DEVELOPMENT AND APPLICATIONS OF C-SCAN ULTRASONIC FACILITY

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Abstract

This paper presents the in-house development and application of a C-scan ultrasonic facility ULTIMA 200M2 at the Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, carried out in collaboration with the Electronics Division, Bhabha Atomic Research Centre (BARC), Mumbai. The paper describes various constituents of the system developed and also highlights the typical results obtained using this system, including bond integrity assessment of explosive welds and imaging of fuel sub-assembly heads of the Fast Breeder Test Reactor. The system has also been used for imaging both the sides of a one rupee Indian coin. All the finer details of the coin could be extracted, demonstrating the resolution capabilities of the system.

Introduction

Conventional ultrasonic testing is generally a contact test and is subject to the operator's ability to efficiently hand-scan a component. Further, the results need to be analyzed by reading a scope-type display or listening for an audio alarm. The most commonly used form of presentation of the ultrasonic testing is known as A-scan presentation. In this presentation, the horizontal line on the screen indicates the elapsed time (distance traveled) and the vertical deflection shows the echo amplitude. From the location and amplitude of the echo on the screen, the depth of the flaw in the component and an estimate of the size of the flaw can be made respectively. Ultrasonic test results can also be presented in the form of images providing the details of the component and two of these presentations are known as B-scan and C-scan presentations. B-scans are generated by scanning the probe in a straight line across the surface of the test piece at a uniform speed and acquiring all the A-scans at predetermined distance intervals. One axis of the display, usually the horizontal axis, represents the distance traveled along this line and the axis orthogonal to the probe position axis, usually measured top to bottom on the screen, indicates the depth of the echo within the component. Echo amplitudes are indicated in the gray scale. The principal advantage of B-scan presentation is the ability to display cross sectional view of the component and the flaws within it.

In an ultrasonic C-scan presentation, the transducer scans the part and initially displays the A-scan in which radio frequency (RF) waveforms show the ultrasonic signals reflected from the component. This display is used to set up the data collection gates, which are individual areas on the A-scan that correspond to specific depth ranges. The peak amplitude of the signal, within this gate, is then converted to a color or grayscale image called a C-scan, which shows the variations within the component. The data gates can either be placed along a single timeline (depth) to detect defects in the full volume of the component, or they can be located at various depths within the thickness of the component. Each data gate produces a separate C-scan image, which allows the component to be profiled through a top view (like an X-ray) or through individual layers. The results of the scan are provided as an image, showing the sectional view of the component and the flaws within it. Fig. 1 shows the schematic setup of a C-scan ultrasonic testing system. It consists of a computer (containing ultrasonic pulse-receiver card, analog-to-digital converter card and system operating software), mechanical scanner, motion control subsystem, ultrasonic transducer and an immersion tank.

The multi-channel C-scan ultrasonic imaging system ULTIMA with 100 MHz digitization was originally

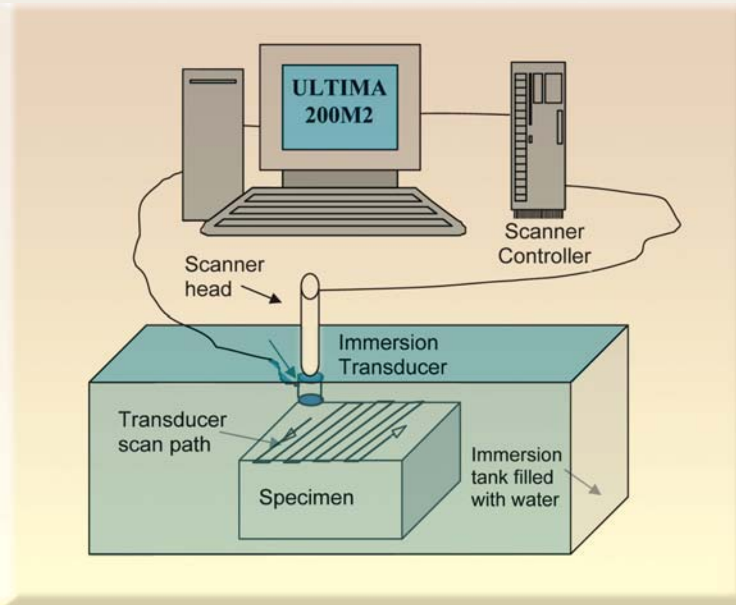

Fig. 1 : Schematic setup for ultrasonic C-scan imaging system

developed at Electronics Division, BARC, for various specific routine applications [1-5]. The details of various components of the two channel ULTIMA 200M2, with higher digitization capabilities and enhanced versatility, developed and established at IGCAR in collaboration with BARC are dealt first in the paper, followed by a few typical results obtained using this system.

