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# Development of a Virtual Instrument for Immersion Type Ultrasonic Inspection with a Computer Controlled Multi-Axis Motion Controller

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## ABSTRACT

The Pulse Echo (PE) technique is a widely used ultrasonic non destructive testing technique to test materials by analyzing ultrasound echoes reflected from flaws and discontinuities. In conventional PE technique, called contact type PE, an ultrasonic transducer is in constant contact with a test piece, transmitting and receiving ultrasonic signals from the test specimen. The inherent shortcomings of PE are the need for; uniform couplant conditions, the ultrasonic transducer to remain in contact with the test object throughout the scan and a limitation to scan regular surfaced objects only. This paper provides for extending a system initially developed for contact type PE, to perform Immersion Testing (IT) which is a contactless pulse-echo inspection method with the probe and test piece separated by a predetermined volume of water of certain thickness. A computer controlled 3-axis transducer position manipulator (motion frame) is constructed for assistance in conducting automated tests. The efficacy of immersion testing relies on the precise control of the motion of transducer. The existing immersion type motion controllers along with dedicated data acquisition and analysis system are quite expensive and are beyond the affordability of smaller ultrasonic labs. Hence the proposed system including the motion frame and Data Acquisition Unit (DAQ) can serve as a competent, low-cost and reliable IT system benefitting several small scale industries and labs.

## General Terms

Ultrasonic Testing, Virtual Instruments, LabVIEW

## Keywords

Pulse-echo technique, Immersion Testing, Motion frame

## 1. INTRODUCTION

Ultrasonic Testing (UT) is a non-destructive evaluation method in which high-frequency sound energy is made to traverse through the materials for the detection of surface and subsurface flaws. The sound waves travel through the material with some loss of energy (attenuation) and are reflected at interfaces and discontinuities. The echo carries structural information of the test specimen and requires appropriate presentation for locating irregularities accurately. [1] Pulse echo technique is the simplest of all UT testing methods in which the test object is accessed from only one side as transmission and reception of ultrasound is done on the same surface of the object [1]. Contact-type pulse echo technique is very effective for smooth and regular surfaced objects whereas it is not suitable for irregular surfaces, especially when the transducer motion is automated. It also requires uniform couplant conditions for accurate detection of discontinuities [2]. Hence, a more versatile technique, the immersion testing came into practice which could scan both regular and irregular surfaces. Previously, a contact-type pulse-echo testing system was developed using LabVIEW and convincing results were obtained in all three conventional modes of scanning. To extend the functionality of the system to scan irregular objects, this paper concentrates on developing an immersion system for UT. Immersion testing (IT) is a subset of UT in which tests are carried out inside a water filled tank. Both, the test piece and the transducer are submerged in water before the inspection is begun, providing a uniform thickness of couplant over the test piece. This method can detect very small irregularities with high resolution and it can be used to scan specimens of very low thickness [3]. As the transducer is placed inside the water, there is a necessity to automate the motion of transducer over the test object to obtain accurate A-scan, B-scan and C-scan data. Multi-axis manipulators are used for this purpose and they are generally expensive, which makes them unaffordable to some laboratories and industries. Hence in this work, a low cost substitute for the existing high end axis manipulator is realized with a computer controllable 3-axis motion frame which can manipulate the position of transducer in X, Y, and Z directions. Motion control programs and virtual instruments for presenting received echoes are developed using LabVIEW.

## 2. PHYSICAL MODEL OF THE IT SYSTEM

The model, as illustrated in Figure1, consists of a Pulser/Receiver (PR) to excite and receive signals from the ultrasonic transducer, a Data Acquisition (DAQ) unit with A/D and D/A converters, and the motion frame to automate tests.

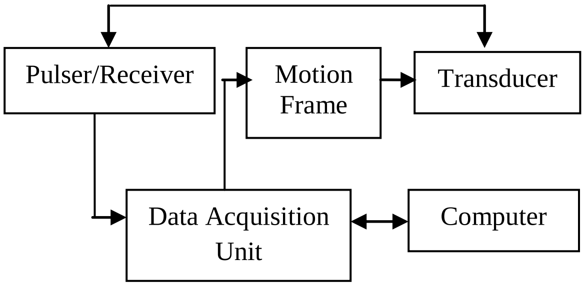


**Fig1. The physical model of the IT system**

The PR produces high energy pulses that trigger the transducer generating ultrasonic pulse. When coupled to the test object, the pulse gets modulated in terms of amplitude and phase [3]. The transducer and the test part are then immersed in a water-tank to carry out tests. In the present work, NI ELVIS II+ DAQ board is used to acquire the modulated echo into the computer. It has both analog and digital I/O channels. Analog input channels have a maximum sampling rate of 100 MHz and signals are acquired through these channels. The waveforms are then plotted using virtual oscilloscopes in the computer.

