IMAGING OF DEFECTS IN CONCRETE COMPONENTS WITH NON-CONTACT ULTRASONIC TESTING

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Abstract: The building industries require NDT- methods for the quality control and damage detection. The high specific inhomogeneity of concrete causes scattering and large sound attenuation so that the pulse parameters have to be optimised very carefully. In dependence of the size of the aggregates frequencies in the range of 50 to about 150 kHz can penetrate concrete components. Using immersion technique most of pores and internal holes will be filled with water so that their indication is very difficult. Therefore the coupling usually is carried out with pastes or even with honey. The point to point inspection and the cleaning of the component is very time consuming.

New developments open the possibility of non-contact ultrasonic testing with air- coupling without increasing the air pressure. The new technique is very easy to handle and delivers images of the interior of concrete components in a few minutes.

This paper reports on the new developments for such a system: high effective and broadband transducers, matched ultra low noise amplifiers, freely programmable high power pulser and an imaging software for A-, B-, C- and D- scans including full-wave scans and shows on the other hand typical results of applications on concrete components e. g. with a crack plane, a gravel nest and bore holes.

Introduction: Ultrasonic testing for the quality control of metallic materials and high-tech materials as well as for medical diagnoses is one of the most successfully and most frequently applied NDT-methods. A comparable successful application of the ultrasonic testing for mineral building materials has not been so far carried out. Ultrasonic testing can be successfully applied on construction sites and on finished building for damage assessment and for the quality control of the production [1-4]. In spite of the possibility of the application of the echo-technique the ultrasonic technique is seldom used for concrete. One reason is the high specific inhomogeneity which causes a considerable sound attenuation which means that extremely low test frequencies in a range of 50 to 150 kHz have to be used. Another one is the coupling which has to be carried out with paste or water. However, the roughness of the surface makes a reproducible coupling very difficult.

In spite of all, it was shown that the ultrasonic imaging technique, especially the B-scan technique, provides a non-destructive view into cross section direction of concrete components. The recording of C-scans of concrete components is very time consuming. Using immersion technique for the inspection of prefabricates does not make sense because the penetration of water fills up all cracks and holes so that their detection is very difficult or even impossible. Up to now an inspection with air-coupling was not possible. The airborne ultrasonic testing avoids all these disadvantages. But the large acoustical mismatch between gas (air) and solids produces an amplitude loss larger than 160 dB [5]. Therefore, special transducers and a special ultrasonic system are required.

Results: *Ultrasonic imaging system*

An ultrasonic imaging system has been developed for air-coupled ultrasonic testing. The new system USPC 4000 AirTech shown in Fig. 1 consists of a scanner with controller (area from 300 x 400 mm to 1500 x 1000 mm and larger), the two transducers with fixtures (one as a transmitter, the other one as a receiver), a matching box for the transmitter, an ultra-low noise preamplifier, a pulser unit and the components built in an industrial PC with Windows^{TM} operating system. The main amplifier and the programmable pulser unit are situated on PC-boards. The programmable pulser provides a power of up to 1.2 kW. This board does not only produce quartz-controlled

burst pulses (from n = 1 to 15 in the frequency range from 20 kHz to 1 MHz), but also free programmable pulses generated by a digital arbitrary generator. Therefore, chirp and coded signals can be used in order to increase the signal to noise ratio.
The receiver of the USPC 4000 AirTech consists of an ultra low noise preamplifier (matched to the receiver transducer), a main amplifier with digital gain control and frequency filters and a 12 bit analogue to digital converter board (ADC).

