Design and development of real–time welded metal defect classification automated ultrasonic testing system

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Abstract. This paper discusses the design and development of a portable PC-based Automated Ultrasonic Testing (AUT) system, which is capable of classifying defect types on a welded metal components in real-time. Three types of welding defects such as a crack, slag inclusion and cluster porosity plus the normal condition (no defect) were used as the test states for the classification process. The system utilizes an ultrasonic pulse-receiver card model attached to computer notebook for signal display. A new specific software package (RUSS) was developed to control the operation of the scanner, displaying the data, extract the signal defect and classify type of defect. The proposed algorithm and complete system were implemented in a computer software developed using Microsoft Visual BASIC 6.0. The classification process NNTool in MATLAB component was manipulated by using the ActiveX. Some result shows the successful of the calibration module and real – time extraction for classification module type of defect

1. Introduction

Non-Destructive Testing (NDT) is important for controlling the quality of structural and engineering materials. This technology is very important for human security and the capacity of industrial plants. The Automated Ultrasonic Testing System (AUT) is an advanced ultrasonic test technique that uses computerized techniques in evaluating and interpreting the reflected signal from any sound reflector including deficiencies in the material. One of the most commonly used imaging techniques is the C-scan system that can provide an image of defects in the welds examined.

However, the ability to interpret the type of disability from interaction with ultrasound can also be important. For example, some ultrasonic reflectors (eg planar crack) are more likely to lead to ultimate failure than volumetric weakness such as slag or porosity. While this development is important, the recognition of ultrasonic patterns is not widely used in practical examination in the industry, since the application of this approach requires the operator's understanding of all the details related to this method [1].
Figure 1 (a) and (b) show the hardware and software in previous development of AUT system for weld flaw analysis to allow real-time measurement of ultrasonic flaw signature features. The system includes an ultrasonic transducer that scans in an x-y plane and is connected to an electronic pulser/receiver, a dual timing gate, a peak detector, and a universal timer. At each position x-y along the scan, the computer estimates the maximum amplitude of any feature that reflects ultrasound, using back wall pulse-echo (also called "time of flight") of the ultrasonic signal. After calibration, the peak detector operates with a time gate chosen so that its output indicates the amplitude of the signal reflected from the feature of interest at x, y. Once the scan has been completed, the computer processes the x-y scanning-position data and the associated amplitude data into a C-scan plotting. The value of the data is plotted using colors to produce detailed images of the internal features in welded plate. The area of interest which contains the maximum amplitude can be chosen automatically from the image and the scanner is set to move the transducer to the target area for flaw signature analysis. The software obtains the A-scan at the point and performs both time-domain and frequency domain analysis to obtain unique characteristics which can be used to classify the type of flaw at the selected point.

**Figure 1.** Hardware fabrication for RUSS System.
2. Material and Method

The defect signals can be obtained from the echo signal if the equipment has been properly calibrated. In this study, an angle-beam probe 60° with 5MHz and the standard calibration V2 block were used for the equipment calibration. The zero point on the scale is directly connected to the surface of the object being tested.

When specifying the calibration range, the naming of the material is also important because the displayed distance of the echo, sound path, $s$ (BPL, mm), is always deduced from the time of flight, $t$ of the pulse and the sound velocity, $c$ (km/s) according to the equation [2]:

$$s = \frac{c \times t}{2}$$

Figure 2. Software modules for RUSS System.

Figure 3. Equipment calibration using V2 block.

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$$s = \frac{c \times t}{2}$$

(1)
Referring to Figure 4, if the signal obtained from the deflection of defect, the depth, $T$ and the actual depth, $T_s$ can be calculated from the equation 4 as below.

$$\text{Figure 4. Beam path length (BPL), } s \text{ from reflected signal.}$$

If sound path, $BPL$, $s = ik$ then real depth, $T_s$;

- Full skip distance, $j-k$, $FSD = BPL \times \sin \theta$ (2)
- where, $i-j$, $T = BPL \times \cos \theta$ (3)
- Real depth, $T_s = 2T_i - T = 2T_i - (BPL \times \cos \theta)$ (4)

