Automation

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Automation in Ultrasonic Imaging of Under-water Concrete/RCC Structures

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4-channel Ultrasonic Imaging System for Concrete/ RCC

ABSTRACT

There has been a rapid increase in the construction of under-water concrete structures all over the world and the maintenance and rehabilitation of these concrete structures pose a major concern for estimating the quality and the useful remaining life of these structures. This article provides brief details of the in-house developed Automated 4-Channel Ultrasonic Imaging System for the detection of flaws, porosities and rebar locations inside the concrete/Reinforced Cement Concrete (RCC) structures, and the system is interfaced with 2-axes automated mechanical scanner, for operation either in Pulse Echo (PE) or Transmit-Receive (T-R) mode. The imaging system performs data acquisition and temporal averaging of the RF bipolar signals using Spartan-6 FPGA to achieve high Signal-to-Noise Ratio (SNR) (> 20 dB).

KEYWORDS: *Ultrasonic Imaging, Concrete/RCC, Automation, Under-water,z UPV, Pulse-Echo*

Introduction

Ultrasonic wave propagation is sensitive to distributed damages in concrete structures and ultrasonic testing (UT) technique can be applied in-situ for inspection of large structures. However, the inhomogeneous and porous nature of concrete gives rise to scattering and absorption of propagating ultrasonic waves. As a consequence, the wave attenuation and structural noise are predominant in the received signals, which mask reflections received from flaws which are required to be detected. Low frequency ultrasonic transducers (50 kHz to 250 kHz) are routinely employed for the inspection of non-homogeneous structures like Concrete/RCC etc, to avoid the attenuation due to divergence and scattering of ultrasonic waves within the material[1]. However, with low frequency ultrasound also, the concrete still acts as an excessive at tenuative material which makes the inspection of Concrete/ RCC structures a challenging task. Ultrasonic Pulse Velocity (UPV) testing is an effective and indirect method as per BIS standard IS 13311 (Part-1) [2] & IS 516 (Part-5/Sec 1) [3], for the assessment of material homogeneity, providing information about the compressive strength and the existence of internal flaws and anomalies. At the same time, evaluation of UPV result is a specialized field activity, which requires careful data collection and expert knowledge and experience to obtain reliable diagnosis. In order to map the homogeneity of a concrete structure, it is necessary to acquire and interpret a large number of UPV values for the concrete structure under test[4]. Therefore, the automated ultrasonic imaging technique is needed which provides internal details of the Concrete/RCC structure under test and the estimation of flaw size and flaw characterization.

Automated 4-channel Ultrasonic Imaging system

Due to a rapid progress in the computing technology, many imaging techniques like Synthetic Aperture Focusing Technique (SAFT), Reverse Time Migration (RTM) technique, Total Focusing Method (TFM) etc., are widely utilized by the researchers for the ultrasonic imaging of Concrete/RCC structures. The SAFT algorithm has been applied extensively by researchers on ultrasonic data to image the tendon ducts, defects and rebars inside concrete structures. Many commercial instruments utilize these digital techniques using phased array shear wave transducers for imaging of the concrete structures[5]. But for imaging of under-water concrete structures, instruments which are generally based on shear-wave transducers cannot be employed due to the non-feasibility of shear wave propagation in water.

The water-immersion based and automated 4-channel Ultrasonic Imaging System has been designed & developed by Electronics Division (ED), BARC for the acquisition of B-Scan images of the under-water concrete and RCC blocks using Pulse-Echo (PE) mode as shown in Fig.1(a), which needs access from one side of the concrete structure under test. The linear array fixture using commercially available narrow band, longitudinal-wave type water-immersion, 92 kHz ultrasonic transducers have been fabricated at workshop, ED as shown in Fig.1(b). Four transducers are sequentially energized as transmitters to enable image data acquisition by utilizing same transducers as receiver of ultrasound. The technique is completely contactless as ultrasonic immersion transducers with fixed stand-off distance between transducer's front face and top surface of concrete block are employed for imaging purpose[6]. The four-channel imaging system consists of four-channel high voltage (HV) tone-burst square-wave bipolar pulser[7], four-channel pre-amplifiers with maximum gain of 66 dB for each pre-amplifier channel and a common main amplifier with 66 dB maximum gain; multi-channel data acquisition module which includes in-house developed 100 MSPS, 8 bits high speed digitizer, commercially available Spartan 6 FPGA module which controls the timing of the entire

