A Modular Approach to Non-Contact Ultrasonic Testing of Composites

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Abstract
Ultrasonic testing is increasingly utilized for verification of industrial composite materials. Air-coupled ultrasound has clear advantages compared to coupling techniques. The new technique - electronic hardware, probes, software, scanning systems - is predominantly used at the relatively low frequencies which are needed for the air coupled methods. On the other hand, the physical properties of plastic materials require the consideration of pecularities such as slower sound velocities, stronger attenuation and dispersion. The system is directed to practically usable sensitivity. Furthermore, the modular approach is aiming to higher testing speeds to meet practical needs. Different scanning are implemented ranging from scanning modules to robot supported testing. It is important to note that the image generation of flaws by scans is the first step only. The real challenge arises from the automatic differentiation between simple material inhomogeneities or unimportant distortions and relevant defects. The emphasis of the development will be on the automatic flaw classification under practical circumstances such as in production lines. A modular and open software structure have been chosen in order to enable flexible data processing on different levels enabling the implementation different filters, algorithms and classification tools in the processing chains and costumized visualisations .
The air-coupled experiments are exemplified on composite parts of different processing techniques, shapes, sizes and defects structure.

Keywords: air coupled ultrasound, inspection system~~-~~, composite testing

1. Introduction

All materials which are used to make objects need different kind of inspections in order to determine its fitness for use. Composites are often designed for applications under extreme mechanical applications. The particular challenges for inspection have their source in the inhomogeneous and anisotropic structure. Many inspection techniques (and particularly the inspection hardware) are not designed for composite materials. Different types of defects influence the mechanical strength and the properties of the material under load. Typical material problems arise from the major types of damage: matrix cracking, fibre-matrix debonding, fibre breakage and delaminations.
Despite of several demanding issues, ultrasound technologies possess a great potential for testing composite materials by means of non-destructive materials. A practical difficulty and challenge arise when ultrasound technology must be used without coupling. Despite of its value non-contact/air-coupled ultrasound techniques have been successfully demonstrated since more then 20 years ([1-5]) it is still ambitious to transfer the method to robust industrial testing.
It is beyond the scope of this paper to cover all aspects of the done air-coupled ultra-sound investigations. The work includes also simulations of transducers and the estimation and evaluation of acoustic properties of plastic and composite materials. Latter resulted in a comprehensive data base of acoustic properties. Such data are indispensable for correct and interpretation of acoustic data. An important point of interest for any user or costumer arises from the question how a flaw becomes critical and has to be classified as a defect. There will be reports in future publications.

2. Experimental

2.1 Measurement system

The experimental system consists of transmitter and receiver units which can be used modular. Single channel and multi-channel operation is enabled. The system can be extended if required. The power consumption is about 15 W in the single T-R-channel mode. The pulse voltage can be up to 400 V (peak-peak) in the burst mode. The pulser frequency enables up to 200 scans per second. Ultrasonic experiments can be carried out with frequencies between 50 kHz and 12.2 MHz. However, the system is predominantly designed for the non-contact use and the investigations of high damping materials such as plastics and composites. Resolutions of flaws are possible in the order of 1 mm^2 which depends also from the scanning speed and the scanning procedure. The low-noise gain can be adjusted up to maximum 110 dB. External pre-amplifier are available for 0-30-60 dB. The main amplifier can be adapted in steps of 0.5 dB ranging from 0-50 dB. The system is assembled in housings for industrial environment (e.g. in 19" racks).

2.2 Transducers

Transducers for non-contact ultrasound have been developed. In order to increase the signal-to-noise-ratio efforts have been made to improve the quality the acoustic properties and to reduce the acoustic mismatch. A series of transducers has been built up with frequencies between 50 and 400 kHz. Furthermore, transducers with improved acoustic field have been designed in order to achieve a more concentrated focus. The focus properties are illustrated in figure 1 and 2. Amongst the geometric improvement, the signal to-noise-ratio can be further enhanced by selection of suitable transmitter-receiver-pairs.

