Feature Extraction and Classification of Welding Defects using Artificial Neural Network

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Abstract:- The detection and classification of the defects in the welded components are very important in order to ensure the structural integrity of the fabricated components of the test blanket module (TBM). RAFM steel is used as structural material for the TBM, therefore ultrasonic based technique are the most suitable for high sensitive defect detection. In this work ultrasonic pulse echo technique is used to perform the experiment and the ANNs (artificial neural networks) technique is used to detection and classification of the defects in the welded region. For this study, artificial defect (Side drilled hole, notch and flat bottom hole) are fabricated in the welded region. In this paper this data acquisition from different type of defects and extraction of feature from these signal are discussed. Artificial neural network will be used for the classification of the defects.

Keywords: *Electron beam welding, Artificial neural network, Signal processing, Defect detection. Test blanket Module, Ultrasonic testing.*

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I. INTRODUCTION

India is developing its own concept of Lead-Lithium Ceramic Breeder (LLCB) Test Blanket Module (TBM) for testing in ITER. The manufacturing of the TBMs is one of the most challenging tasks. Each of the manufacturing process steps has to include reliable quality control and Non-Destructive Evaluation (NDE). Therefore it is very important to develop the NDT methods for 100% examination of the welded components of the TBM [1-3]. Ultrasonic based methodologies are the most widely used for inspection of the welded components. The ultrasonic waves propagates thorough material under test and is reflected by any discontinuity encountered in its way of propagation. The signal obtained from discontinuity possess information about defects size and orientation.

Despite the advantages of the ultrasonic technique, a high speed of inspection, high probability of detection, and low number of false results, the classification of defects based on ultrasonic signals is still frequently questioned, since the analysis and the identification of defect types depend exclusively on the experience and knowledge of the operator. The correct classification of the type of flaw present in the material reduces measurement errors, increasing the confidence in the test and consequently the safety of the material in future application.

The weld defect classification using artificial neural network can be divided in three parts: 1) Acquisition of signal experimentally 2) Feature extraction from these signals 3) Develop MATLAB programme for feature extraction. 4) Develop artificial neural network methodology. 5) Testing of neural network.

II. EXPERIMENTAL PROCEDURE

The test piece used in this work is a box structure fabricated using electron beam welding. It was fabricated using 10 RAFM steel plates having dimensions 180 mm × 65 mm × 6 mm. Welding defects (lack of penetration and porosity) were generated during the welding process as depicted in figure 1. Also, in the weld region of the box structure, notches having depth 10%, 5% and 2.5% of wall thickness (WT = 6 mm) and length 12 mm and 6 mm, were fabricated at outside or inside of the box structure with the use EDM technique. The experiments were performed using the 70 degree angle beam ultrasonic transducers of central frequency 5 MHz. The pulser-receiver used for the excitation of the transducer and receiving of ultrasonic waves is a USB-based pulser-receiver from M/s. Lecoeur Electronique, France. The pulser receiver is powered by a laptop computer via USB. The pulser-receiver is controlled by a LabView program loaded in the laptop computer as shown in figure 2. The parameters such as the emission voltage of 170 V, centre frequency of 5 MHz, pulse repetition frequency of 1 kHz, gain of 38.5 dB, averaging of 5 and a filter of 8 MHz were used for the mock-up sample. The ultrasonic transducers were placed across the weld, as shown in Figure 2. Normal beam inspection is also carried out using the normal probe (frequency 5 MHz) over the welded region.

A programme was developed for the data acquisition of the ultrasonic experiment using the LabView. It gives the ultrasonic experimental results in A-scan, B-scan and C-scan configuration [4]. In A-scan results the information about the signal amplitude, location in the material and sound path traverse in the material were given. In this study A-scan signals acquired from the defects were used for the signal processing and feature extraction.

Flat bottom hole was detected using the normal beam technique as shown in figure 3. For the detection of the other welded defects angle beam technique was used. Approximately 50 A-scan signals (pulse-echo configuration) for each defects were recorded as shown in figure 3 and 4. For this, the transducers were placed at several positions along two lines parallel to the weld bead (the adopted perpendicular distances from the weld bead center line were 16 mm and 18 mm).

