Interval Dependant Thresholding based De-noising of Ultrasonic TOFD Signals from Austenitic Stainless Steel Welds

Angam Praveen
School of Electrical and Electronics Engineering
SASTRA UNIVERSITY
Thanjavur, India

K Vijayarekha
School of Electrical and Electronics Engineering
SASTRA UNIVERSITY
Thanjavur, India

B Venkatraman
Radiological Safety Group
Indira Gandhi Centre for Atomic Research
Kalpakkam, India

ABSTRACT
Austenitic stainless steel has structural values in almost all industries. It is one of the most widely used materials. Qualitative assessment of such important components is of greater importance in very sensitive applications such as nuclear reactor vessels. Ultrasonic based Time of Flight diffraction is a reliable technique in testing the materials for many types of defects in welds.

Echo signals obtained by the receiver are also accompanied by ambient scattering noise due to the signal interaction with the grains of the material. This noise degrades the quality of the defect echo signal and at times completely deteriorates the shape of the defect signal there by making it unsuitable for characterization. Signal processing is a necessary aspect in restoring the defect signal's shape, size etc for proper detection and positioning of the defect in the material. Wavelet Transform is one such popular technique for de-noising of the signals in which thresholding of high frequency components removes the unwanted noise. Conventional global thresholding gives good improvement in SNR values. This paper implements an Interval dependant thresholding method and it is found that it has very good improvement in SNR values compared to conventional techniques.

Keywords
Interval Dependant Thresholding, TOFD, Discrete Wavelet Transform, Signal-to-Noise Ratio.

1. INTRODUCTION
Ultrasonic Testing is one of the most widely used non-invasive techniques for evaluating the quality of materials of structural value. Some of the conventional methods such as pulse echo and through transmission methods fail to detect flaws in many situations when the defect orientation is random. A new technique based on diffracted energy from the tips of the cracks has gained popularity in the recent past. It is known as time-of-flight diffraction (TOFD) technique derived from its diffraction principle.

TOFD technique method involves interaction of ultrasonic waves with the material grains while propagating through the material. This interaction with the material grains results in unwanted disturbances in the signal. When the defect size is small the noisy signals dominate the defect signal especially in coarse grained materials like Austenitic Stainless Steel. As a result the detection of defects become difficult and hence poses a threat in nuclear reactor components where structural quality is of at most importance. So it is necessary to ensure the acquired signals are free from noise thus enabling proper detection, sizing and characterization of defects.

Signal processing of the noisy defect signals is an important step in non destructive evaluation of structurally important materials. Split spectrum processing (SSP), Power cepstrum, Hilbert transform, Correlation technique and discrete wavelet transform (DWT) are some of the signal processing techniques [1-5] used for de-noising of signals. DWT is one of the best techniques for de-noising as it gives very good improvement in SNR values. In the present paper an interval dependant based thresholding technique is used for de-noising based on DWT.

2. TIME OF FLIGHT DIFFRACTION
Time of Flight Diffraction is a well established technique in ultrasonic NDT working on the principle of diffraction from the tips of the cracks [6-13]. Fig. 1 shows a typical set-up of TOFD and principle of working. When an ultrasonic signal encounters a defect waves get diffracted from the tip of the defect. These tips act as source for diffracted signals with lower amplitudes that are caught by the receiver. This enables exact positioning and sizing of the defects. Longitudinal waves are launched from the transmitter because of their higher velocity compared to the lateral waves.

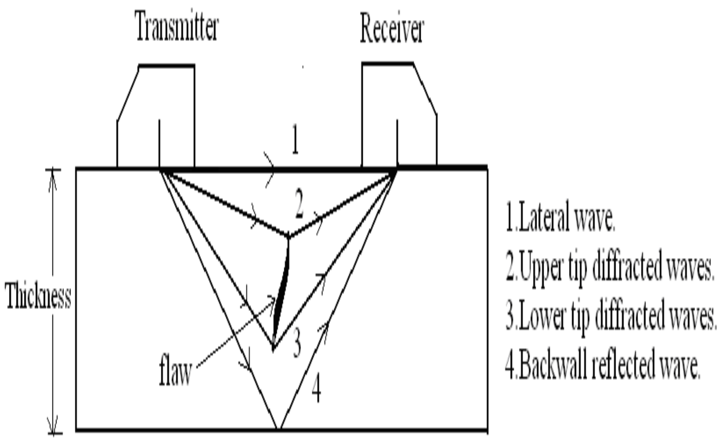

Fig 1: TOFD Schematic set-up

3. DISCRETE WAVELET TRANSFORM

Discrete Wavelets [14] are small wave like functions with limited extension in time and frequency domain. Just like Fourier transform uses sinusoids as its basis functions, wavelet transform uses wavelets as basic functions. A signal can be represented by using translation and dilated versions of a mother wavelet. The principle involved in DWT is sub band coding where a signal is decomposed into low and high frequency components. Decomposition process involves filtering with high and low pass filters described by the wavelet and scaling functions respectively. The filtered coefficients are then decimated in order to compensate for the reduced bandwidth after filtering. The low frequency components namely the approximations are further decomposed and the process is repeated till a certain selected level. Using n^{th} level approximations and details, signal can be reconstructed. DWT is widely used for the time-frequency analysis [15] and de-noising [16-23] of many of the non-stationary signals.