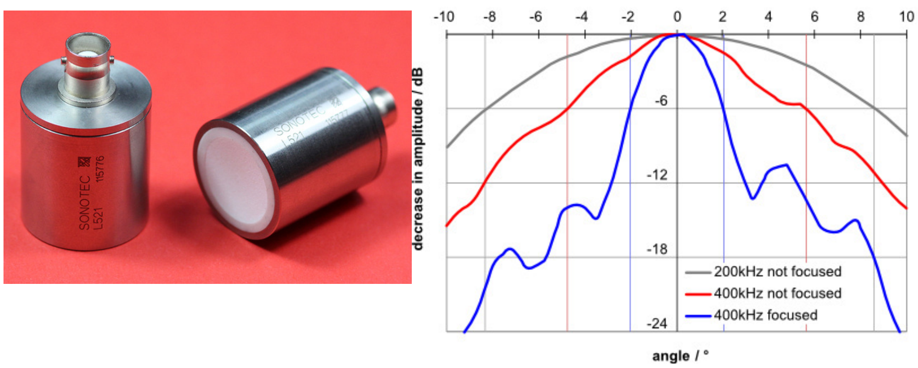

Figure 1. Transducer for air-copuled transducers, comparison of non-contact transducers with different frequencies and focusing properties.

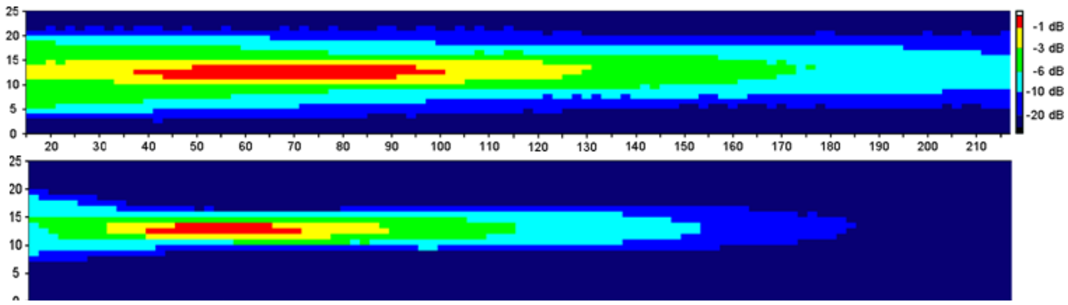

Figure 2. Improvement of the ultrasound pattern of the transducers: above: unfocused, below: focused

A further improvement can be achieved by the actively focusing transducers (figure 3). The ultrasonic field can be controlled by a Fresnel-structure of the electrodes.

