Study of Passed Array Techniques for Concrete Inspection

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Abstract : From a safety standpoint the concrete containment of the nuclear power plant is one of the most essential components because it serves at the final barrier to the release of fission products. The safety authority supervises the study and development of a phased array equipment and technique for ultrasonic (US) testing of concrete structures. The aim is to detect and characterize the presence of cracks which can be responsible for loss of structural capacity and leak tight integrity of the containment. Typical frequency range used for ultrasonic testing of concrete is between 50 and 300kHz which provide a wide and non directive ultrasonic beam and yields to poor signal to noise ratios.
One objective is to use the focusing and steering of the ultrasonic beam in order to reconstruct trough imaging tools the whole profile of a detected defect. First reconstructions resulting from phased array acquisitions on an artificial crack embedded in a concrete block are presented. The study for the development of simulation tools dedicated to US concrete inspection is also briefly described and preliminary results are shown.

1. Introduction

Wall containments in Pressurized Water Reactor are extremely important because they must retain radioactive materials if an accident should occur. These walls are thick (1.2 m or 0.9m) pre-stressed and reinforced concrete structures containing pretensionned cables. The containment is cylindrical with a hemispherical dome. For the safety authority (IRSN) it is essential to maintain the integrity of the wall containment of nuclear power plant.
The concrete containment building of nuclear power plant structures are susceptible to ageing by various processes depending on the operating environment and service conditions. In order to ensure the structural capacity and leak tightness of the concrete structure it is necessary to detect cracking phenomena which is one of the primary sign of ageing. Potential degradations of the concrete material can affect the ability of Nuclear Power Plant containment to perform satisfactorily its functions. The degradation of concrete can be the result of various attacks [1]. Physical attack mechanisms include freeze/thaw cycling, thermal expansion, thermal cycling abrasion. Chemical attacks may also occur in several forms : efflorescence, attack by sulphate and by acids, salt crystallization and alkali-aggregates reaction.
Such mechanisms and fatigue effects can be responsible for surfaces and bulk flaws such as cracks, porosity and laminations.
The aim of our work, supported by IRSN, is to detect and characterize the crack inside the concrete wall, in order to check the defect growth between two inspections. Ultrasonics were identified as having a great potential to inspect such thick concrete structures [2].
Compared to inspection of steel components the difficulty of ultrasonic control in concrete comes from the heterogeneous structure. Concrete is a composite material constituted of a

binding cement medium with embedded particles from sand to gravel with size up to 20-25 mm. The propagation of a wave in such media generates heavy scattering and attenuation of the sound energy that provide a resultant poor signal to noise ratio (SNR) of the reflected signal amplitudes.
For that reason typical frequency range used for ultrasonic control in concrete is quite low between 50 and 250 kHz. In order to increase the SNR we propose to apply phased array technique.
The studied mock up includes a known artificial crack composed of different orientated facets localized at different depth. Modelization tools which are developed to simulate the ultrasonic propagation in heterogeneous media such as concrete are presented with preliminary results.

2. Mock-up

The formulation of concrete used for that study is well representative to the one used in wall containment with a maximum size of aggregates of 25 mm. The measurements are carried out on a concrete block of 800x800x600 mm^3.
The artificial crack is composed of four facets with different orientations included in concrete. Each facet noted Pi on Fig. 1 has a surface of 40x70mm² and is considered as a reflector for sound wave. These facets are supposed to represent the surface extension of crack, they are located between 200 mm and 500 mm below the surface of inspection and tilted between 10 and 20°. We assume that crack with an aperture up to100 µm acts as a perfect reflector for ultrasonic waves propagating in concrete.