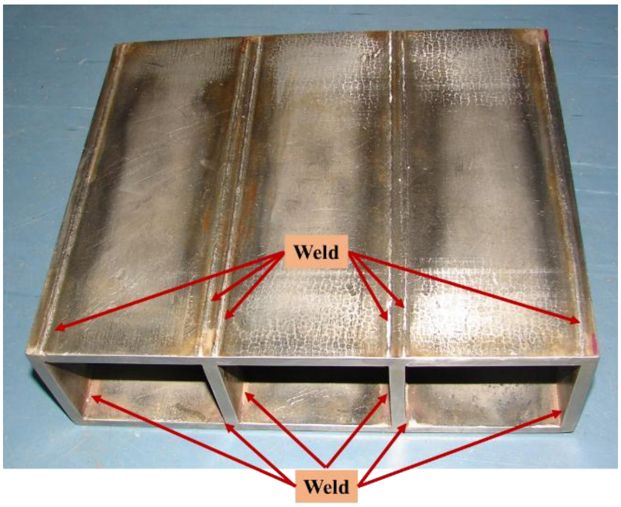

Figure 1: Photograph of the box structure

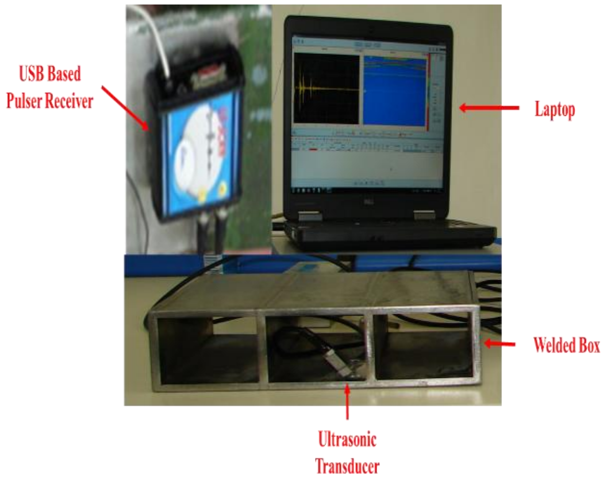

Figure 2: Photograph of the experimental set-up used during the experiment.

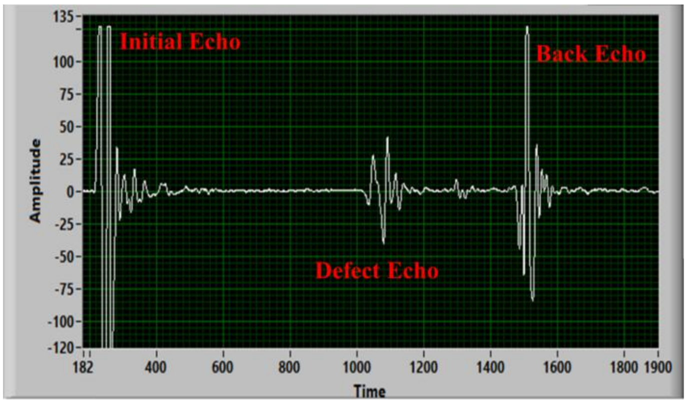

Figure 3: A-Scan signal obtained from the defect location in the welded region (normal beam technique).

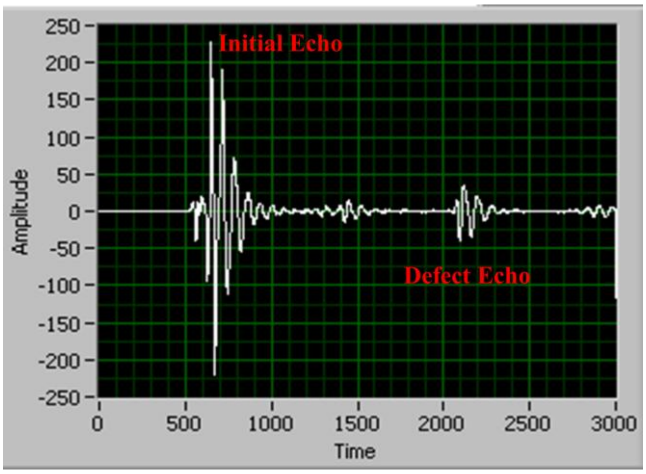

Figure 4: A-Scan signal obtained from the defect location in the welded region (angle beam technique).