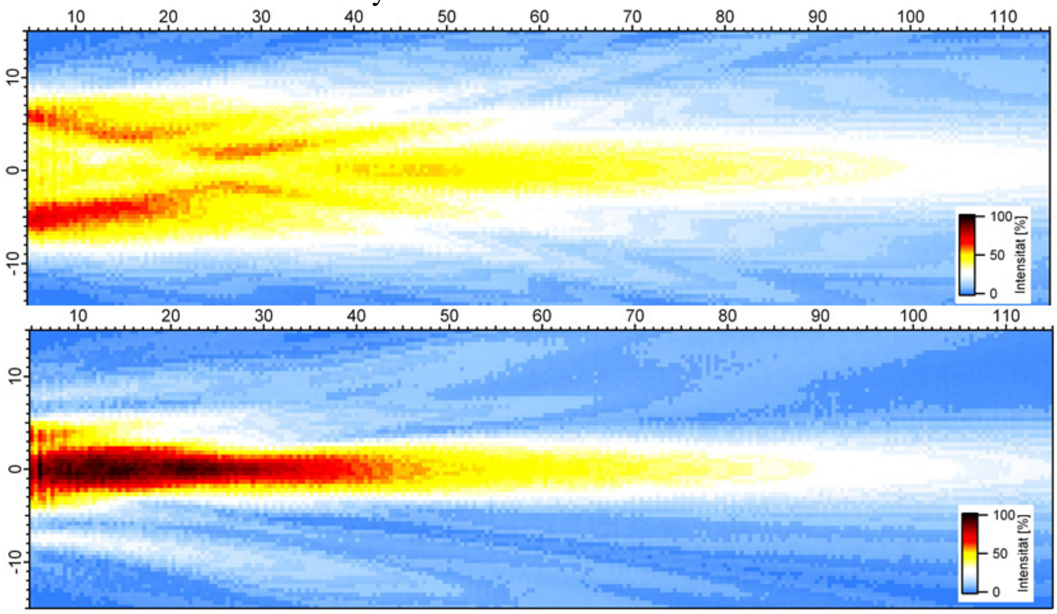

Figure 3, Active controlling of the acoustic properties of the transducers by Fresnel-arranged electrodes (3 channels). (x-axis distance to the surface of the transducer, y-axis distance to the acoustical axis)

2.3 Software

Core of the flexibility is the modular software. Although designed for non-contact ultrasound applications, almost any ultrasound experiment can be carried out. The system is completely open at all signal processing levels. This concerns real-time operations and the post-processing as well. Amongst the electronic improvements, the signal-to-noise-ration can be also influenced by the implementation of effective filters and algorithms. In this way, the system can be configured optimally costumized. Figure 4 and 5 illustrate the general structure and organisation of the layers. Various interfaces enable the communication with the hardware components or within the data chain. Since, the system has an open structure even other hardware could be integrated. Of course, the open interface enables also the link to high-performance data treatment such as MATLAB.

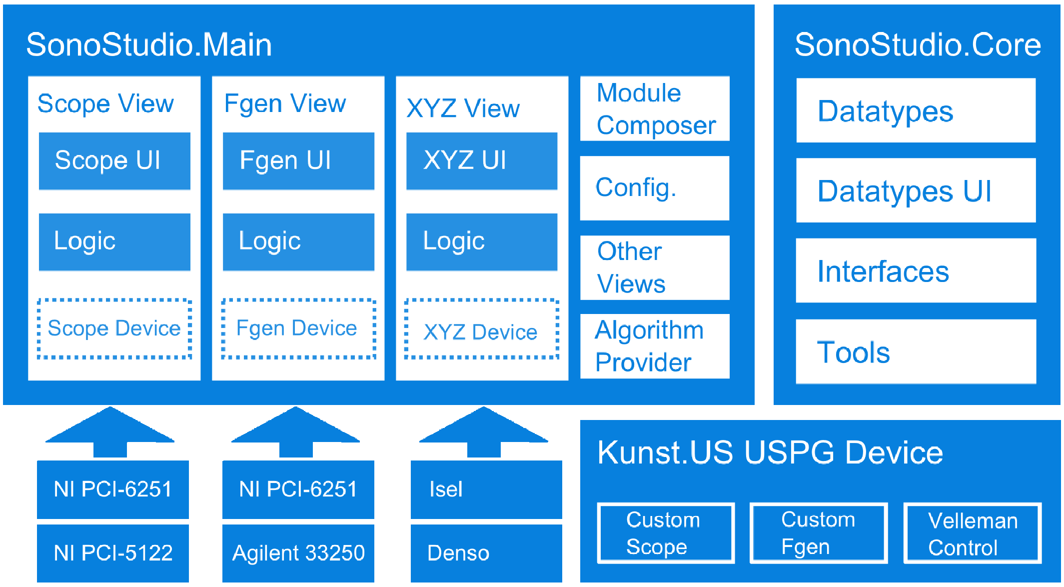

Figure 4, Principle structure of the software module and their link to hardware components. The concept is highly scalable and has no limitations with respect to the hardware performance (e.g. number of channels) or the amount of data.