ULTIMA 200M2 : Two-Channel Ultrasonic C-scan Imaging System

Hardware

ULTIMA 200 M2 is a two channel ultrasonic system which can excite two ultrasonic transducers in a sequence and digitize the data (acquired by both the transducers) at a maximum sampling rate of 200 MHz. Fig. 2 shows the schematic block diagram of the ULTIMA 200M2. The Pulser / Receiver units (one for each transducer), 200 MHz Digitizer and the channel sequencer are configured in the form of PC add-on cards, which are mounted in an Industrial Personal Computer. An additional amplifier card (PC-plug-in type) provides additional amplification for the received signals and the rectifier card carries out envelope detection of these signals so that either the rectified or un-rectified (i.e. RF) echo data can be digitized. Thus, the basic hardware for ultrasonic data acquisition consists of the following PC plug-in boards:

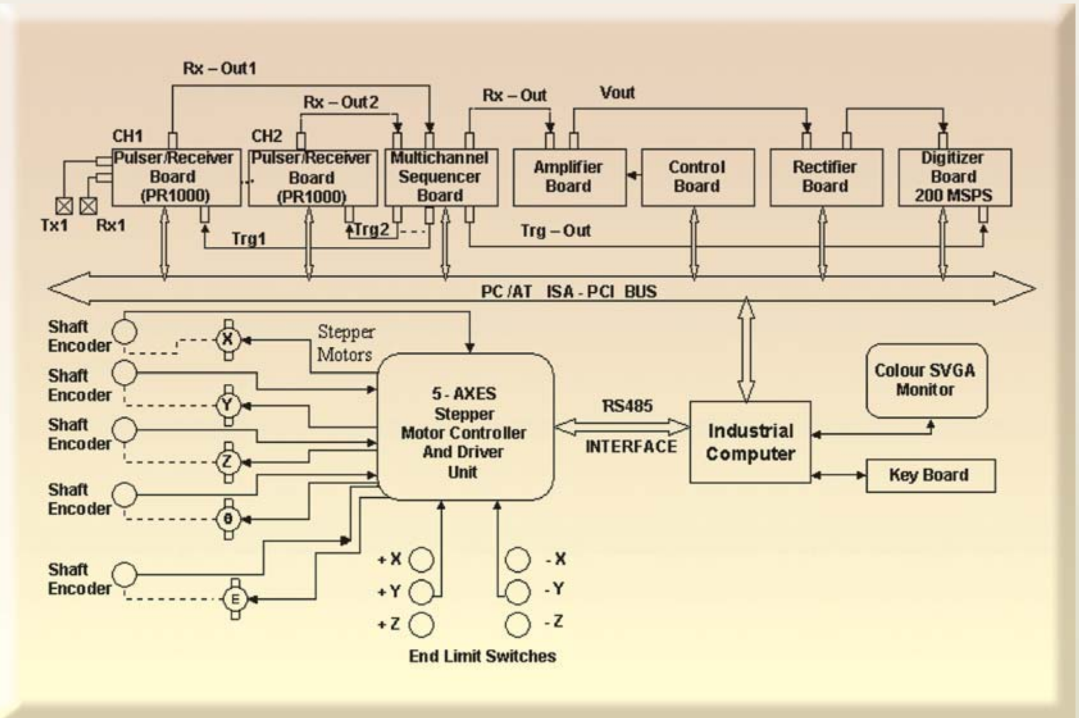

Fig. 2 : Schematic block diagram of ULTIMA 200M2 system

- Multi-channel Sequencer Board
(Programmable channel-to-channel duration; Sequencing of respective triggers and multiplexing of echo signals for max. 8 channels; On board programmable 26 dB gain amplifier with 30 MHz Bandwidth)
- Wideband, Programmable Gain Amplifier Board
(RF amplifier with a Programmable gain of 40 dB; Bandwidth: 30 MHz)
- Envelope detector Board
(Full wave precision Rectification and envelope detection)
- 200 MHz, 8 Bits (ISA Bus) RF Digitizer Board
(Sampling rate: 200 MHz @ 8 bits resolution; RF Digitization; On board 8 Kbytes FIFO memory; Internal/External Trigger facility)

This setup enables one to obtain digitized A-Scan information received by the transducer from the test object. For generating B-scan (i.e. a vertical cross section) and C-scan (horizontal cross section) images, controlled movement of the transducers is necessary. This is achieved with the help of PC-controlled multi axes mechanical scanner with a provision for mounting the transducers. A 5 axes (X, Y, Z, q and f axes respectively) stepper-motor-driven scanner, developed earlier [6], has been coupled with ULTIMA 200M2. Each axis imparts a controlled movement to the transducer holders in the specified direction with defined rate and increment. Each axis has a stepper motor, driver electronics and motion controller. The controller is interfaced to PC via an industry standard RS-485 interface. This interface permits cascading of multiple interfaces and hence it has been employed for the ULTIMA 100 M2 System.

Thus the PC plug-in cards mentioned above and RS-485 interface along with the 5 stepper motor controllers, 5 motor drives and associated power supply unit constitute the complete electronics hardware of the system. The hardware design of the ULTIMA100M2 system is modular in nature and all the function-specific PC Add-on boards are interfaced to PC via ISA or PCI Bus. Function-specific units/boards have an advantage that they can be independently upgraded without changing the rest of the system.