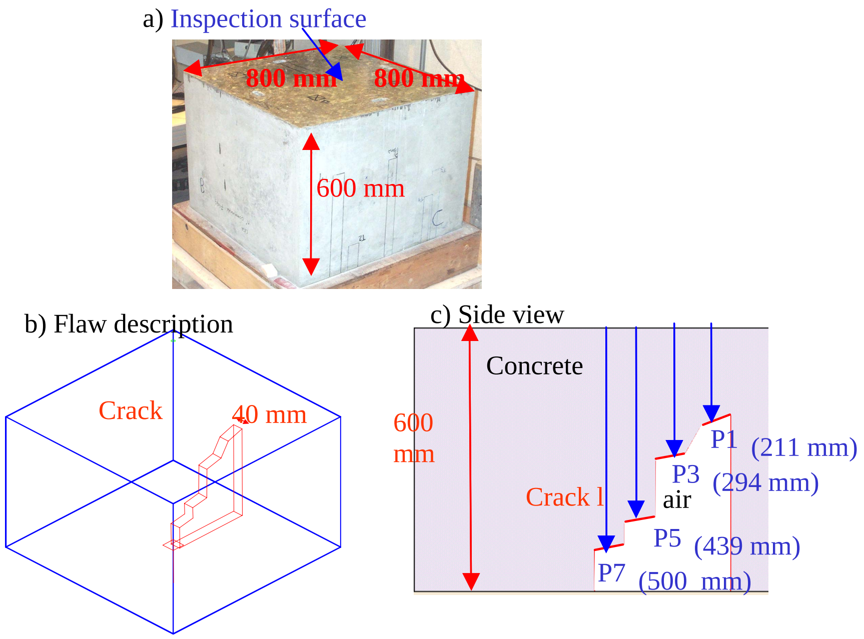

Fig. 1: a) Sample of concrete b) 3D view of that sample c) Crack with the different facets “Pi” to be detected

3. Ultrasonic equipment tested

The pulse echo technique is commonly used to detect and characterize cracks in steel components. Such ultrasonic inspection is based on the analysis of the backscattered signal from the inside of the concrete which is collected during the acquisition.

As we try to detect with an increased spatial resolution small reflectors in a medium with aggregates of 20 mm, we use broadband transducers (34 mm diameter) operating at 250 kHz. In order to improve the signal to noise we use an array of probes in order to apply phased array methods and signal reconstruction. Transducers are mechanically displaced in order to scan the surface of the concrete.
A multi channel system is used which allows to drive the transducers, to adjust their relative parameters as delay and amplitude laws. The signal of excitation is 250 V square pulse. The coupling is a film of water and the probes are spring loaded in order to compensate the variations at the surface of the block due to possible roughness.

3. Study of *phased array technique*

Phased array technique has been applied to experimental data resulting from control of the artificial crack. The principle of the technique [3] is briefly presented and results are discussed.

3.1 Principle of phased array techniques

In order to apply phased array technique to concrete we use a specific arrangement of 8 transducers. The electronic focusing produced by the large aperture of the array (~200*80mm²) will improve sensitivity and signal to noise ratio. The focusing of the ultrasonic beam is performed by applying delay laws on transducers either at transmission and reception. This enhances and concentrates the energy at a selected depth which increases the resolution and signal to noise ratio. Preliminary measurements in transmission [2] have successively shown the ability of focusing an ultrasonic beam in a concrete structure. Compared to multi probes reconstruction inspired from SAFT processing [4] we have shown that phased array technique takes advantage of transmitting higher energy on a much more concentrated region.

3.2 Comparison of phased array to mono element acquisition

We present a reconstructed Bscan image on Fig. 2 resulting an angular scanning of the US beam focused at each facets depth. The reconstructed Bscan image is compared to a Bscan measured with one transducer.
The profile of the crack is plotted in dotted line on the Bscan in order to compare relative positions of the different facets and detected echoes+.
The detection of tilted reflectors is improved by adjusting the orientation of the nominal ultrasonic beam perpendicularly to the flaw surface. So the angular scanning is performed between 4 and 21° by using different delay laws to transducers. Then the post acquisition treatment consists in summing constructively each Bscan image corresponding to one angle of inspection to each others in order to enhance the flaw echo and to reduce the structural noise. Such technique takes advantage of phase array technique since the transmitted energy is optimized at a given depth and of reconstruction that improves SNR by averaging the structural noise over the whole aperture of the transducer.
The principle of this technique could be adapted to a blind inspection since the application of a sweeping angles of inspection enhance the ability to detect an unknown tilted defect.