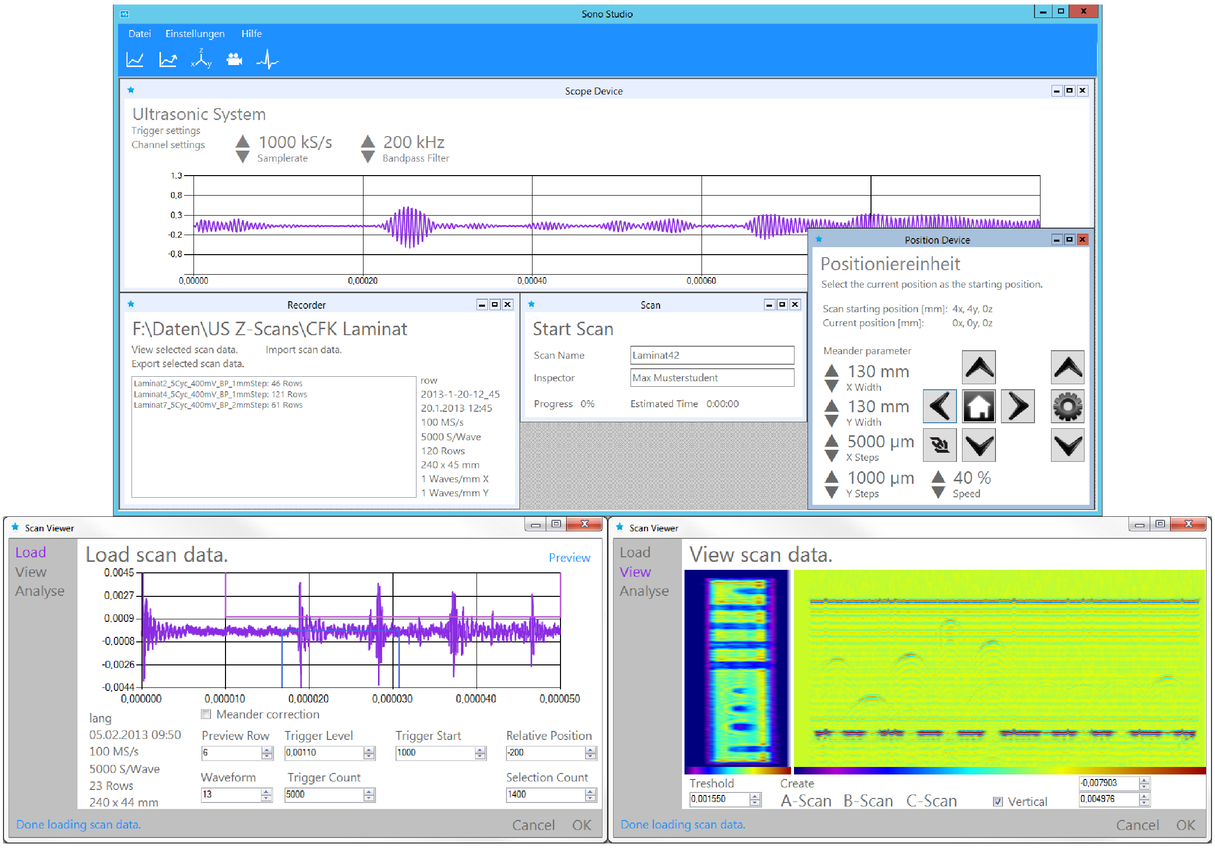

Figure 5, Impressions of the software modules (screenshots). The surface can be completely costumized. The software can also be used in control mode and script mode. Loading of the active modules is organized by an XML-structure).

The scanning systems (xyz-scan unit and the robotic system (figure 6).) are integrated as module in the software.

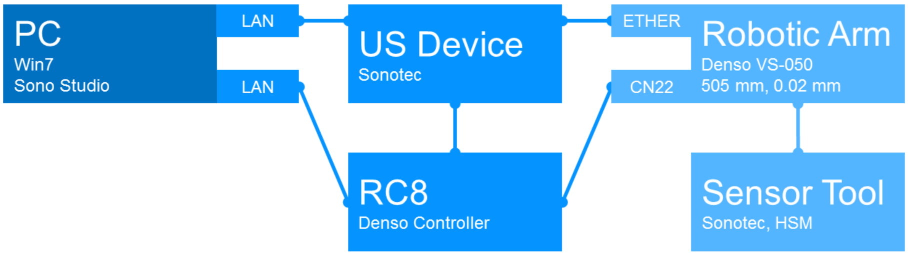

Figure 6, Schematic structure of the integration of the roboter system in the software. The system architecture will be designed to achieve high scanning speeds and to be able for the handling of complicate forms.