Software

A comprehensive Windows 98/ME compatible System software has been developed for ULTIMA 200M2 using Microsoft Visual Basic (VB) and Visual C++ (Version 6.0). The required Graphical User Interface (GUI) has been provided using VB, whereas controls for all the hardware boards/units have been established in the form of Dynamically Linked Libraries (DLLs) using VC++.

The system software has the following major features:

- Selection and calibration of transmitter/receiver transducer in terms of probe delay and angle of incidence.
- Selection and calibration of material in terms of velocity of propagation.
- Selection of digitizer parameters viz. sampling rate, depth range and initial delay for delayed data acquisition (DAQ) for thick objects and immersion scanning method.
- DAQ, storage/retrieval and display for A-Scan waveforms or B-Scan (cross-sectional front view) and C-Scan (cross-sectional top view) images for all the channels.
- Storage and retrieval of A-Scan data in Binary or ASCII format and B/C-Scan images in Binary or BMP format.
- Measurements of amplitude, flaw depth, linear distance, material velocity, transducer delay, transducer angle etc.
- Storage and retrieval of setup (*.INI) files for repeating the test using the same setup, if so desired.
- 4-Axis mechanical scanner control and test software.
- Return-On-Defect for C-Scan mode for confirmation of the defect and quantitative evaluation of the defect.

A 'project file' is generated for storing the multi-channel A-Scan data. This contains the header-information that includes all the major data acquisition parameters followed by the actual digitized data. The data from each channel is stored in separate files. The data retrieval and view feature enables to perform measurements like flaw depth, amplitude, linear distance / depth for angle beam probes, probe angle, velocity of propagation, two probe delay value etc.

In B-Scan mode, probe can be moved either manually or under the control of the scanning mechanism. While acquiring and displaying the B-Scan image on-line for a selected channel, the current A-Scan waveforms for the channels are also displayed. The B-Scan image can be displayed either in pseudo colors or gray shades.

In C-Scan mode, an on-line C-Scan image (in pseudo colour/grayscale) corresponding to the selected channel along with current A-Scan waveforms for both the channels is displayed. In the C-Scan retrieve mode, the software provides display of a B-Scan (cross-sectional front view) or a D-Scan (cross-sectional side view) image also along with the A and C-scans.