## 3. MOTION FRAME- THE BUILD

To achieve automated and complete acquisition of the ultrasound signal, the *motion frame* is designed. The motion frame is a unique low cost design comprising the use of scrap wood, a discarded printer, gear mechanism and a stepper motor. Figure2 is a 3D representation of the motion frame done using AutoCAD 2010.

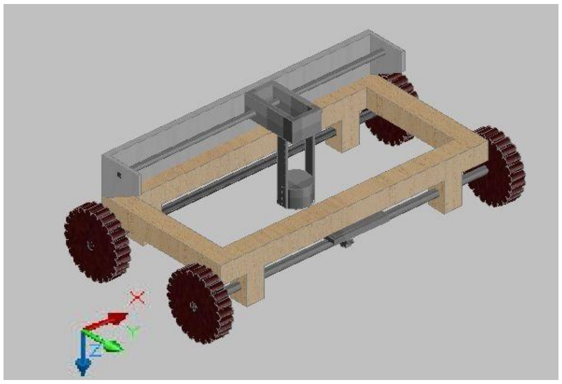


**Fig.2. AutoCAD schematic of motion frame**

Motion can be achieved in all the three directions, where; the printer frame helps motion along the X-axis, the stepper motor attached to the front shaft provides motion along Y-axis, and simple hydraulics assists for the motion of transducer along Z-axis.

The programming of the motion control is done using LabVIEW 2009 software. Using this program a resolution of 1 mm in translation along both X and Y axes can be achieved. This enables complete coverage of scan of the test specimen providing for increased detailing of the flaws in the material.

### 3.1 X-axis Motion

By removing all non-essential components of a discarded printer except for the track assembly, the motor, the print head holder and the drive belt and fixing of the *transducer set up* along with the head holder, the movement along the X – axis is set up. The actuation of the DC motor that drives the track assembly is programmed in such a manner that for every one step along the Y – axis there is a complete length traversal along the X – axis. Speed control is very essential for only at very low speeds proper transfer and retrieval of ultrasound waves through the medium is possible. [4] Hence with careful observation the right amount of voltage is supplied to the motor using the data acquisition board. A Linear optical encoder enables to determine the position of the transducer at any given time. The feedback from the encoder in turn gives the operator a virtual vision of the position of the transducer. The repeatability of the movement is good enough for start - stop operations conducted during the experiment. Figure3 illustrates the printer frame with track assembly used for x-axis movement.

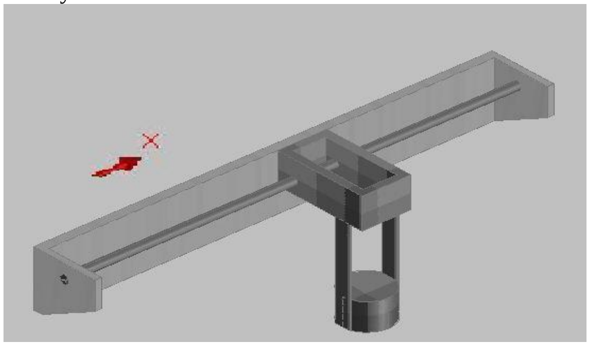


**Fig.3. Printer frame with track assembly and other features**

### 3.2 Y-axis Motion

Scrap wood material made of dried nutmeg variety which is easy to fabricate is made into one rectangular frame that can support the printer frame. To the frame is attached a pair of shafts to drive the motion frame as illustrated it figure4. The frame is a front wheel drive, set up with a gear assembly for obtaining higher torque. The gear train is driven using a stepper motor, whose pulse signals are operated using the data acquisition board. The program is programmed in a manner such that the stepper motor receives pulsed signals after every traversal along the X – axis. Since the printer frame is bolted on to the rectangular wood frame, therefore for every step induced by the driving stepper motor the transducer too moves an equivalent step along the Y-axis. Careful observation helped identify the correct step sequence for the motor in order to achieve the right amount of torque required to move the frame along the Y-axis. In ultrasound scanning it is very important that no area in the material is left un-scanned (or missed), hence the use of stepper motor with which 1 mm traversal along the Y-axis is possible.