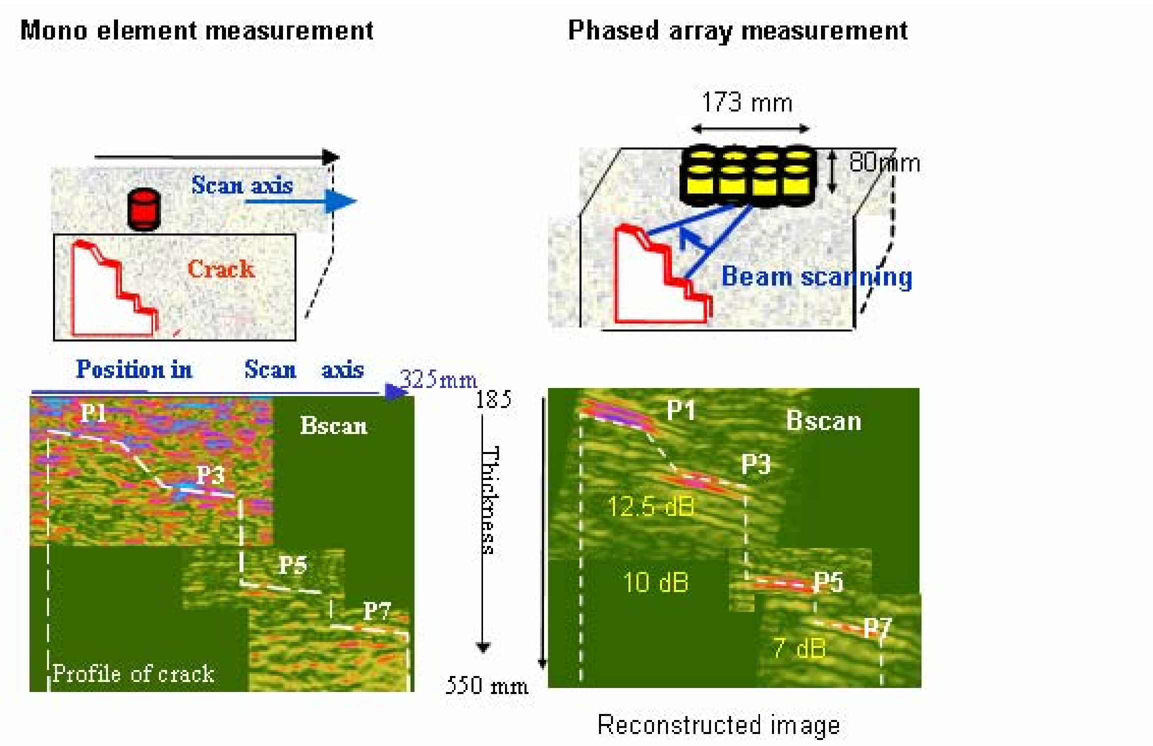

Fig. 2: Comparisons between mono-element measurement of the crack and the reconstructed Bscans images resulting from phased array measurements

The applied technique has reduced importantly the structural noise compared to the mono-element case and there is a good match in time and position of the theoretical profile of the crack with the detected echoes coming from the different reflectors. The steering of the ultrasonic beam adapted to each tilted facets optimizes the direction of the reflected energy toward the receivers. This improves the detection of the crack compared to a control without deflecting the ultrasonic beam as shown in reference [2].

4. Development of simulation tools for heterogeneous media

Sensitivity of UT methods in heterogeneous media such as concrete depends on attenuation and noise, due to scattering by aggregates. Modeling tools for UT simulation are developed at CEA assuming generally a perfect elastic media. However in the case of noisy materials, performances are affected by noise and attenuation phenomena. It's very important to take them into account for predicting accurate sensitivity values of a given method. The paper shows how simulations tools have been modified in CIVA software by introducing simplified models of attenuation and noise.

4.1 Simulation of ultrasonic attenuation

In order to predict the attenuation phenomena in concrete we apply the Waterman &Truell homogeneous model which takes into account multiple scattering. The principle consists in defining an homogeneous medium equivalent from acoustical properties to that of concrete. For applying this model, we describe concrete as a distribution of aggregates embedded in a matrix of mortar. The granulates are assumed to be hard spherical scatterers with a defined distribution of size and nature (entering particular density).

The model uses the equivalent homogeneous media to calculate the attenuation law versus frequency. Fig. 4 shows the attenuation law calulated for a distribution of aggregates representative to those present in concrete of wall containment.

