Modular Air-Coupled Ultrasonic Multichannel System for Inline NDT

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Abstract

In many production processes it is important to detect in a very early stage basic errors in the fabricated material. If the errors are not visible from the exterior, ultrasonic inspection is a convenient technique, at least if the nature of the error influences the characteristics of sound passing through the material. Examples are local density variations in non-wovens, delaminations in composites, bad bondings in laminates, inclusions, cracks or other artefacts in plastic or metal plates, etc. There are two major, difficult requirements imposed by industry to the used detection technique: the sensors shouldn't make physical contact with the material and the speed of testing must be sufficiently high to enable testing in-line. The former requirement can be met by employing an air-coupled ultrasonic approach, the latter by using a multichannel system. We propose a modular air-coupled ultrasonic multichannel system.

Each multichannel module contains 12 air-coupled transducers and exists in a transmitter and a receiver version. The desired scan width is obtained by connecting several modules to each other. During the scanning all transducers are spatially fixed while the material is moving forward. This way, speeds up to 1m/s are possible, irrespective of the width of the material. To that purpose a FPGA based platform with parallel processing of large numbers of data streams is implemented in the modules. This allows the implementation of all kind of procedures, going from point measurements to more sophisticated techniques.

In spite of all measurements being performed in ambient air, the ultrasonic frequency is rather high (1 MHz), but lower frequencies are possible as well. The most obvious set-up of the modules is a through-transmission configuration. However the system can also be used in a pitch-catch configuration which is very suitable for one-sided testing of thick materials. An examples established in the laboratory is shown to illustrate the performance.

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1. Introduction

Since 2000 air-coupled ultrasound (ACU) has proven to be an attractive material testing and characterization tool [1]. Especially under controlled laboratory conditions, ACU has provided useful and reliable methods for convenient material examination. Air-coupled ultrasonic C-scans can be applied to detect erroneous areas in a variety of materials at ultrasonic frequencies up to 2 MHz or even higher, in spite of the strong acoustic impedance mismatch between air and any solid and the rapidly rising acoustic attenuation beyond 1 MHz [1,2].

However such C-scans require a high recording time. Therefore, in general they are only useful for laboratory purposes or for any off-line examination. Industry likes to perform the assessment during production or manufacturing, and that requires speed. In case full material covering is required, a single transducer or transducer pair mostly cannot do the job and a multichannel system is needed.

Many requirements can be imposed to such a system, the major one, of course, being speed. A scanning speed meeting the speed of production is the main requirement and the motivation to develop a multichannel system.

A second important requirement is an easily adaptable scanning width. Producers of many basic materials such as metal, plastic or composite plates, wood panels or veneer, chip or fibre board, woven or non-woven textiles, etc. are faced with the problem of assessing materials with different width. Therefore an error detection system should be easily adaptable to the width of the material to be evaluated.

Next, the scanning system should cover 100% or close to 100% of the whole surface and it should be appropriate to test both acoustically soft and hard materials. Also the system needs to be flexible, in this respect that the electronic hardware must be independent of the configuration (through-transmission or pitch-catch mode for instance) and frequency.

Another important requirement is the ease of use, among which the availability of an autocalibration procedure. All channels should have the same sensitivity. This is one of the most difficult requirements to achieve, because transducer elements seldom have exactly the same characteristics, even if they originate from the same fabrication batch. Slight differences in physical properties may result in small shifts of the centre frequency or bandwidth and this may result in different sensitivity. In a reliable multichannel system, however, all channels should deliver the same signal level after transmission through a homogeneous error-free material.

![Multichannel configuration with N transmitter and receiver modules.](image-url)
Finally, nothing has an infinite life-time. Therefore especially the ultrasonic elements should be easily replaceable.

2. Technical concept

In order to meet most of the requirements, we propose a modular system with transmitter and receiver modules. The total desired scan width can be obtained by connecting several modules to each other which all communicate with a PC user interface by (a gigabit) Ethernet (Fig. 1).

Each transmitter and receiver module contains 12 transducer elements, a built in FPGA for DAQ and signal (or data) processing, a communication interface and a synchronization link in order to enable synchronization between the modules. The modules can be positioned in any configuration (e.g. through-transmission or pitch-catch).

Regarding the electronic hardware, the transmitter and receiver modules do not have the same architecture but they are partially different. Further, all data processing is done on-board (see more details elsewhere) [3,4].

An already built prototype module contains 12 square 1 cm² transducer elements with a total width of 12.6 cm (Fig. 2). The 12 transducer elements are separated by half a mm. The centre frequency is 1 MHz with a small bandwidth of 40 kHz. As matching layer to facilitate the coupling with air, we have chosen for a hydrophilic polyethersulfone layer (132 μm). If no material is inserted between transmitter and receiver module, the voltage loss at 4 cm distance is 32 dB which in the case of 1 MHz is quite acceptable.

The waveform which is preprogrammed in each module is a continuously repeated chirp with a centre frequency of 1 MHz, a bandwidth of 100 kHz and a duration of 0.41 ms. Chirps of 2 neighbouring channels are shifted in time 7/12 of the chirp duration. Cross-correlation is made for each channel between the received signal (if necessary after averaging) and the transmitted signal. Thanks to the time shift between the channels, one can distinguish contributions from neighbouring transmitting channels by selecting the appropriate time windows of the cross-correlation. Finally the desired parameter is determined from the cross-correlated signal (e.g. the peak value).

The concept makes it possible to connect two or more modules to each other, for instance to establish a system with the same width of the material to be tested or a 2D-system to make snapshots of selected areas.

Fig. 3 shows a result obtained by the prototype system consisting of two modules (24 channels) operating at 1 MHz. The upper picture represents a partially coated textile. On the upper half there is no coating, on the lower
part, the coating on the left is more penetrating the textile than on the right side, and in the middle there is a strip without coating. It takes only a few seconds to perform the scan and to distinguish the different areas on the user interface.

3. Use as a phased array

The proposed modular system has been designed as a multitransducer system and not as a phased array. For instance at 1 MHz (see Fig. 2), the sound fields of the 12 transmitting elements of 1 cm hardly interfere with each other, which is a necessary condition to steer or focus the total sound field. On the other hand, if the frequency or the width of the transducer elements is decreased (which is possible within the same architecture of the modules), both steering and focusing is possible.

Fig. 4 shows an example based on numerical simulations. At a frequency of 20 kHz and 12 elements of 1 cm, it is theoretically possible to focus the sound in any particular point. However when the frequency is raised to 50 kHz, the effect is very poor due to the appearance of disturbing side lobes. But replacing the 12 transducer elements of 1 cm by 24 elements of 0.5 cm, the focusing effect is restored.

![Fig. 4. Simulation of the focusing effect at low sound frequencies (a) f = 20 kHz, 12 elements of 1 cm; (b) f = 50 kHz, 12 elements of 1 cm; (c) f = 50 kHz, 24 elements of 0.5 cm.](image-url)

4. References