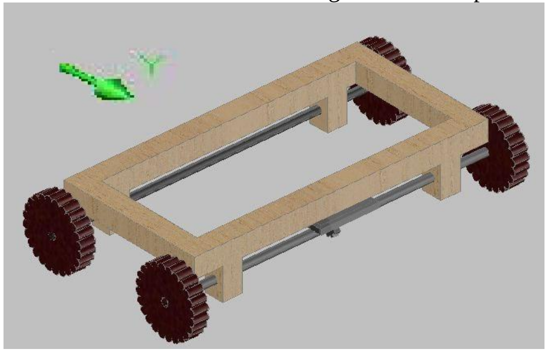


**Fig.4. Wood frame and its components**

### 3.3 Z-axis Motion

The motion along Z-axis is assisted by a syringe pair whose flow could be controlled using a simple and efficient roller controller often used in blood transfusion. The working liquid medium is water. This simple hydraulics is used to adjust the water path distance between the probe tip and test piece. In immersion testing, the water path travelled by the transmitted ultrasound plays a vital role in identifying echoes from defects and backwall of the test specimen. When normal beam transducer is used, the water path distance must always be longer than the distance S given in equation [4];

$$S > \text{thickness of test piece} * \frac{\textit{speed of sound in water}}{\textit{speed of sound in test piece}} \qquad (1)$$

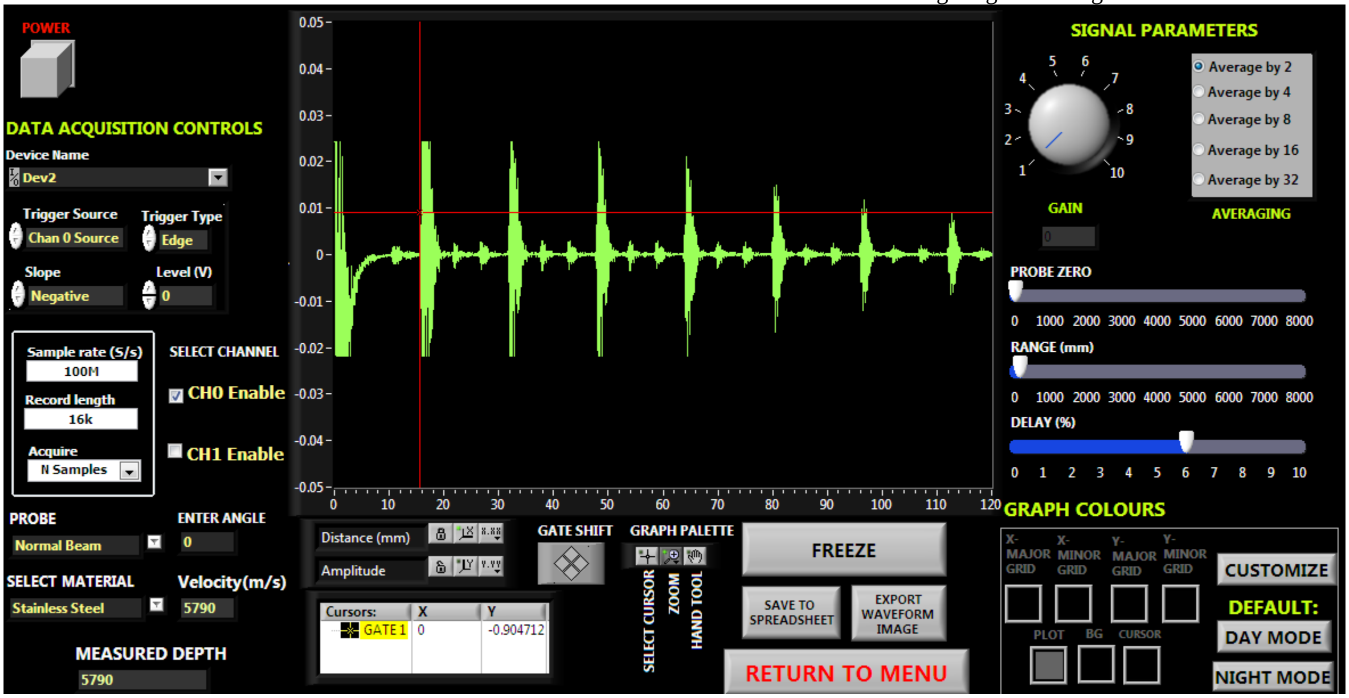
When this condition is not met, the first backwall echo overlaps the second surface echo and defects near the backwall may not be seen. The ultrasonic transducer is fixed to the syringe pair in such a way that the water path distance can adjusted to the required level by adjusting its position along the Z-axis so as to obtain accurate results.