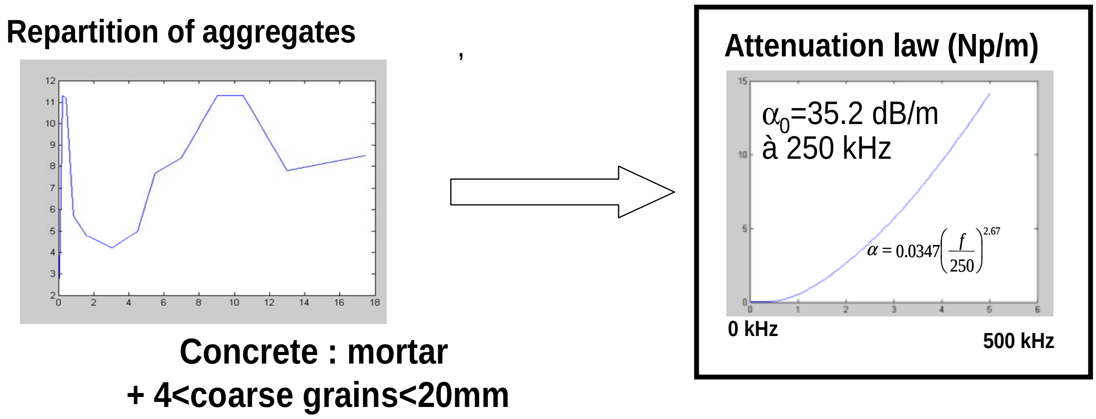

Fig. 3: Calculation of attenuation law from homogenization model

4.2 Prediction of backscattered noise

A simplified model is developped to predict the noise level for a given composition of concrete.
The inspected concrete component is supposed to include a set of randomly distributed scatterers associated to a specific reflectivity. The reflectivity of each scatterer is calculated taking into account the entered distribution of granulates. Then the simplified approach used, consists in considering the noise in the time domain and for each scanning position as the superimposition of echoes arising from back-scatterers in the medium**.**

4.3 Examples of application

The attenuation and backscattered noise models have been implemented in CIVA in order to simulate the control of bulk flaws in concrete.

Detection of a flat bottom hole

We compare on Fig. 5 the result of a measurement performed with a single transducer on a flat bottom hole located at 200mm deep in concrete to the simulation taking into account attenuation and noise.