Return On Defect (ROD) command can be employed for repositioning the transducer at the desired location on the job for careful scrutiny of suspected regions and quantitative evaluation of the defects.

Further details of the development of hardware and software for the system can be obtained from the earlier publications [2-6].

Results of the Application of Ultima 200M2 C-Scan Imaging System

Fig. 3 shows the photograph of the C-scan test facility established at IGCAR. This system has been used for various applications such as imaging of weld profiles in ferritic and austenitic steel weldments; interface characterization of braze joints, explosive welds of different metals, various cladded specimens and imaging of dummy fuel sub-assembly heads of the Fast Breeder Test Reactor (FBTR). Some of the typical results obtained are presented in the following sub-sections.

Fig. 3 : C-scan ultrasonic facility at IGCAR

Bond integrity of weld and braze joints

Ultrasonic testing is one of the most popular nondestructive testing techniques for the evaluation of bond quality and defects, such as delaminations. The amplitude of the interface echo is dependent upon the acoustic impedance ($Z = \rho V$, where ρ is density and V is velocity of ultrasonic wave) of the two media on both sides of the interface. The reflection coefficient is given as:

$$R=(Z_2-Z_1)/(Z_2+Z_1)$$

where, Z_1 and Z_2 are the acoustic impedances of the first and the second media respectively. In the case of a good bond, the amplitude of the interface echo is less, because of the small difference between the acoustic impedances of the two metals. Whereas, in the case of any debond, because of the presence of metal-air interface, all the energy gets reflected back due to the large difference in acoustic impedance between the metal and the air and hence a signal with large amplitude is observed. This is indicated as a gray or black area in the C-scan.

C-Scan imaging has been carried out for evaluation of bond integrity of a titanium-carbon steel explosive weld joint [7] and a titanium-aluminum braze joint using aluminum foils as the brazing material. C-scan ultrasonic studies were carried out, using a 6 MHz point focused immersion transducer, focused at the interface. Figs. 4 a and b show the photograph and C-scan image of the titanium-carbon steel explosive weld joint. The ultrasonic inspection was carried out from the carbon steel side of the weld joint. The gray area in the C-scan image depicts the good weld joint leading to lower reflection from the interface, whereas, the black area indicates the delamination at the interface.

Fig. 5 shows the C-scan of the titanium-aluminum braze joint. The ultrasonic inspection was carried out from the titanium side of the braze plate. Two black areas in the C-scan indicate the delaminations at the interface. The observed delaminations are attributed to the improper thermal distribution due to clamping of the fixture at these locations.

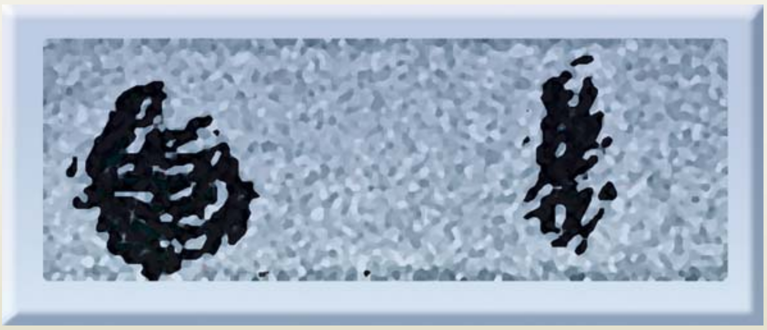

Fig. 5 : C-Scan image of the titanium-aluminum brazed plate indicating lack of bond (Black patches).

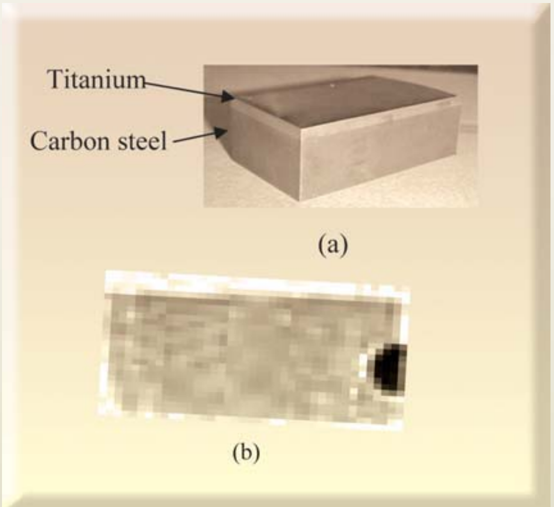

Fig. 4 : (a) Photograph and (b) C-scan image of the titanium–carbon steel explosive weld joint. (Gray area shows good weld and black area shows the delamination)