## 4. PRESENTATION OF SIGNALS

There are 3 modes of scanning employed in UT. They are A-scan, B-scan and C-scan. These modes are basically different representations of echoes received from defects or from the backwall of the test piece. In practice, dedicated instruments are being used for each scanning mode thereby making advanced testing quite expensive.

The **A-scan** detector which is a simple storage oscilloscope displays these echoes as alternating signal in time domain. A-scan gives information about the irregularities in the test piece in one dimension. It denotes amplitude modulated scan and gives information about irregularities in one dimension [5]. The proposed system provides a virtual oscilloscope for displaying A-scan data. The A-scan is also the fundamental method from which B and C scans are obtained. [5-6] Figure5 illustrates the front panel of the virtual instrument developed for presenting echoes in A-scan.

**B-scan** and **C-scan** are ultrasonic imaging techniques. B-scan, also known as Brightness-mode scan, gives the cross-sectional view of test objects. [6] In B-scan, echoes are indicated by bright spots on the screen rather than by deflections of the time trace. The position of a bright spot corresponds to the depth from which the echo is received. The strength (amplitude) of the echo determines the intensity of the spot. Most B scans are generated by scanning along a straight line across the surface of the object at a uniform rate [7]. The motion frame is used to automate scan along a straight line at a uniform rate with simultaneous data logging. The length which has to be scanned is provided in the user interface and scanning procedure is started [8]. The motion controller moves the probe in steps of 1 mm covering the entire length with uniform speed. The echo obtained at each point is mapped onto a brightness scale as mentioned above thus giving a 2D image of the cross section.



Device Name: Dev2
Trigger Source: Chan 0 Source
Trigger Type: Edge
Slope: Negative
Level (V): 0
Sample rate (S/s): 100M
Record length: 16k
Acquire: N Samples
☑ CH0 Enable
☐ CH1 Enable
PROBE: Normal Beam
ENTER ANGLE: 0
SELECT MATERIAL: Stainless Steel
Velocity(m/s): 5790
MEASURED DEPTH: 5790
Distance (mm)
Amplitude
GAIN: 0
● Average by 2
○ Average by 4
○ Average by 8
○ Average by 16
○ Average by 32

| Cursors: | X | Y |
|---|---|---|
| GATE 1 | 0 | -0.904712 |

**Fig 5: Front panel of Virtual A-scan detector**

On the other hand, C scan imaging is done to present the planar (top) view of the entire test specimen [9]. It provides the depth of defects and backwall as a coloured image where the colour scale corresponds to the depth from which an echo is received. C scan image gives the planar position of defects [10]. With the help of the motion frame the complete area of the test piece is covered with 1 mm resolution in both X and Y axes. Figure 6 and 7 illustrate the results obtained from tests. Figure8 illustrates the front panel of virtual B-scan and C-scan detectors. Along with display of echoes in various modes, it has been programmed such that after every 1mm position change of the transducer along any axis, the corresponding A-scan at that point is automatically logged into computer memory in the form of spreadsheet data.

