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DE-NOISING ULTRASONIC TOFD SIGNALS: A COMPARATIVE STUDY OF WAVELET PACKET METHOD USING SURE WITH SSP TECHNIQUE

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ABSTRACT:

The signals obtained from a system generally contain a number of unwanted information, termed noise, which needs to be removed during the pre-processing of the signals, for further analysis. Unprocessed ultrasonic welding defect signals, which contain noise, are not easily identified for the type and pattern of flaws they contain. Especially with TOFD welding defect signals which is often mixed with noise, distinction between grain noise and small flaws is not always easy. Presence of larger grain noise makes it difficult to interpret the defect result and noise. Thus, it is of great importance to de-noise the ultrasonic welding defect signal before classification of defect is carried out. This paper mainly focuses on the use of wavelet packet method using Stein's Unbiased Estimation of Risk(SURE) to de-noise the TOFD welding defect signals and the results has been compared with that of Split Spectrum Processing (SSP) with Polarity Thresholding algorithm (PT) for de-noising of the same.

Keywords: *Split Spectrum Processing (SSP) Technique, Time of Flight Diffraction (TOFD), Wavelet Packets, Signal to Noise Ratio (SNR).*

1. INTRODUCTION:

A number of signal processing techniques are available for the detection and characterization of defects. The signal to noise ratio (S/N) is mostly used to measure the strength of desired signal to that of the background noise [1]. Ultrasonic welding defect signals come under the category of nonlinear and non-stationary signals [2]. The SSP technique and the wavelet packet method, both enhance the SNR of the TOFD welding defect signal and produce clear waveform namely back-wall echo, defect diffracted wave and lateral wave. However, the wavelet packet method proves to be more effective to that of the SSP technique as it provides greater enhancement of SNR of the defect signal. A noise-free or a signal with very little noise ensures easy characterization of the defects [3]. Back-wall echo, diffracted echo and lateral wave constitute the typical pattern of waves involved in the TOFD technique [4][5] as shown in figure 1.

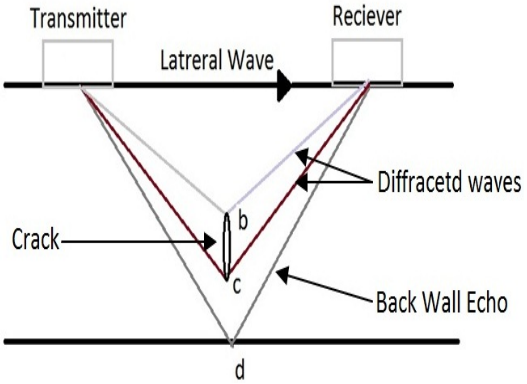

Figure 1.Pattern of waves in TOFD.

This paper has been divided in to various sections. At first the simplified model for the experimental setup for obtaining the sample TOFD signals has been discussed, followed by a brief overview of SSP technique for de-noising the signals. The next section deals with a brief description of the wavelet packet method, which has been used to de-noise the signals and then the result has been tabulated and compared.

2. EXPERIMENTAL SETUP:

The TOFD A-scan signals are obtained by using the TOFD experiment model of M|S AEA technology, UK with manual scanner along with longitudinal wave (4 MHz) angle beam probe of 45˚ (model WSY 45). Several A-scans were obtained by scanning of the welded bead using a manual weld scanner. A total of 330 signals were obtained by inspecting 11 test samples. Since raster scanning is not necessary, the time required to scan a length of weld is very short. As shown in figure 2, probe separation between transmitter probe and receiver probe should be maintained [6].

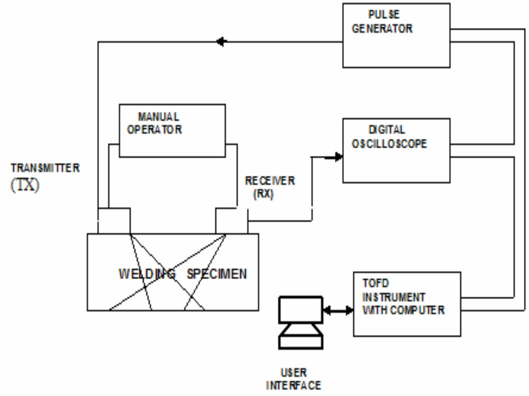

Figure 2.Experimental setup

3. SPLIT SPECTRUM PROCESSING TECHNIQUE:

In SSP technique, the received TOFD testing signal's spectrum is splitted, by means of equally spaced band pass filters mentioned in figure 2, into different overlapping frequency bands. Using non-linear selection technique, only those signal information is retained which have a strong correlation among a number of the sub bands at a given time instant. Amrit *et al.*[7] applied polarity thresholding algorithm on the obtained time domain signal Gn(t) for TOFD welding defect signal.