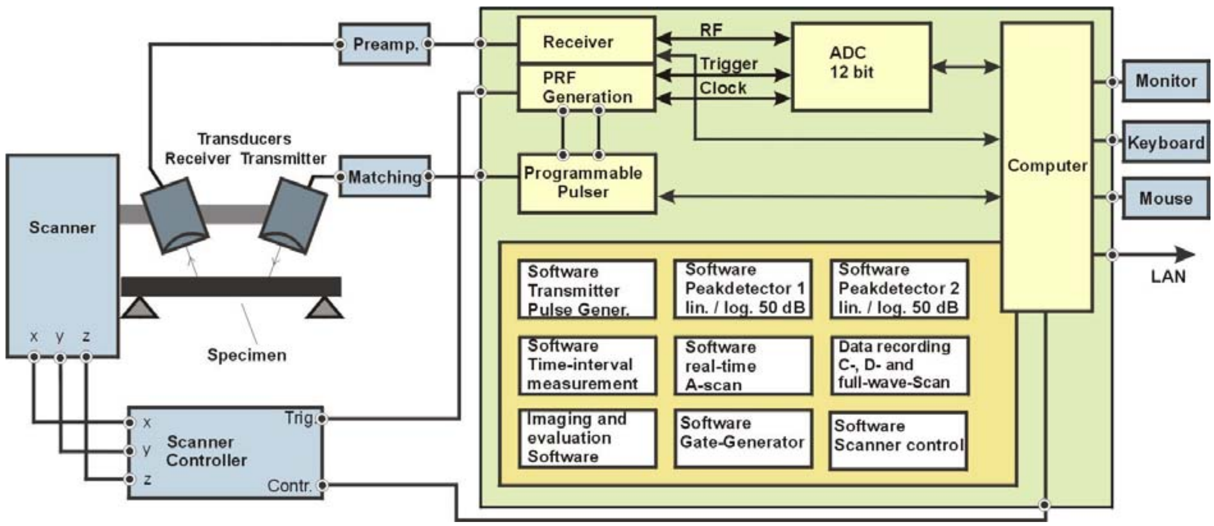


Fig. 1: Block diagram of the new imaging system USPC 4000 AirTech

Transducers: Two pairs of prototypes of GMP^{TM} (glass matrix piezoelectric component)-transducers have been evaluated. GMP^{TM} descries a new piezoelectric transducer material characterised by the highest possible thickness mode coupling coefficients (K_{33}) of the solid piezoelectric material [6]. Among others the most important parameter of transducers for air-coupling is the sensitivity given by :

$s = 20 \log V_R/V_T$ (V_T = Excitation in Volts, V_R = Receiver signal amplitude in Volts), (1)

which has been measured in through-transmission-technique with air-coupling and without a specimen. Using an excitation voltage of 190 V_{ss} with a tone-burst signal, the receiver transducer generates a voltage of 4.2 V! Equation (1) delivers in this case -33 dB, which is about 6 dB (100 %) higher than those of the best standard air-coupled transducers.
Tab. 1 resumes all important data. The broadband transducer provides a relative bandwidth of 26.9 %.
Notable is also that this transducer reaches its maximum amplitude with an excitation of only 3 burst pulses, a larger number of bursts only increases the pulse width! Standard transducers require between 9 and 15 cycles. These kind of transducers are suitable for the inspection of materials with high sound attenuation. The large bandwidth does not only provide more precise amplitude measurements, but also the evaluation of the frequency spectrum. Therefore, the materials can also be characterised by changes in the frequency range. Another important advantage for fast imaging is a higher pulse repetition frequency (PRF).
Before recording C-scans of concrete specimens the sound field has been recorded in echo-technique using a ball reflector. For a clear C-scan the distances between the transducers and the specimen have to be chosen in this way that no side lobes of the transducers “touch” the surface.

Type	GM 201.4
Active diameter	60,6 x 55 mm
Maximum frequency	135 kHz
Frequency range	116-152 kHz
Bandwidth	36 kHz
Relative bandwidth	26,9 %
Impedance	247 Ohms
Optimal excitation	T= 4,9 µs, n=3
Sensitivity	- 33 dB
Beam diameter	20 mm

Tab.1: Technical data of the transducer GM 201.4

Concrete inspections

Fig. 2 presents the inspection of concrete with air-coupling in through-transmission technique. The specimen with an artificially inserted gravel nest is situated on the desk. The dimensions of the specimen are 20 x 20 x 50 cm. The U-shaped fixture for the two transducers is mounted on a scanning system. The two transducers have to be aligned carefully. Small variations of the normal incidence can cause other wave-modes in the material. The scanner is only for a demonstrator, other scanners with larger scanning areas can also be used. This arrangement provides a maximum PRF of 70 Hz due to the distances in air of 15 cm between the transducers and the specimen. The monitor in the background of Fig. 2 shows a recorded C-scan.