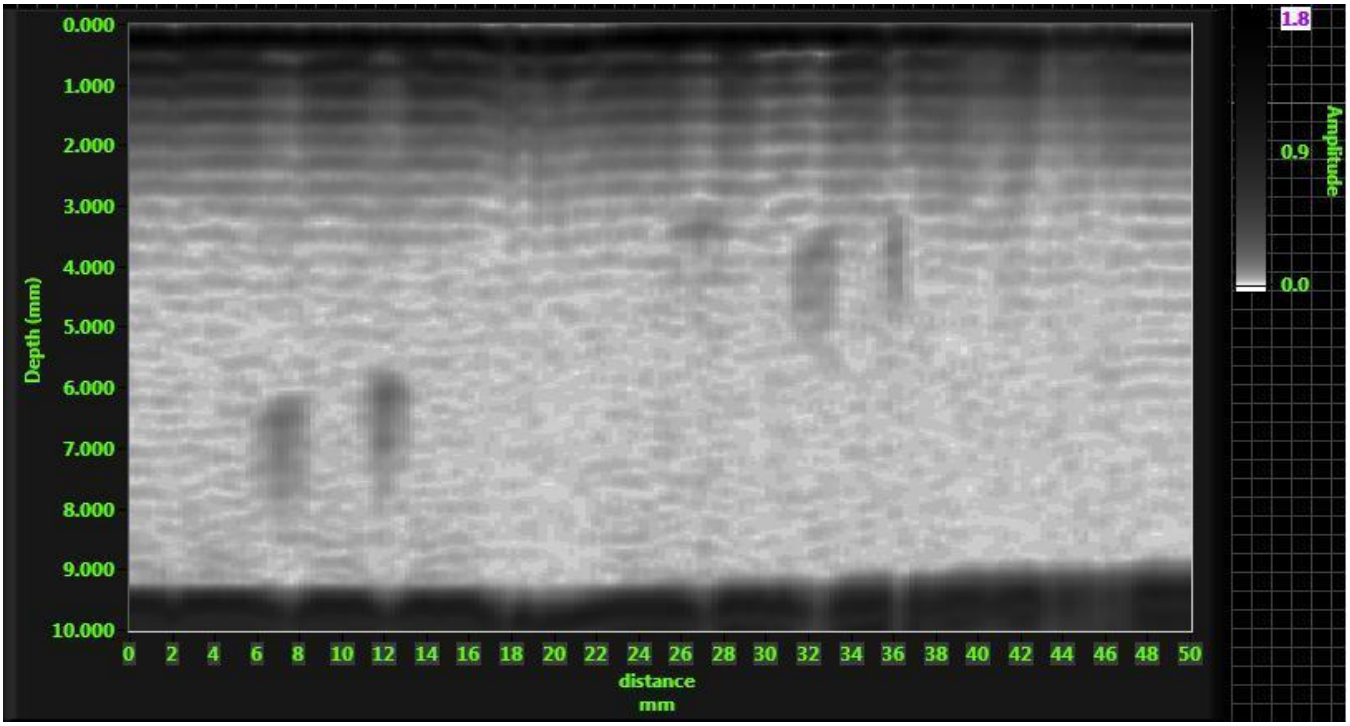


**Fig.6 B-scan image (cross-sectional view) obtained from a test piece with five side-drilled holes**

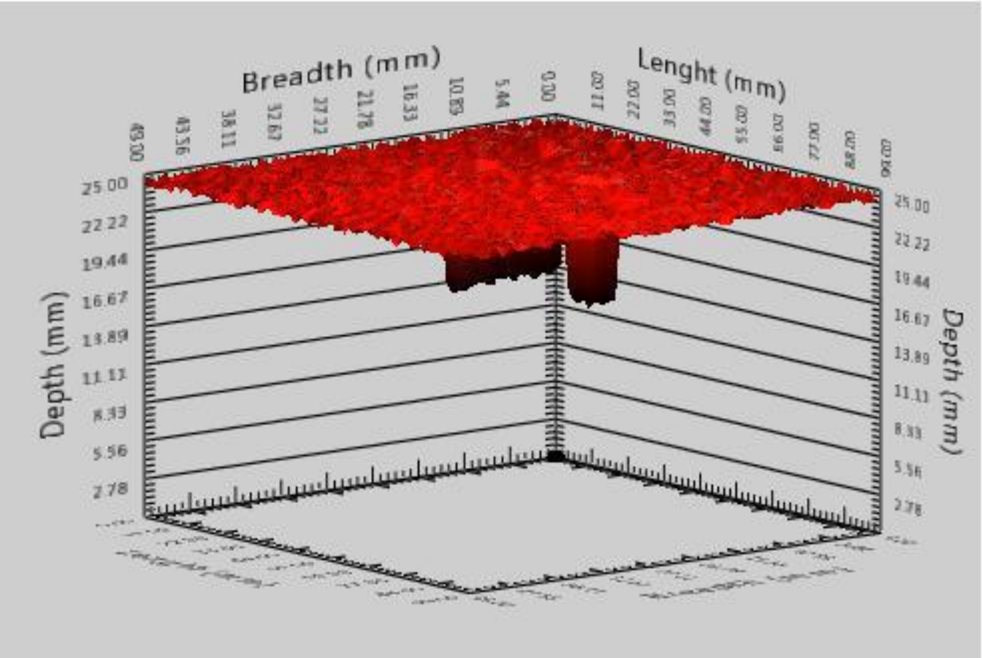
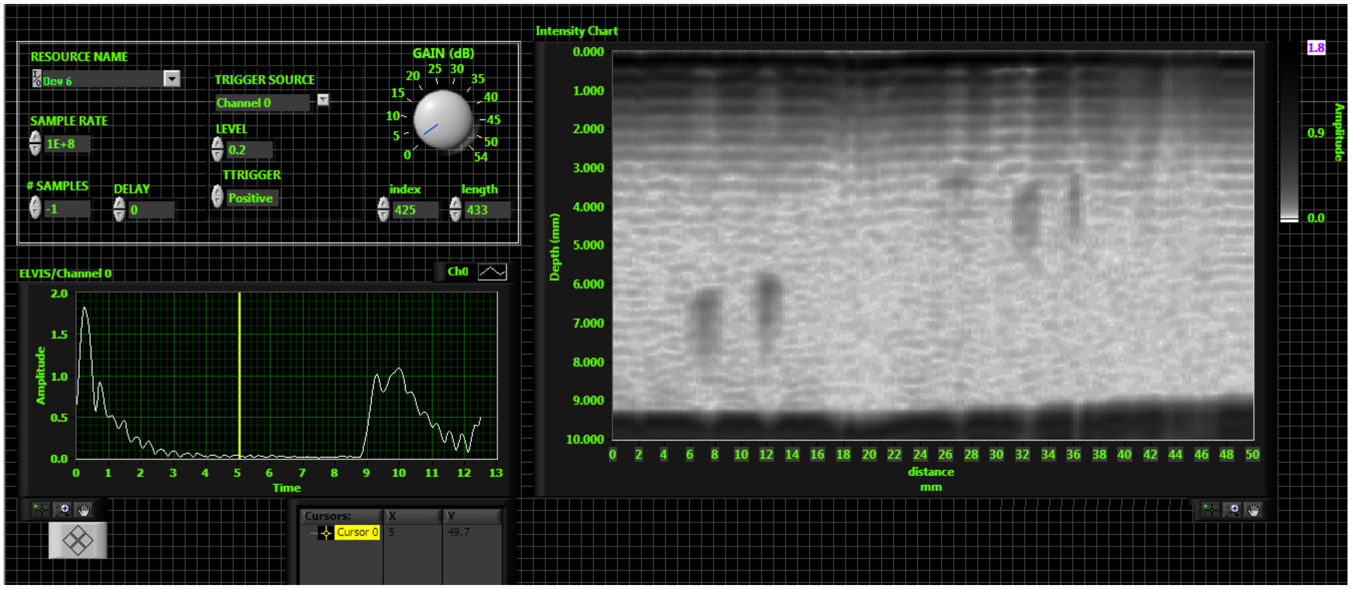


**Fig.7 Three-dimensional view of C-scan obtained from a test piece with a side-drilled hole and a volumetric defect.**



RESOURCE NAME: Dev 6
TRIGGER SOURCE: Channel 0
SAMPLE RATE: 1E+8
LEVEL: 0.2
TTRIGGER: Positive
# SAMPLES: -1
DELAY: 0
index: 425
length: 433
Cursors: Cursor 0, X: 5, Y: 49.7

**Fig.8 Front panel of B-scan and C-scan Virtual instrument**

## 5. CONCLUSIONS

A low-cost, table-top, computer controlled motion frame with 3-axis manipulator is built. Using this motion frame the movements of transducer was controlled with precision. Automated immersion tests were carried out using the motion frame and the signals were presented in A-scan, B-scan and C-scan using a solitary virtual instrument. Location and size of flaws in the test specimen could be determined accurately from the results obtained. Automatic data logging capability has been included in the system to acquire and store signals in spreadsheet format for every point of inspection. Options are provided to save the scan images in disk.

## 6. ACKNOWLEDGMENTS

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