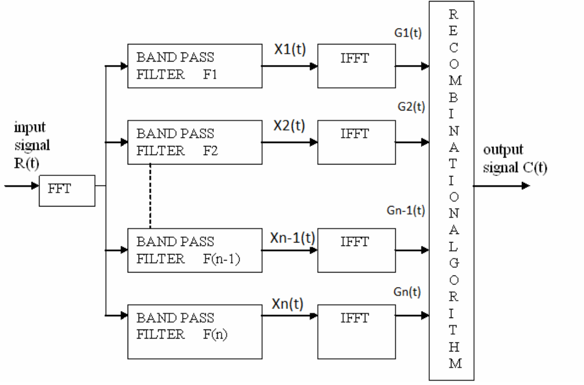

Figure 3. Split Spectrum Processing Technique.

The following observations were made by Amrit *et al* [7] for Split Spectrum Processing of the TOFD defect signal, obtained from AISI steel plates with dimension 260 X 260 X 25mm. Figure 4(a) shows a typical unprocessed signal named LF-01 possessing the information back-wall echo, defect diffracted wave and lateral wave. The TOFD welding defect signal is mostly embedded with highly scattering grain noise. Figure 4(b) shows the magnified version of high frequency component (caused by scattering).

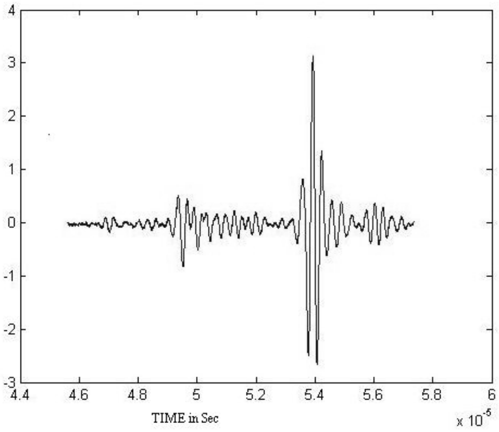

Figure 4(a). TOFD welding defect A-scan signal

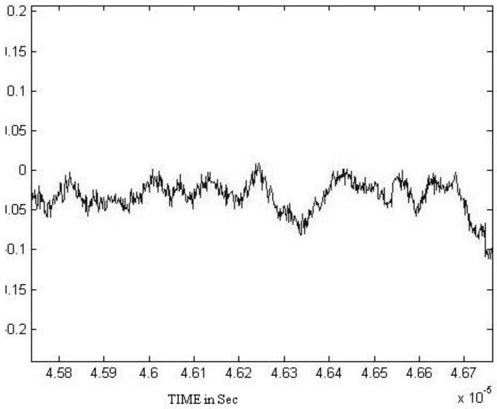

Figure 4(b).Magnified version of high frequency component present in TOFD welding defect signal.

Figure 5 shows the output obtained when TOFD welding defect signal was applied to SSP filtering network [7] where the defect location and back-wall echo of the signal can easily be identified.

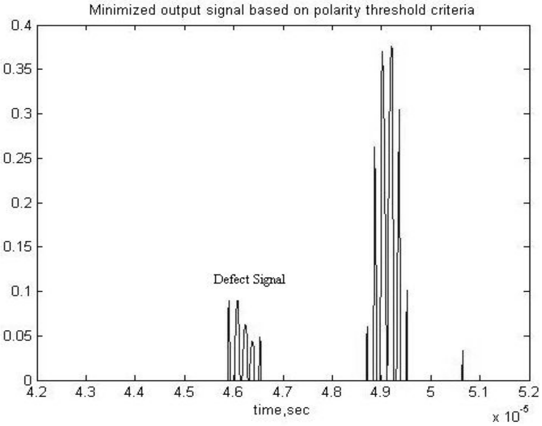

Figure 5. SSP filtered output signal.

Hence, applying the SSP technique over the selected LF-1 signal, the SNR of the output was calculated to be 25.41 while the SNR of original signal was 3.36.

4. THE WAVELET PACKET METHOD:

As compared to wavelet transform (WT), which decomposes the low frequency of the signal whereas, high frequency component (detail component) is not decomposed continuously, in Wavelet packet transform (WPT), the frequency band is divided into a number of levels. The high-frequency components are further decomposed, so that the signals, containing a lot of information can be suitably expressed. The frequency band is chosen adaptively in Wavelet packets, based on the characteristics of analysis signal and it is matched with signal spectrum thereby increasing the processing ability of the signal greatly [8].