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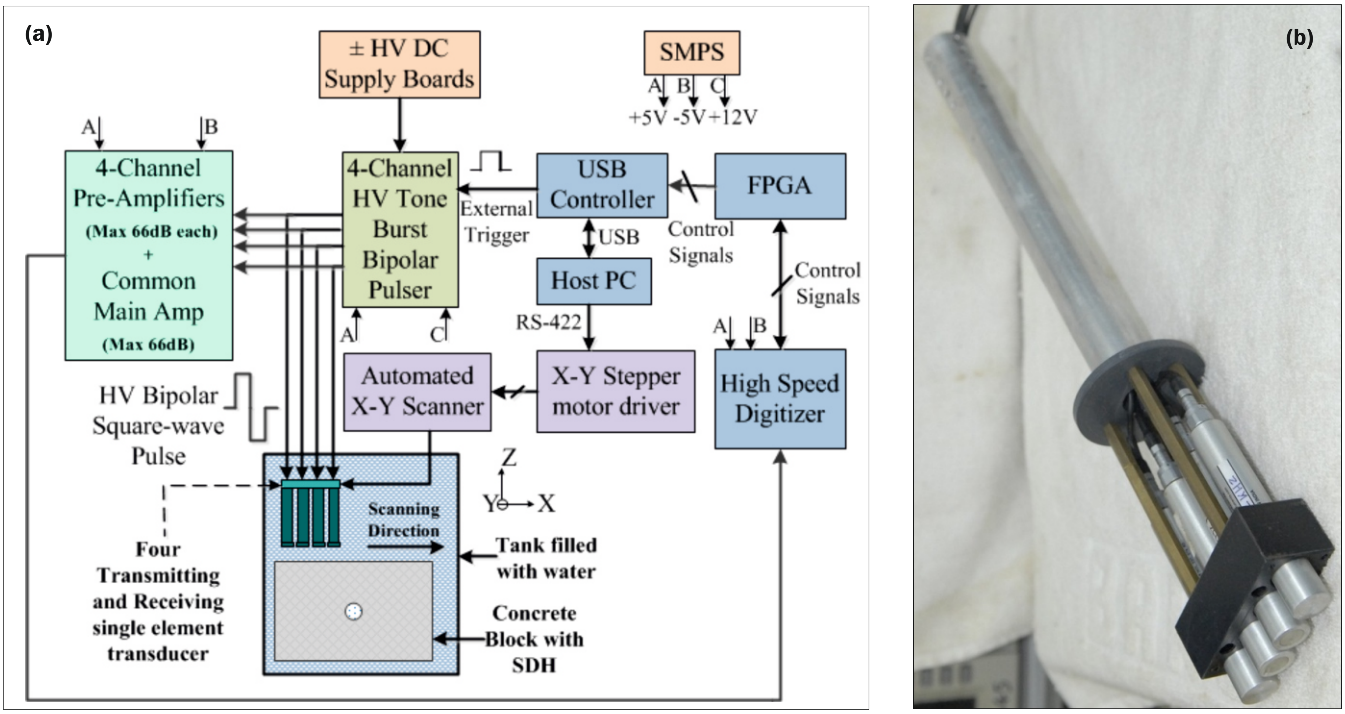

Fig.1: (a) Schematic Block Diagram of Automated 4-Channel Ultrasonic Imaging System for inspection of under-water Concrete/RCC structures in PE mode; (b) Photograph of linear array transducers assembly.