The pulse response and the frequency spectrum of a signal received from a the concrete specimen with a gravel nest is shown in Fig. 3. In comparison with the parameters in Tab. 1 measured without specimen the pulse parameters have been changed due to the attenuation: the peak frequency from 135 to 127 kHz and the bandwidth from 36 to 32 kHz.

Fig. 4 shows a through-transmission C-scan of a concrete specimen (20 x 20 x 50 cm) with a plane crack in a distance of 9.7 cm from the surface recorded with air-coupling. The scanning grid of 2.5 to 2.5 mm and the scanning speed of 100 mm/s delivers a PRF of 40 Hz, so that the whole C-scan was recorded in a few minutes and without any coupling problems. The indication in the C-scan does not only show the crack plane, but also other (natural) defects.

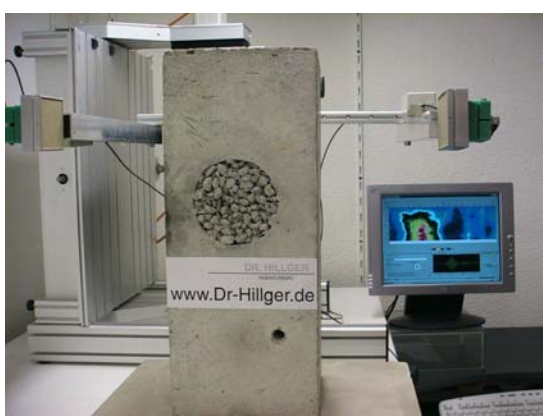
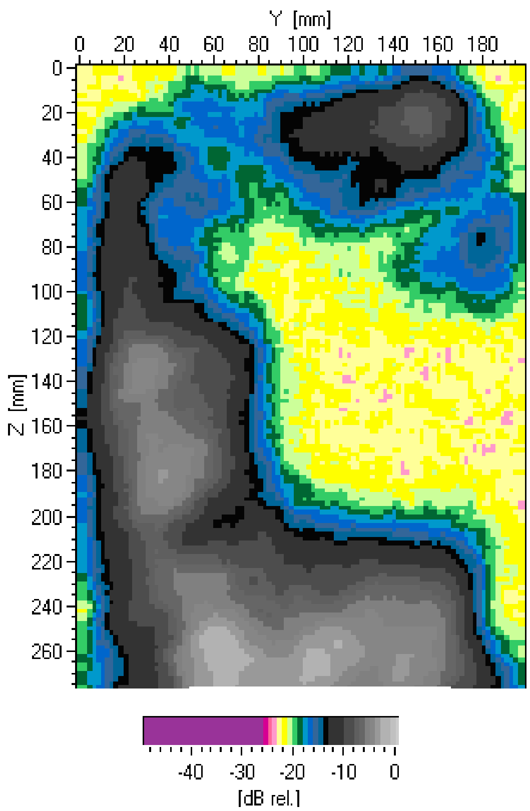
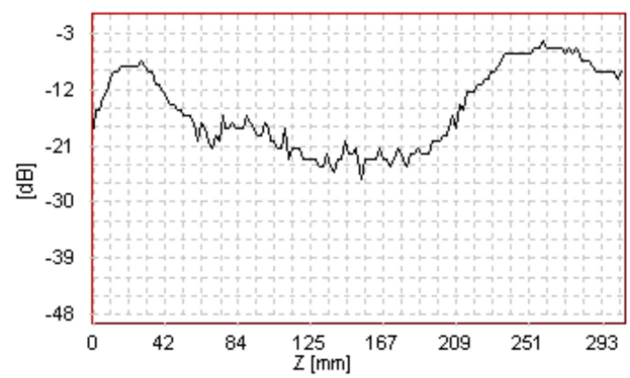