3. Results and Discussion

The potential of the new system will be demonstrated by means of several examples. As mentioned, the system is predominantly designed for the investigation of lightweight structure made of composites. However, it can be useful applied for the investigation of other classes of materials such as commodity plastics, plastic composites and so on. All kinds of internal delamination and internal interfaces can be detected. Therefore, some typical examples will be given in order to illustrate the power of the modular approach.

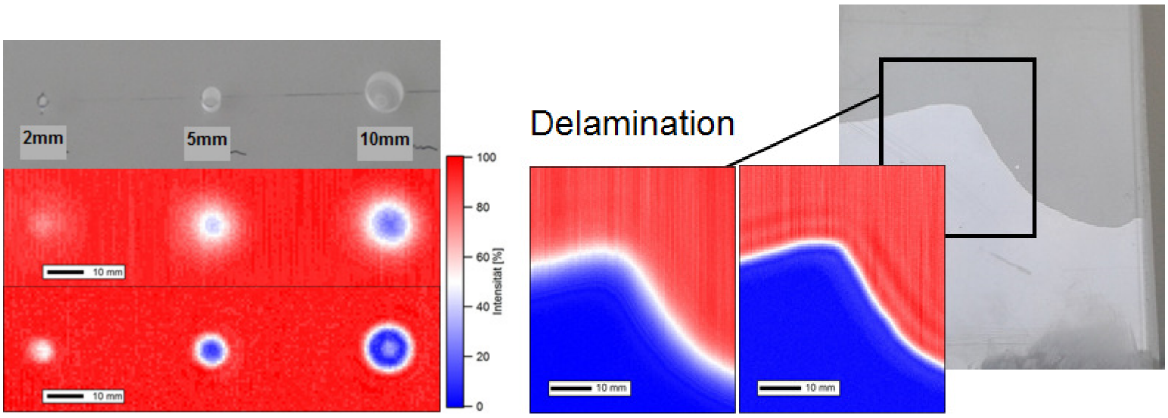

Figure 7, ultrasound transmission pattern of a reference block. The holes can be much better found and classified with the focused transducers. The examples demonstrates also the improvement for the detection of the boundary of the beginning delamination.

Amongst investigations of test specimen (Fig. 7), some typical applications with different requirements are given. The bandwidth covers the investigation of typical delamination and adhesive problems (figure 8) up to the demonstration, that the ultrasound wave of the system can pass even very thick parts in the transmission mode. This is illustrated in figure 9. The part of the GFC rotor blade is about 7 cm in thickness.

Thermoplastic composite parts are an interesting field of investigation for non-contact ultrasound for in-line and off-line quality assurance. The reason is obvious. Contact techniques using water are often not possible under production condition and even not "allowed" (e.g. for the water sensitive Polyamides). A continuously LASER-welded thermoplastic composite (PA-CFC) tube has been used in order to evaluate the processing quality by activating of delaminations by changing the LASER modus (on/off). Although measured in transmission, it was necessary – caused by the size of transducers - to modify the mode by a reflecting (45°) mirror arranged in the tube (figure 10).