The examination was performed on different welded samples (dimension 145mm x 70mm) with thickness of 10mm. Three types of welding defects such as cracks, slag and petal cans are used as test and normal conditions (no defect) welding as a reference for the next classification process. Figure 5 shows the area of interest which contains the maximum amplitude that can be chosen automatically from the C-Scan image and the scanner can set to move the transducer to the target area for the features extraction analysis.

$$\text{METHOD OF SCANNING}$$

$$\text{C-SCAN IMAGE}$$

$$\text{crack}$$

$$\text{slag}$$

$$\text{cluster porosity}$$

$$\text{Figure 5. C-scan and DIR image of crack, slag and cluster porosity.}$$
3. Results and Discussion
Figure 6 shows that the calibration process has been successfully performed where the first peak value at the box gate for the beam path length, BPL = 25 mm, skip distance, FSD = 21.65 mm and depth, T = 12.5 mm. The calibration panel shows shear wave velocity for steel calibration block V2 equivalent to 3266.1 m/s. The distance between the two echo peaks is 75 mm which is equivalent to 2392 sample data and for each 1 mm equals to 31.9 sample data. The zero point and maximum peak are equal to 354.6 and 1120. Examples of calculations for obtaining shear velocity values, BPL, FSD and T are shown as below.

![Figure 6. Calibration module using V2 block.](image-url)
From equation 1, sound path i.e. \( S = \frac{c \times t}{2} \):

\[
\text{shear velocity} = \frac{2 \times \text{first peak}}{(\text{linegate}1 - \text{zeroline}) \times \frac{1}{\text{sampling rate}} \times 1000} \]
\[
= \frac{2 \times 25}{1120 - 354.6) \times \frac{1}{50000000} \times 1000}
\]
\[
= 3266.3 \text{ m/s}
\]  

(5)

Beam Path Length, BPL is given by:

\[
\text{BPL} = \frac{\text{shear velocity} \times (\text{maximum peak} - \text{zeroline})}{2 \times \frac{1}{\text{sampling rate}} \times 1000}
\]
\[
= \frac{3266.3 \times (1120 - 354.6)}{2 \times \frac{1}{50000000} \times 1000}
\]
\[
= 25 \text{ mm}
\]  

(6)

From equation 2, Full Skip Distance FSD = BPL x Sin\( \theta \):

\[
\text{FSD} = \text{BPL} \times \sin \left( \frac{60 \times 3.142}{180} \right)
\]
\[
= 25 \times 0.8661
\]
\[
= 21.65 \text{ mm}
\]  

From equation 3, Depth \( T = \text{BPL} \times \cos\theta \):

\[
\text{T} = \text{BPL} \times \cos \left( \frac{60 \times 3.142}{180} \right)
\]
\[
= 25 \times 0.4999
\]
\[
= 12.5 \text{ mm}
\]  

(7)

After the noise has been removed, time and frequency domain analysis were executed automatically on the filtered data. The first analysis was done in full wavelength-time domain where the value of the maximum amplitude, pulse duration, rise time and fall time is calculated. The second analysis was done in RF wavelength-time domain where the same features value of number of peaks, pulse duration, rise time and fall time are calculated. Then the software transforms the frequency domain signal via the application of discrete Fourier transform to extract maximum frequency spectrum and number of peak. Figure 7 shows example extraction of the time and frequency domain for slag weld defects. All parameters setting at the same condition for others defect signal.
Figure 7. Features extraction for slag weld defect (a) full wavelength, (b) RF wavelength and (c) frequency domain.

For early stage, back propagation algorithm is used to train the neural network. The neural network architecture has three layers consists of input, hidden and output layer. Figure 8 shows the twelve real time input of neurons as input data. The hidden layer consists of 3 activation functions (tansig, logsig and purelin) which are determined by trial and error and the output consists of 4 neurons representing type of defect classification.
Figure 8. Neural network architecture

Figure 9 shows the results of the classification signal to the specimens crack, slag, cluster porosity and normal. By referring to the feature values in each diagram, this software has successfully automated the classification of each data obtained with a value of '1' which represents the type of defect.
4. Conclusion
This paper shows that the combination of time domain, defect location and frequency domain can be used for features extraction of weld defect. Simple neural network models have been developed and successfully classified the types of defect. For future improvement, we recommend confirming results with more specially designed test specimens and others artificial intelligent to provide a better learning environment.

5. References
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