Fig. 2: Non-contact (air-coupled) ultrasonic inspection of a concrete specimen with a gravel nest and a bore hole

The colour palette was chosen so that the amplitude changes caused by the natural inhomogeneity are plotted in grey-levels and relevant defects are plotted in colours. The test frequency in the band of 127 kHz enables a longitudinal wave length of something like 3.2 cm in the material. The crack plane causes an amplitude decrease of about 18 dB (yellow region), shown in the echo-dynamic curve (Fig. 3).

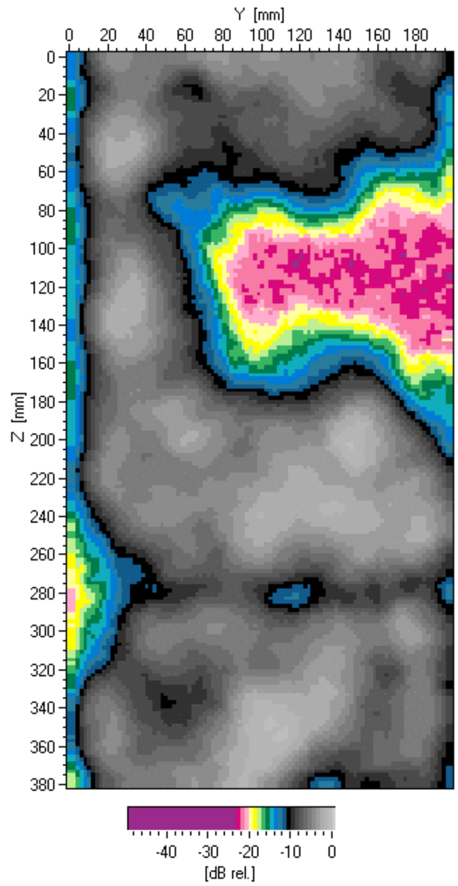




Y = 254 mm

Fig. 4: C- Scan and echo dynamic (vertical) of specimen PK16 with artificial crack

The artificially inserted gravel nest with a diameter of 10 cm of specimen 2 (20 x 20 x 50 cm) is also clearly mapped in the C-scan (Fig. 5) because of an amplitude decrease of 18 dB. Even a bore hole of a diameter of 16 mm can be displayed with a change in amplitude of 9 dB. But the “natural” inhomogeneity also produces amplitude changes in the same dimension so that this size of a defect is the limit of the resolution.



Y= 100 mm

Fig. 5: C-Scan and echo dynamic (vertical) of specimen with gravel nest and 16mm bore hole

Discussion: New developments for airborne ultrasonic techniques such as GMP™ transducers and a new imaging system USPC 4000 AirTech open the possibility of a very easy inspection of concrete components in through-transmission technique. The new ultrasonic system USPC 4000 AirTech is of modular design and enables high PFR (1000 Hz) for high speed imaging. Due to the high sensitivity and high bandwidth of the new GMP™-transducers a non-contact imaging technique for concrete and other materials with high sound attenuation is possible now. In spite of the large acoustical mismatch between air and solids the C-scans recorded in single-shot technique with a scanning speed of 100 mm/s clearly show the artificially inserted defects like a plane crack and a gravel nest. The inspections have been carried out with an excitation of 4 bursts and an image enhancement using a median filter.

Conclusions: The airborne inspection of concrete components like stilts, pillars and columns can be carried out without any problems. Further investigations will show the possibility of monitoring the hardening process with non-contact ultrasonic testing. The automatic evaluation of the frequency spectrum will give further details about the status of components and buildings.
Possible options are chirp- and codes signals which provide an increase of the signal to noise ratio up to 8 dB [7]. However, the longer pulse lengths decrease the PRF. Therefore, special transmitter excitations should only be used for the inspection of components thicker than 1 m.
A testing from one side is possible in pitch and catch technique. This method is being used in application for natural stone plates.

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