The noise present in the signal of interest is primarily high frequency whereas the original signal is of low frequency, thus it is likely that the detail component will contain more noise. The approach used to de-noise the signal is thresholding or shrinkage of detail component, in which the size of detail is reduced before signal reconstruction [9]. The detail component cannot be discarded fully as they may contain important information. Various type of thresolding is available but for the de-noising of the TOFD defect signal, the soft thresholding was used in which the wavelet coefficients are reduced by a quantity which is equal to the threshold value [10].

The de-noising of signal involves estimation of noise level, for which the Stein’s Unbiased Estimation of Risk (SURE) [11] was chosen for selecting a threshold. De-noising of the signal is done in the following four steps [12].

1. Computation of wavelet packet decomposition of the TOFD welding defect signal at level 4.

2. The optimal wavelet packet tree is computed for the given entropy.

3. For each packet, thresholding is calculated as follows.

$$\text{Threshold} = \frac{\sqrt{2 \text{ X} \log\left(\text{length X} \log\left(\text{length}\right)\right)}}{\sqrt{\log\left(2\right)}}$$

Where, length is equal to the length of the signal.

4. Computing wavelet packet reconstruction based on the original approximation coefficient at level 4 and the modified coefficients.

Figure 6 shows the result of wavelet packet de-noising of the signal LF1-C. The smoothening and compaction of the signal is clearly visible. The high frequency component of the signal is removed keeping the original information of the signal almost unaffected. The SNR of the de-noised signal LF1-C is obtained to be 35.5927. Table 1, compares the result of de-noising of some TOFD defect signal through SSP technique and wavelet packet method.

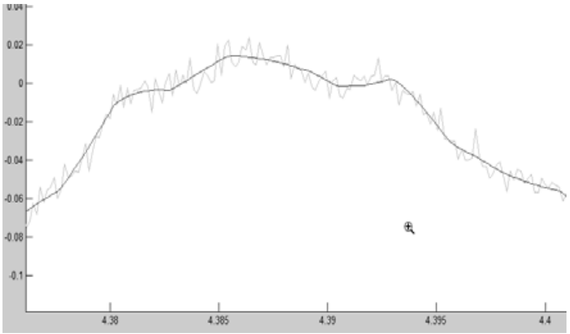

Figure 6.Result of wavelet packet de-noising.

Table 1.Comparision of de-noised signals through SSP and Wavelet Packet method.

Signal identification	SNR Original	SNR after de-noising signal with SSP technique	SNR after de-noising signal with Wavelet Packet method.
LF1-C	3.36	25.41	35.59
LF2-C	3.25	24.70	35.42
LF3-C	2.48	24.49	34.03
LF4-C	2.13	27.09	35.60
LF5-C	1.53	27.90	37.87
LF6-C	0.87	31.57	37.09
Average of original SNR=2.27 Average of SNR of the de-noised signal through SSP technique= 26.86 Average of SNR of the de-noised signal through WP method= 35.93			

Table 1 shows the SNR value of the de-noised output of the wavelet packet method using SURE. As given in the table, it is clear that the applied method enhances the SNR of the signals to a significant level. Furthermore, the SNR for the de-noised output using SSP method has also been given. On one hand where average SNR obtained after using wavelet packet method using SURE is 35.93, it is 26.93 for that using SSP technique. Hence it proves the relative superiority of the presented method for ultrasonic welding defect signal over SSP.

5. CONCLUSION:

Hence for the de-noising of TOFD defect signal, the wavelet packet method gives better output as compared to that of the SSP technique. The wavelet packet, being an important time-frequency analysis technology, is especially suitable for the processing of ultrasonic signal which contains unstable and time-varying sharp pulse. The superiority of the wavelet packet method for the processing of the TOFD defect signal, over SSP technique, can easily be observed as the former enhances the SNR of the signal more and provides better output of smooth signal, with high frequency noise removed to a larger scale. The frequency domain of the signal, divided by wavelet packet, can be easily selected and classified as per the characteristic of the analyzed signal and hence more suitable than wavelet for signal analysis [13].

The de-noised signals have higher content of useful data which is required for the further analysis of it. Furthermore, the de-noising of signals removes (or reduces the unwanted details to a great extent) which reduces the computational effort required to analyze the output. Therefore de-noising is an important area of research for which this paper presents a comparatively better method for TOFD welding defect signal.

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