A new approach to air-coupled broadband measurement:
Effective testing of composite laminates by using a new multi-element transducer

Dr. rer. nat. Ralf Steinhausen¹, Dr. rer. nat. Mario Kiel¹, Andreas Bodí² and Tobias Gautzsch²

¹ Forschungszentrum Ultraschall Halle gGmbH, Germany, ralf.steinhausen@fz-u.de
² SONOTEC Ultraschallsensorik Halle GmbH, Germany, t.gautzsch@sonotec.de

Extended Abstract

Effective testing of composite laminates by using a new multi-element transducer

Due to the large variety of possible flaws (e.g. air inclusions, delamination, gluing errors, impurities and kissing bonds), the established ultrasonic testing (UT) methods for metal bonds are not applicable and new methods have to be applied for the inspection of composite laminates. Depending on the type of discontinuity the requirements on the inspection are very diverse. The differences in the lateral and axial dimensions of flaws in combination with changes of sound attenuation the signal strongly depends on the ultrasonic frequency. To avoid multiple measurements with different frequencies which are indeed very time consuming, it is necessary to measure as broad-banded as possible. In contrast to broadband transducers as used in classical UT in contact mode, air coupled UT requires a significantly smaller bandwidth to achieve the maximum signal output.

We describe an efficient method of such an inspection with significant improvements compared to conventional systems. It is based on a new multi-element air-coupled ultrasonic transducer. Each element is excited at a different frequency. The overlapping sound beams of the individual elements are allowing us to generate a broad-band signal which can be steered additionally inside the material as it is well-known from phased-array UT.

The new transducer increases the bandwidth considerably by an in-phase simultaneous activation of all elements. In order to operate such an ultrasonic transducer special transmitter-receiver electronics are necessary. As the individual transducer elements have to be activated simultaneously, the system must have at least as many channels as the ultrasonic transducer. Additionally, all channels with different frequencies have to be activated with a very high time accuracy relative to each other.

The evaluation takes place under consideration of the dispersive properties of the inspected test objects with respect to the interaction with ultrasound. Frequency-dependent properties like attenuation as well as geometry characteristics such as scattering behavior at interfaces cause a change in the measured ultrasonic signal. Accordingly, it is possible to achieve new contrast mechanisms. An increase of the effective bandwidth by combining a multi-element air-coupled ultrasonic transducer and a multi-channel measurement system will allow gaining more information of the sample within only one measurement cycle. This decreases the time needed for measurements at different frequencies significantly and eliminates any uncertainties during the alignment of transducers running at different frequencies.
Feasibility study

Before building up the multi-frequency probe, a feasibility study was made using a stock CF4003E probe with three separated elements for electronic focusing. It was possible to generate a broad-band signal by exciting each element with a different frequency. This creates a Fourier transformed signal as shown in Fig. 1. The three peaks in the spectrum were achieved by adjusting the frequency and the phase delay of each element in an appropriate way. In a first approach the aim was to superimpose the maximum signal of each element, creating a large signal with a short duration. The result is shown in Fig. 2. The three different applied frequencies lead to a beating in the ultrasonic signal which creates a rather complicated envelope of the signal. However, a well-defined maximum is observed.

These results additionally exhibit the high demands on the applied electronics. It is necessary to adjust each element by its frequency, voltage and phase-delay with a high accuracy. Small miss adjustments or temporal jittering will extinguish the broad-band signal completely, rendering a measurement in scanning mode impossible. Assuming frequency-dependent properties of the specimen this signal can be used to gain more information after post processing of the data.

Fig. 2 shows that we had to utilize long exciting bursts to force the frequencies upon the CF4003E. Two of the three elements were working outside of their normal operation range which reduces the signal intensity significantly. This led us to the construction of the three element multi-frequency transducers that we will present. These probes have three different elements that are engineered to work best in the specified frequency range needed to build the broad-band signal. Thus, the number of excitation pulses in the burst can be reduced leading to a shorter temporal pulse. This further improves the testing results.
Figure 2: Broad-band signal of the CF4003E with a frequency range between 380 kHz and 420 kHz

In the presentation we will showcase the capabilities of the new probes and demonstrate the possibilities of broad-band air coupled ultrasound inspection. We will present the achieved bandwidth of the prototype probes and discuss the results of the first lab tests including sound pressure level, beam spread and attainable focal distance. In addition, we will analyze the effect of broad-banded probes exemplary on different air-coupled ultrasonic applications in transmission as well as pitch-catch setup.