COMPUTERIZED ULTRASONIC TEST EQUIPMENT-A VIRTUAL INSTRUMENT FOR ULTRASONIC NON-DESTRUCTIVE TESTING

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Abstract

Ultrasonic Testing (UT) is a widely used Non-destructive evaluation method to evaluate materials on the basis of their structural properties and to predict their lifetime. A number of UT techniques have emerged, each of them being specialized for a certain class of test objects. In practice, dedicated instruments are employed to implement all these techniques under one roof making advanced testing quite expensive. With the intention to provide an economical and integrated platform for these techniques, Computerized Ultrasonic Test Equipment (CUTE) was developed. CUTE is a virtual instrument for UT, built using LabVIEW, which replicates traditional instruments and can be installed in any compatible computer. It aids in performing two conventional UT techniques; contact-type pulse-echo and pulse-echo immersion testing. Apart from traditional A-scan presentation of signals, CUTE is also extended for ultrasonic imaging (B-scan and C-scan) and provides a 3D-view of specimens in addition. The efficiency of the results obtained from the performed tests relies on the precise control of the motion of transducer and also the effective control of noise during testing. The existing motion controllers along with dedicated data acquisition and analysis system with signal processing tools are quite expensive and are beyond the affordability of smaller ultrasonic labs. Hence a competent, low-cost and reliable system with a computer controlled motion frame, data acquisition device and a signal processing unit is developed to benefit several small scale industries and labs.

Keywords: Ultrasonic Testing, pulse-echo technique, LabVIEW, motion frame, signal processing unit

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. 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]. The same transducer both transmits and receives the pulsed waves as the ultrasound is reflected back to the device. Reflected ultrasound comes from an interface, such as the back wall of the object or from an imperfection within the object [2]. In contact-type pulse-echo technique, the transducer is kept in contact with the test object through a thin layer of liquid couplant to prevent attenuation of ultrasonic pulse in air. In immersion testing, 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 [3]. This method can detect very small irregularities with high resolution and it can be used to scan specimens of very low thickness [4].

CUTE is a virtual instrument built using LabVIEW to eliminate the use of multiple instruments in advanced testing. Some highlights of CUTE are; presentation of signals in all three conventional modes, a 3D view of flaws in test specimens, automated testing with the help of a computer controlled motion frame, Contact-type pulse-echo testing and pulse-echo
immersion testing. It also provides—an option for simultaneous data logging and advanced de-noising tools in order to improve the signal-to-noise ratio of received signals.

2. Physical Model of CUTE

2.1 Motion Frame for automating tests-The Build

Ultrasonic imaging techniques require automation of transducer motion over the test object [5]. 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. Figure 1 is a 3D representation of the motion frame done using AutoCAD 2010.

![Fig.1. AutoCAD schematic of motion frame](image)

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. 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. 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. 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. The programming of the motion control is done using NI 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.

2.2 De-noising

The ultrasound echo is subjected to different types of noises such as material noise, structure noise, thermal noise, ringing noise, pulse noise, shot noise etc [6]. The quality and reliability of tests are also degraded to a great extent by the inclusion of noises in the signal. Thus, there arises a necessity to eliminate the noises to improve the signal-to-noise ratio (SNR) of received signals.
for a better inference about the discontinuities [7]. This system is programmed to eliminate two predominant noises that accompany the signal during testing; structure noise and thermal noise.

2.2.1 Elimination of structure noise

Structure noise is the most predominant noise found in ultrasonic signal and it is very difficult to identify this type of noise as it blends with the signal well and it occasionally masks the signal completely. It is characterized with grass shaped waveform and is virtually impossible to prevent it as it arises due to the back scattering from grain boundaries of the material. Thermal noise is generated by random thermal motion of charge carriers and it is independent of the applied voltage [8]. It is called white noise because the power spectral density is nearly equal throughout the frequency spectrum.

From a literature survey it was concluded that Wavelet Packet Transform (WPT) has been used in practice to eliminate structure noise [9]. In WPT the frequency band of signal is divided into many levels and then the high frequency components are further decomposed. The signal is passed through LPF whose output is a smoother version of the signal. The HPF result is the wavelet function. The resulting output from both the LPF and HPF are taken as the recursive input for the next levels of wavelet transform [8-9]. Figure2 describes the second order wavelet packet decomposition.

The low pass filter result is given by equation1,

\[ H = \frac{\text{even}-\text{odd}}{2} \]  

The high pass filter result is given by equation2,

\[ G = \frac{\text{even}-\text{odd}}{2} \]  

Figure4 illustrates the algorithm developed in LabVIEW for second order wavelet packet transform in which the wavelet decomposition algorithm illustrated in figure3 is used as a subVI in every frequency ordering level.

![Fig.2. Wavelet packet decomposition](image-url)
Fig. 3 LabVIEW Algorithm for wavelet decomposition

Fig. 4 LabVIEW algorithm for WPT

Fig. 5 a) Signal with structure noise
b) Result of WPT frequency order 4
### 2.2.2 Elimination of thermal noise

Moving average (MA), also called as running average, is performed on random time series data to smooth out short term fluctuations. Thermal noise has a uniform Gaussian distribution and hence can be easily eliminated using MA algorithm [10]. The amplitudes of the noisy signal are stored in the form of an array. The signal is smoothened by taking the average of odd number of successive points, $2n+1$ ($n=1, 2, 3, \ldots$) where $(2n+1)$ is the width of the filter as shown in equation 3. As the width of the filter increases, the smoothing effect also increases [11].

$$y[i] = \frac{1}{2n+1} \sum_{j=-n}^{n} x[i+j]$$

The amount of noise reduction due to this type of filtering given by square root of number of points is the average. Figure 6 illustrates the algorithm in a flowchart.

![Algorithm Flowchart](image)

**Fig. 6 Algorithm for moving average**

**Fig. 7 Elimination of thermal noise by moving average**

- **a)** Original signal with thermal noise
- **b)** 25 times average
- **c)** 55 times average
2.3 Virtual instruments for Signal presentation

A virtual instrument has been developed using NI LabVIEW 2009 which facilitates presentation of signals in all three conventional modes; A-scan, B-scan and C-scan. The A-scan denotes amplitude modulated scan and gives information about irregularities in one dimension as a function of time or distance [12]. Figure 8 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. 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. C-scan imaging is done to present the planar (top) view of the entire test specimen. Figure 9 illustrates the virtual instrument for ultrasonic imaging [5, 12].

Fig. 8 Front panel of Virtual A-scan detector

Fig. 9 Front panel of B-scan and C-scan Virtual instrument
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