Imaging of fuel sub-assembly heads of Fast Breeder Test Reactor (FBTR)

The distance between the centers of the adjacent fuel subassembly heads, is often required to be measured in FBTR, in order to assess the degree of bowing/deflection of the fuel subassemblies due to irradiation damage. C-scan ultrasonic imaging has been attempted on dummy fuel sub-assembly heads in the laboratory, in order to examine the feasibility of using the C-scan based approach for the above purpose. Both focused and unfocused transducers have been used for the C-scan imaging. Figs. 6 a and b show the photograph and the C-scan image of

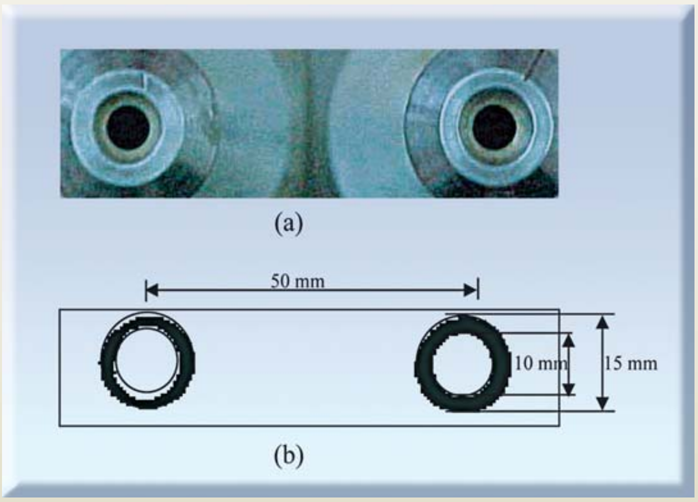

Fig. 6 : (a) Photograph of the top portion of the fuel subassembly head and (b) C-scan image obtained using the reflection from the top surface

the fuel sub-assembly heads respectively, obtained by using a 6 MHz point focused ultrasonic transducer, at a scan step of 0.5 mm. The reflection from the top surface of the sub-assembly heads has been used for the imaging. It was found that the center to center distance between the two heads can be measured from the C-scan image with an accuracy of ~2% and ~3% by using focused and unfocused transducers respectively. The outer and inner diameters of the top reflector of the sub-assembly head can be measured with an accuracy of ±0.5 mm with focused transducer, whereas the unfocused transducer overestimates the outer diameter by about 2 mm.