III. SIGNAL PROCESSING

The digital signal processing plays a vital in the extraction features from the measured signals. Ultrasonic signals contain numerous non-stationary or transitory characteristics. These characteristics are often studied using the wavelet transformation (WT), because it is the recent technique for processing non stationary (transient) signals simultaneously in time and frequency domains. Its application seems to be attractive for ultrasonic data processing, especially for detection of defects in grainy materials. In ultrasonic it is applied for enhancement of detection of defects.

The wavelet analysis makes use of finite-length function ψ (t) (called mother-wavelet) to create a representation for a given time domain signal. Scaled and shifted versions of the mother wavelet function are summed in order to approximate the signals of interest [5-6]. For a continuous-time signal f(t) the wavelet transform F(a,b) is defined in Equation given below:

$$F(a,b) = \int_{-\infty}^{\infty} f(t)\psi_{a,b}(t)dt$$

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Where $\psi_{a,b} = \frac{1}{\sqrt{a}}\psi(\frac{t-b}{a})$ a and b are scale and shift parameters respectively.

The discrete wavelet transform (DWT) analyses the signal by decomposing it into its coarse and detailed information. In this the original signal is first passed through a half band high pass filter and a low pass filter. The above procedure can be repeated for further disintegration.

Feature selection: Transforming the input data into the set of features is called features extraction. According to Haykin (1998), feature extraction is a process which an input space is mapped to a feature space [6-10]. This mapping is carried out such that the feature space has a dimension smaller than the input space, but it still keep data information contents. The input data set can have also reduced dimensionality. In this work S.MALLAT algorithm is used for the feature extraction. It is used to extract characteristics from a signal on various scales proceeding by successive high pass and low pass filtering. The wavelet coefficients are the successive continuation of the approximation and detail coefficients calculated by S.MALLAT decomposition algorithm on different levels using DAUBECHIES window [10-13]. The basic feature extraction procedure consists of

- Decomposing the signal using DWT into *N* levels using filtering and decimation to obtain the approximation and detailed coefficients
- Extracting the features from the DWT coefficients.

MATLAB code was written to perform the signal processing of the ultrasonic A-scan signal. A MATLAB programme also written for the feature extraction of the ultrasonic signal. Feature extraction will be discussed in the next section.

IV. FEATURE EXTRACTION

Features for discrimination of detected echoes are extracted in discrete wavelet representation. In this study, 12 features are extracted from the each signal of the four classes. The extracted features from the signal and their relationship are as below:

1. Mean
2. Variance
3. Mean of the Energy Samples
4. Maximum Amplitude
5. Minimum Amplitude
6. Maximum Energy Samples
7. Minimum Energy Samples
8. Average Frequency
9. Mid Frequency
10. Frequency of Maximum Energy Samples
11. Frequency of Minimum Energy Samples
12. Half Point of the function energy

In the feature analysis, the variation of the twelve features with respect to each classes of defect is analysed and for each defect, the average values for all the features is determined. By analysing and comparing the graphical results, it is inferred that among the extracted twelve features; only eight features have given faithful information and also good discrimination between the flaws.

So in this study, a set of 8 features (which are the important parameters for each type of defects) is calculated from the reflected echo of each signal. These eight features are taken as the input to the ANN.

V. ARTIFICIAL NEURAL NETWORK

The Neural Network Toolbox in the MATLAB 2012 software is used for the design, implementation and simulation of the network with feed forward back propagation algorithm. Two types of neural network architectures are used for classification namely a multi-layer feed forward back propagation network (BPN) and a probabilistic neural network (PNN). There are generally four steps to perform the classification of data

- Assemble the training data
- Create the network object
- Train the network
- Simulate the network response to new inputs.

In the classification, different classes of defect considered in order to test the back propagation neural network performance. Back propagation neural network classifier is implemented with a supervised mechanism using MATLAB software. The transfer function in the hidden layers should be differentiable and thus, either log-sigmoid or tan-sigmoid functions are typically used. They calculate a layer's output from its net input.