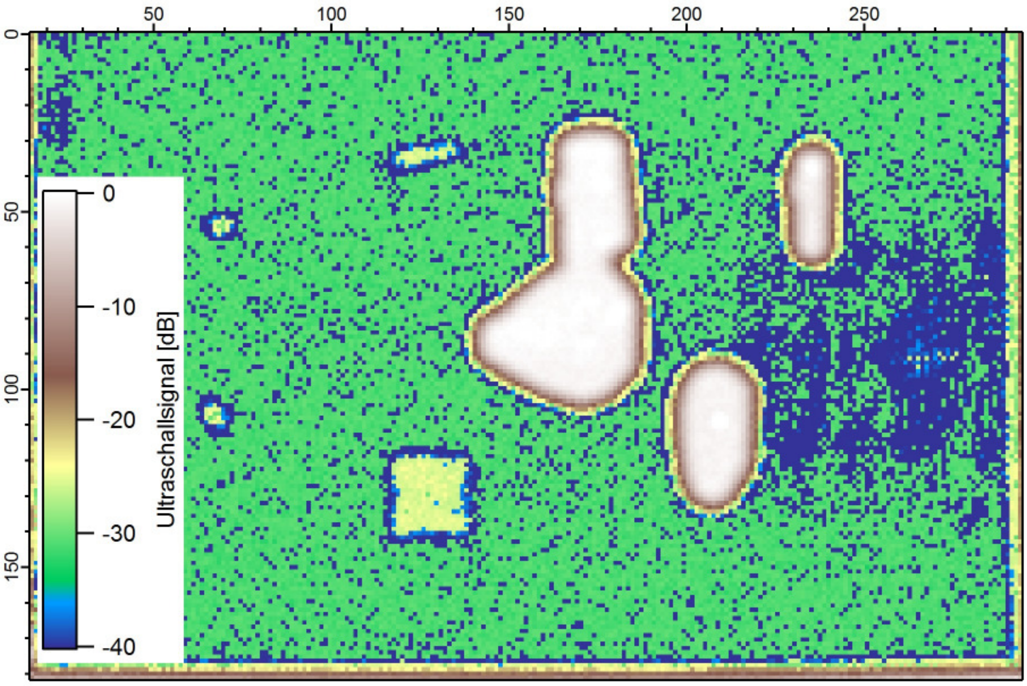

Figure 8, Adhesive bond between aluminium and carbon fibre reinforced composite.
The bright areas stand for non-contact areas. The square indicates a defined non-adhesive spot.