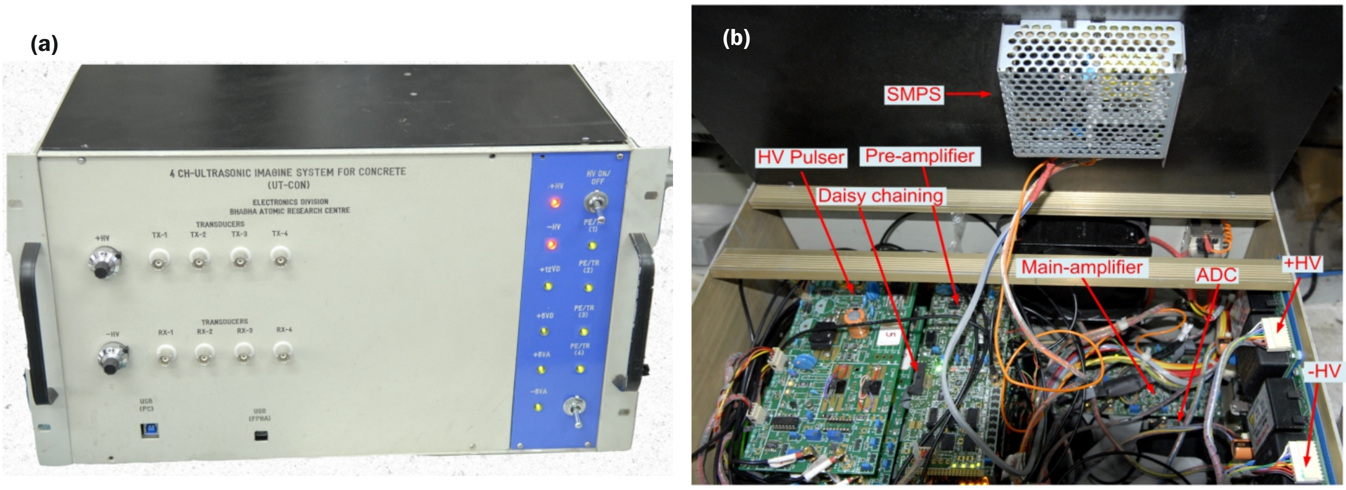

Fig.2: Photographs of (a) Four-channel ultrasonic imaging system hardware mounted inside 19”×6U×300 mm sub-rack, (b) Inside view of imaging system and built-in HV and LV DC power supplies.

system and USB controller module for the communication with computer; immersion type four longitudinal-wave transducers with central frequency of 92 kHz and an automated X-Y scanner mounted onto 300 mm (L) x 300 mm (W) x 500 mm (D) water tank for manoeuvring the transducer assembly inside the water tank for the acquisition of A-Scan 1D waveforms and B-Scan 2D cross-sectional front view images. The automated scanner is controlled through RS422 interface using GUI software developed on C# platform, for PC. Photographs of the 4-channel ultrasonic imaging system are shown in Fig.2[8].

Automated B-Scan imaging is carried out using four numbers of 92 kHz immersion transducers, keeping them perpendicular to the test block's top surface for PE mode. All the transducers utilised for experimentation are Canopus Instruments, Kalyan, Thane, India make. B-Scan image represents the cross-sectional front view along a particular axis for the Concrete/RCC specimen under test. The depth of the test block is shown along the Y-axis, while the position of the 92 kHz longitudinal wave transducer is shown along the X-axis in the B-Scan image shown in Fig.3 (c) and (d) and Fig.4 (g) and (h). Fig.3 and Fig.4 provides the schematic, photograph and B-scan images for two types of concrete test blocks reinforced with High Yield Strength Deformed (HYSD) steel rebars. The binary offset data received from the 8-bits parallel ADC is utilized to represent the data, in the form of coloured pixels for each A-Scan waveform using the GUI software, developed using visual environment. The four-channel data is first processed by temporal averaging in the FPGA hardware to minimize the effects of random noise and then the stored data is routed through the software-implemented 1-D bandpass filter (BPF) with -3dB cut-off of 80 kHz and 120 kHz. The BPF eliminates the high frequency noise and provides a speckle free B-Scan image of the concrete test block under test. The raw B-Scan image is always superimposed with undesired artifacts due to electromagnetic interference (EMI) of motor drive unit and EMI masks the identification of internal reflectors such as voids, inclusions, etc as they are