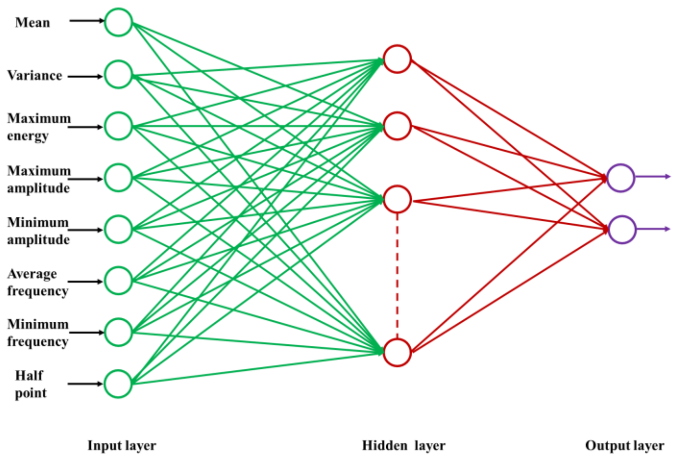

Figure 5: Proposed ANN Model.

Here, the tan-sigmoid transfer function, 'tansig' is used for the hidden layers and also in the output layer. Each hidden layer and output layer is made of artificial neurons, which are connected through adaptive weights. The training functions selected for the back-propagation network are 'trainlm' and 'trainscg' which are built-in functions in Matlab. Trainlm is a

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network training function that updates weight and bias values according to the Levenberg-Marquardt training algorithm. Trainscg is a network training function that updates weight and bias values according to the Scaled Conjugate Gradient back-propagation training algorithm. In this work, different combinations of neurons and activation function in hidden layer and output layer were tried. Finally, a fully connected feed-forward neural network is selected which consists of an input layer, an output layer and one hidden layer.

An input layer has 8 neurons corresponds to number of features and hidden layer consists of 17 numbers of neuron. The output layer has only two neurons. In the output layer, 1 0 is set for Side drilled hole, 0 1 for flat bottom hole, 1 1 for notch and 0 0 for non-defect. The back propagation neural network architecture is 8-17-2 which is shown in Figure 5. The developed NN is trained several times until the number of neurons along with the initial weights and biases satisfies the error goal of 1e-2.
Ten number of signals for each class of defect are considered selectively for analysis. After processing the ultrasonic flaw signals by using wavelet transform, 40 datasets for each class of defect (10x4=40, 10 - No. of signals, 4 - Four detail sub-bands) are obtained. Hence 160 datasets are given as input to the back-propagation neural network. From this, the dataset are divided as training set and testing set in such a way that 136 datasets are randomly chosen for training the neural network and 24 datasets for testing the neural network.

Before training the network, the input data were normalized suitably by using pre-processing (premnmx) and post processing (postmnmx) function in Matlab. The training data are fed into the network and after several iterations, the back propagation neural network is converged to the error goal of 1e-2. After training, the network is tested with the new inputs using sim function in Matlab. Test data do not contain the data used for training the network. During testing, the neural network gives the classification result based on the learning from the input/target pattern.

VI. CONCLUSION

The selected eight features are giving good discrimination between material defects and are considered as the main parameters which influence the classification of defects and hence these eight features are taken as the input to the ANN. Based on feature analysis, other four features such as Mean, Maximum Energy, Average Frequency, Half Point are neglected as it gives similar values for all classes of defect. The obtained classification accuracy for the detection and classification of defects are very encouraging, showing the suitability of the proposed approach to the development of a decision support system for non-destructive testing of materials for defect characterization. The success rate of this approach is higher compared to the other methods.

VII. FUTURE WORK

The eight selected features from the ultrasonic signal (A-Scan) are used as the input to the ANN. Therefore, the input of the ANN is eight component vector. In this present study, four classes of welding defect such as Side drilled hole, notch, flat bottom hole and non-defect are considered for classification of ultrasonic signals using ANN. Classification may be done for more than four classes defect and the classification performance can be compared.

VIII. ACKNOWLEDGEMENT

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