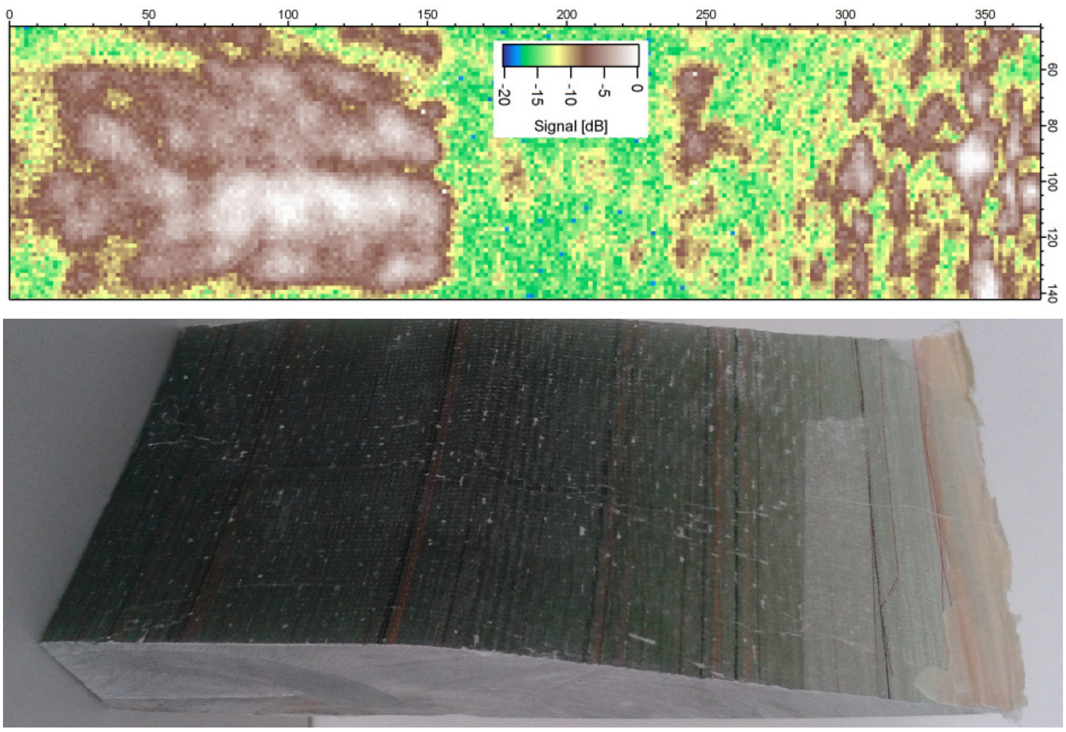

Figure 9, Air-coupled investigation of a part of a wind turbine blade. The photo demonstrates the thickness of several centimeters. The intensity plot of the transmission scan is affected by the reflection properties of non-parallel surfaces.

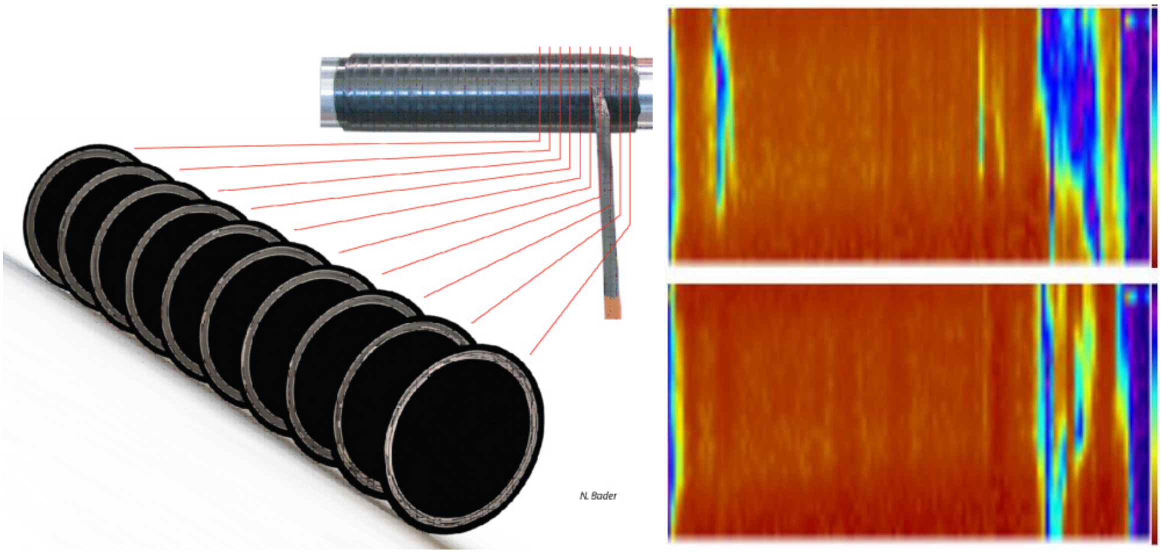

Figure 10 *Left:* Visualization of the defect fine structure measured by means of X-Ray tomography. The thermoplastic material has been supported by AFPT Dörth. *Right:* non-contact transmission ultrasound scan. The manipulation of the production quality (LASER on-off) is clearly visible (delaminations) . The transmission could be realized by a mirror technique inside the tube which has a diameter of 10 cm).

Work is in progress to include various scan techniques. The scan (xyz-table) unit for planar investigations and the implementation of robot system for "freeform" scan are most important. Despite of its obvious potential, this technique remains demanding due to geometric and dynamic issues.

3. Conclusions

It could be demonstrated, that the modular approach for non-contact ultrasound evaluation can be applied for a broad variety of investigation of composites and plastic materials. Improvements could be achieved by new transducers for low frequencies. A highly flexible modular electronic system has been developed which will be predominantly used for non-contact ultrasound in transmission and reflection mode as well. Further development will be directed to the industrial compatibility and integration of the method.

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