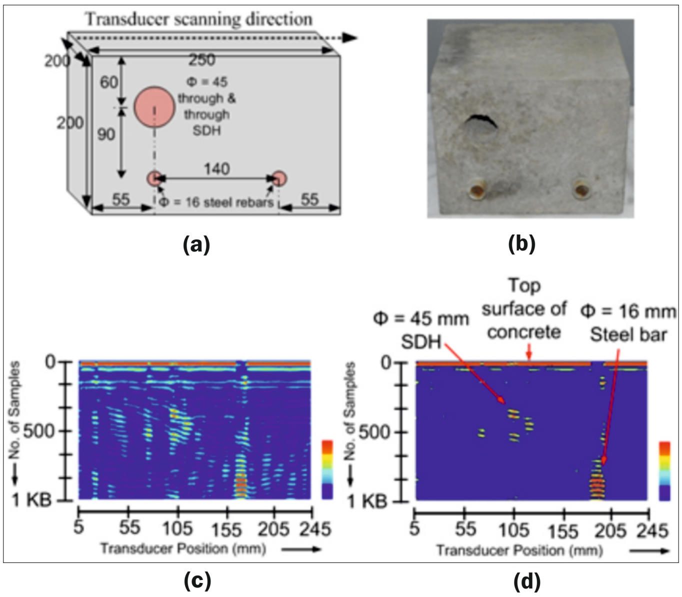

Fig.3: M35 grade concrete reinforced with HYSD two steel rebars of 16 mm diameter each with through & through 45 mm diameter hole (a) Schematic diagram of test block, (b) Photograph of test block, (c) B-Scan image of test block, (d) Gated and processed B-Scan image of test block.

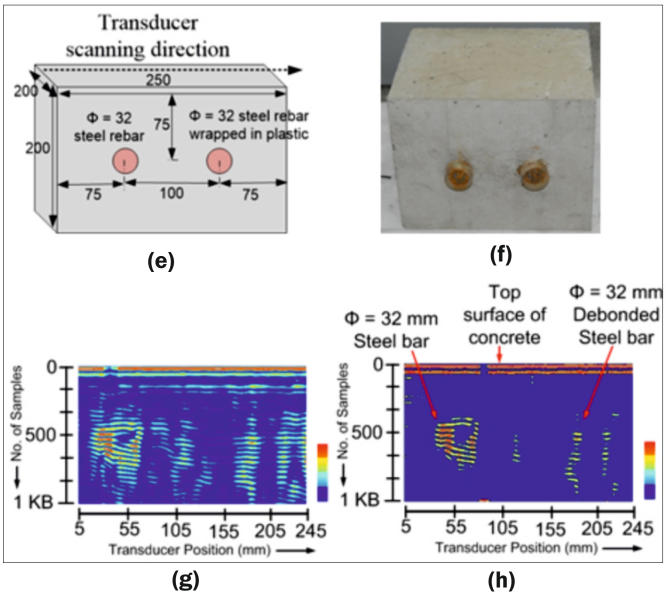

Fig.4: M35 grade concrete reinforced with HYSD steel rebar of 32 mm diameter and another is a plastic wrapped HYSD steel rebar of 32 mm diameter, (e) Schematic diagram of test block, (f) Photograph of test block, (g) B-Scan image of test block, (h) Gated and processed B-Scan image of test block.

corresponding to the received feeble echo signals. Therefore, a software-implemented 1-D band-pass filter has been implemented to minimize the effects of undesired reflections/ artefacts, as an off-line process, to enhance SNR more than 20 dB. The system also operates in UPV mode to compute acoustic velocity of unknown Concrete/RCC material.

Key features of the automated ultrasonic imaging system are as below:

- Transducer frequency – 92 kHz
- 4-Channel Preamplifier (individual) Gain - 66dB (maximum)
- 4-Channel Common Main amplifier (individual) Gain - 66dB (maximum)
- Temporal averages - 64 (fixed) (To enhance SNR)
- Operating mode - Pulse Echo (PE) or Transmit-Receive (T-R) mode
- 4-Channel Tone-burst Square-wave Bipolar Pulser - [50-350V with max. 5 no. of bursts]
- Digitizer - 100MSPS @ 8-Bits, 12kB data/A-scan
- Interface to Computer – USB 2.0

Conclusions

An automated, 4-Channel Ultrasonic Imaging System has been designed and developed and it was employed for the imaging and visualization of inclusions and various flaws such as voids and debonding in M35 grade under-water concrete and RCC test blocks reinforced with HYSD steel rebars, using 92 kHz longitudinal wave, immersion type ultrasonic transducers. The FPGA-based four-channel ultrasonic imaging system has been indigenously developed to image under-water Concrete/RCC materials and structures and also measures UPV for unknown Concrete/RCC structures. The system is stand-alone with FPGA as a control device with USB interface to computer for storage and offline analysis of A-Scan 1D data and B-Scan 2D images. The test setup for imaging of concrete test blocks of various dimensions has been designed and manufactured by Workshop, Electronics Div., BARC and concrete sample blocks of M15-M35 grade, embedded with various inclusions and defects have been designed and manufactured by Civil Engg. Div., BARC.

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