedance discontinuities along the line. Using the time of flight, such discontinuities, which are created by a resin front or the change of the dielectric permittivity of the resin during cure, can be located along the entire sensor line. Figure 2 schematically shows the setup of the sensor system.

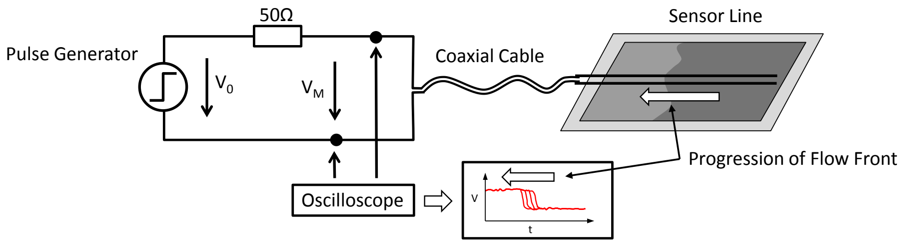


**Figure 2:** *TDR sensor setup*

In the past, the method has been validated for glass fiber laminates and room temperature curing resin systems [4,5]. Many aeronautic applications require resin systems which are infused at around 100°C and cure around 180°C. Using a commercially available TDR reflectometer which incorporates a pulse generator and an oscilloscope, the applicability of the method for these boundary conditions is investigated. Different sensor materials and configurations are tested at different temperatures to identify the optimal sensor design. By infiltrating glass and carbon fiber preforms with epoxy resins curing at room temperature and 180°C, the applicability of the sensor is investigated.

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