Imaging of one rupee Indian coin

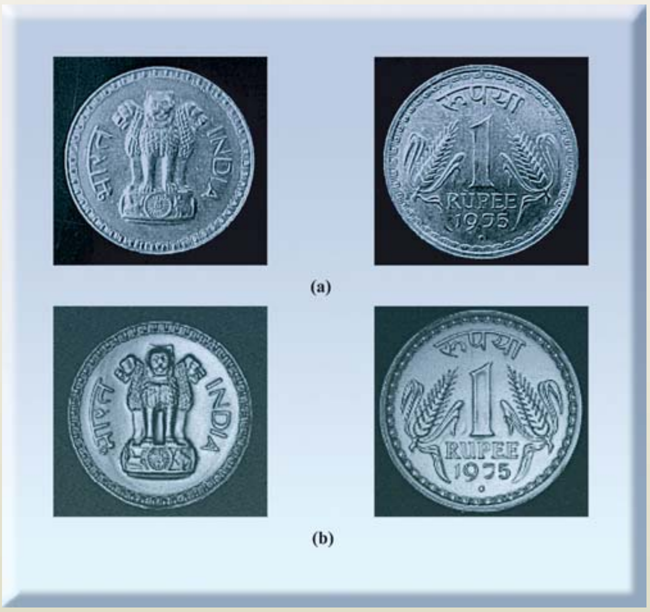

Fig. 7 : (a) Digital photo and (b) Ultrasonic C-scan image of an Indian coin

In order to demonstrate the capabilities of the C-scan ultrasonic system, imaging of an Indian coin of one rupee denomination was carried out, using 20 MHz point focused transducer at a scan step of 0.2 mm. Figs. 7 a and b show the photographs and ultrasonic C-scan images of the two sides of the one rupee Indian coin, for direct comparison. The C-scan images (Fig. 7b) represent in gray scale, the amplitude of the echo obtained from the water-coin interface. The flat area in the coin reflected more energy and seen as light area in the C-scan image. At the edges (peripheries) of the protrusions in the coin, the ultrasonic wave gets deflected in different directions and hence the received amplitude is less, leading to the dark area in the C-scan image. All the finer details of the coin could be revealed, demonstrating the resolution capabilities of the C-scan ultrasonic system established at IGCAR.

Future developments in the ULTIMA 200M2 system

Further developments in ULTIMA 200M2 are in progress at BARC with respect to both the hardware and the software. In the hardware, efforts are being made to upgrade the system to have 500 MHz digitization in order to improve the time resolution. Various modifications and additions in the software, such as facilities to get time-of-flight and spectral content based C-scan imaging are in progress, for microstructural characterization applications.

Conclusions

A C-scan ultrasonic facility ULTIMA 200M2 has been developed and installed at the Indira Gandhi Centre for Atomic Research, Kalpakkam, in collaboration with the Electronics Division, Bhabha Atomic Research Centre, Mumbai. This paper provides the details of various modules of this system and also a few results of applications, such as bond integrity assessment of explosive weld joints and imaging of dummy fuel sub-assembly heads of the Fast Breeder Test Reactor. The sensitivity and resolution of the system has been demonstrated by imaging both sides of the one rupee Indian coin. All the finer details of the coin could be extracted very clearly.

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Dr V.H. Patankar joined Electronics Division, BARC in June 1988, after graduating in Electronics Engineering from Shivaji University, Kolhapur. He completed his Ph.D. in Electrical Engg. from VJTI, Mumbai University in 2006. He is an Assistant professor at HBNI. Initially, he developed microprocessor-based EMG system, for investigation of neural disorders. Since 1991, he is working on the design and development of PC-based, Automated, Ultrasonic Imaging Systems for NDT of mechanical components, tubes, pipes, etc. He received the prestigious National NDT Award 2003 in the System Innovation and Development category, from Indian Society For Non-Destructive Testing (ISNT). Recently, he received the Best Journal Paper Award 2006 by ISNT for the technical paper he published in JNDE, March 2005 issue, jointly with scientists from BARC, IGCAR and a faculty from VJTI. Currently, he is engaged in the design and development of Automated - Under Sodium Ultrasonic Inspection System intended for detection of growth in fuel subassemblies of 500MWe Fast Breeder Reactor. He has more than 25 technical papers on ultrasonics, published in journals and seminars.

Mr. V.M.Joshi joined the Electronics Division of BARC in 1976 after completing his M.Tech. from I.I.T. Bombay in Instrumentation, Controls and Computers (Elect. Engg.). He initially worked on the development of Bio-medical instruments such as Electromyograph and Medical Ultrasonic Scanner (B-Scan system). He then worked on the development of Video Frame Grabbers. Since late eighties, he concentrated his developmental efforts on Ultrasonic Imaging systems for Nondestructive Testing/Evaluation (NDT/E) of materials. Under his leadership, several Ultrasonic Testing systems have been developed and supplied to NDT experts in BARC and IGCAR. Mr. Joshi heads the Ultrasonic Instrumentation Section of Electronics Division and is the recipient of the "NDE AchivementAward" for contributions to R&D in NDT. This award was given to him by the Mumbai chapter of I.S.N.T. Mr. Joshi has more than thirty scientific publications - including journal and conference papers and BARC reports - to his credit. Mr. Joshi is a life member of " The Biomedical Engineering Society of India" and the "Indian Society for Nondestructive Testing" (I.S.N.T.).