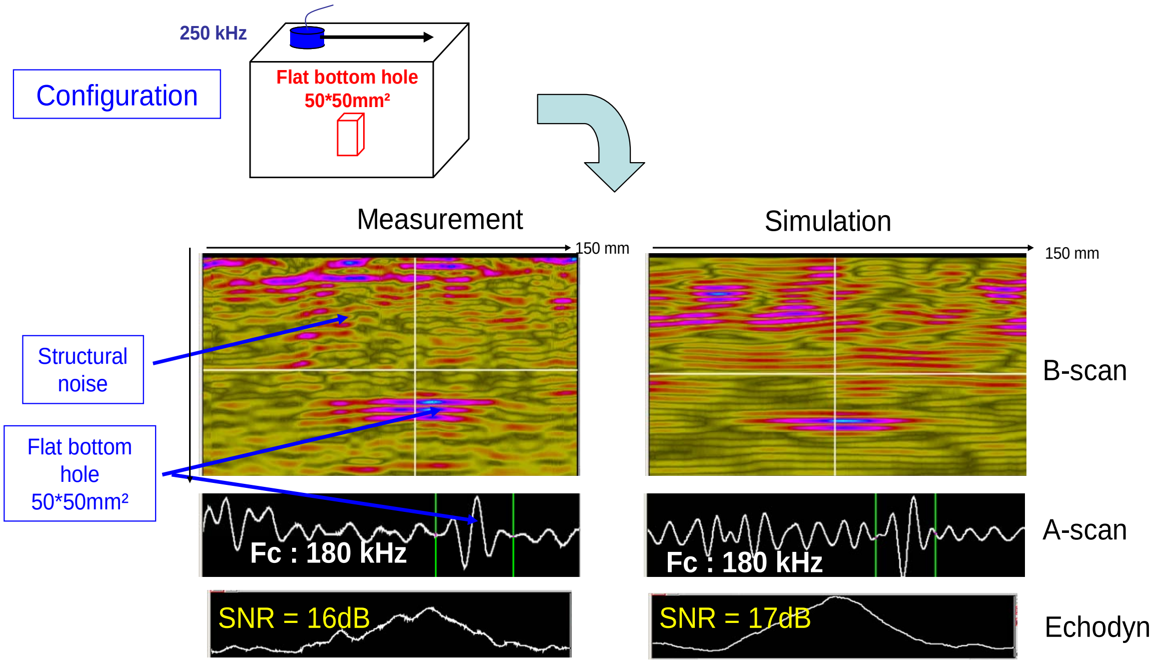

Fig. 4: Comparison of simulation to measurement for detection of a flat bottom hole by a mono element

The simulation predicts the expected shift of the nominal frequency of signals towards 180 kHZ, which is due to attenuation. The signal to noise ratio measured from echodynamic curve at the depth of the defect shows also good agreement, with an experimental SNR of 16 dB compared to a simulated value of 17 dB. This validates the noise model and the randomly reflectivity of scatterers calculated by the noise model.

Detection of the multi facets defect

In order to validate the model, we study the measurement performed with a different aperture and US beam angle of incidence.
Fig.6 shows the detection of the P3 facet using phased array method, focusing US beam at 293 mm deep along L-15° incident waves.

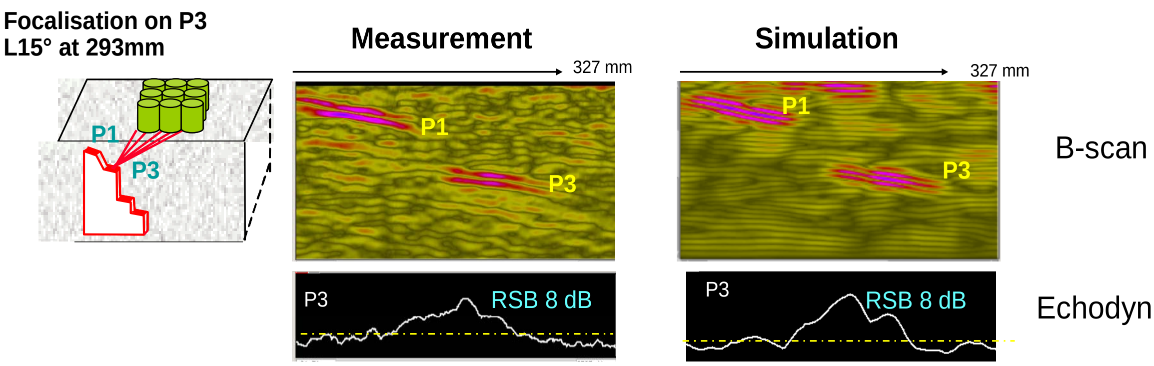

Fig. 5: Comparison of simulation to measurement for detection of a tilted defect by phased array

This preliminary result perfomed with a large aperture and a different angle of incidence show a good qualitative agreement between experiment and simulation. The prediction of SNR evaluated from simulated Bscan is closed from the experimental evaluation. Nonetheless the prediction of noise in term of spatial distribution could be improved since the experimental echoes are less extended than the simulated one. This phenomena may arise from local effects like field shadow resulting from the presence of aggregates which is not taken into account by the models.

Conclusion

The aim of that study is to characterize non destructively defects in deep concrete structures like wall containment of power nuclear plant. Several ultrasonic techniques have been developed and tested since the beginning of the study, in order to improve the detection of an artificial crack embedded in a concrete lab block.

Early results have shown the great potential of the ultrasonics techniques. Application of phased array technique combined with an angular scanning and post acquisition reconstruction allow to improve performance of the detection in term of signal to noise ratios and sensibility by optimizing the transmitted energy.

The post acquisition reconstruction provides full reconstructed images of the concrete structure and shows the profile of flaws.

Modelization tools have also been developed in order to predict sensibility of UT methods in concrete. Two models of attenuation and prediction of the structural noise have been implemented in CIVA software in order to take into account the heterogeneous media and to simulate more realistically NDT control in concrete. Preliminary encouraging results have been presented.

References

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