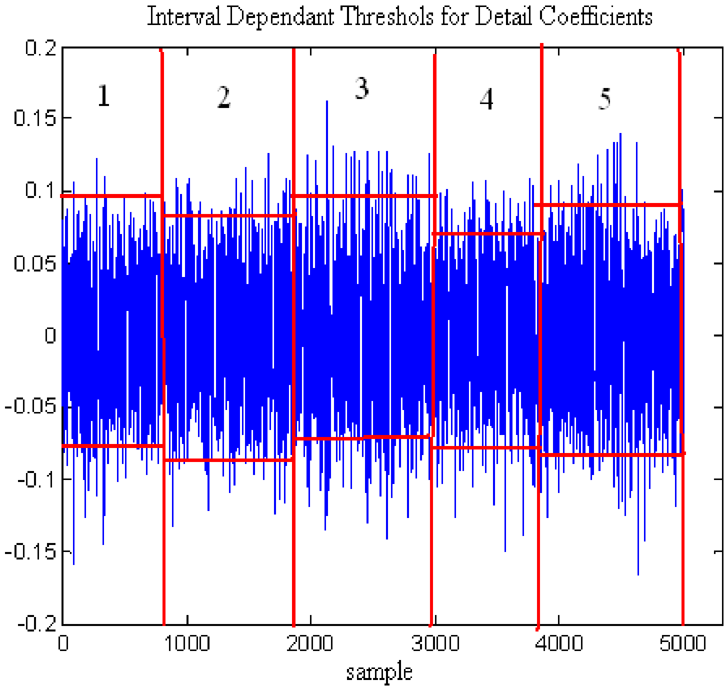

Fig 2: An example showing Interval Dependant Thresholding of detail coefficients.

4. INTERVAL DEPENDANT THRESHOLDING

Thresholding of details can be done using several methods namely global, soft, hard, minmax, level dependant thresholding[24] etc. In this paper interval dependant thresholds [25] are used to eliminate the noise. In this process the details obtained at a particular level of decomposition are split into several intervals based on the distribution of detail amplitudes. Fig.2 shows the procedure where coefficients are divided into 5 intervals and different threshold values are applied for each of the intervals. The selection of number of intervals is an important factor which is done based on the variance levels. Splitting of coefficients into 3 intervals for example indicate that the variance of the noise in each interval varies largely with respect to the immediate next interval.

5. EXPERIMENTAL DETAILS

Austenitic stainless steel weld pad of 25 mm thick, 200 mm length and 200 mm width has been fabricated by Shielded Metal Arc Welding method. A slag inclusion of length 40 mm was intentionally introduced in the weld. This weld pad has been scanned by TOFD technique. The transducers used were 4 MHz, 45° longitudinal angle. Experiment was conducted at room temperature and the equipment used was MICROPLUS from AEA Technology, UK. The channel gain was set to 80 dB while scanning. TOFD signals were acquired using a digital storage oscilloscope (YOKOGAWA –DL9140, 5GS/s, 1GHz). Fig. 3 shows the complete set-up.

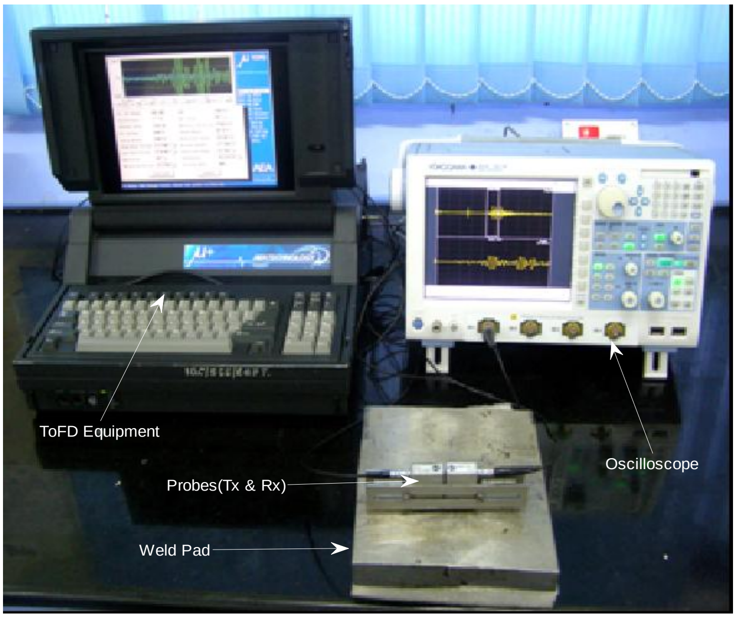

Fig 3: Actual Experimental set-up

6. FOURIER ANALYSIS

A block diagram describing the thresholding based de-noising procedure using Discrete Wavelet Transform is shown in Fig. 4. A synthetic defect signal with added noise is shown in Fig. 5. Interval Dependant Thresholding is applied to the detail coefficients of the 1^{st} level of decomposition as it contains the dominating noise. Corresponding de-noised signal using IDT is shown in Fig.6. Number of intervals taken, corresponding intervals and threshold values are listed in Table.1. Similarly in order to appreciate the performance of IDT method, original TOFD signal acquired from the weld pad is shown in Fig.7. A magnified view of the signal around the defect region is shown in Fig.8. IDT is applied to the signal. The de-noised and original signals are simultaneously shown in Fig.9. Table.2 lists the number of intervals, extension and the threshold values for each of the intervals.

Spectral analysis using Fourier transform gives information about the presence of defects but no information about the time of occurrence of defect signals. To estimate the location of the defects in the material, the A-scan signal has to be evaluated. The time varying A-scan signals from the austenitic stainless steel is highly influenced by the structural noise. Fourier transform can be applied to de-noise the signal. Fig. 9 shows a de-noised signal and the corresponding original signal obtained from an austenitic stainless steel weld. This has been achieved by simple thresholding method. The de-noised signal enables proper positioning of the defect from the surface of the material.

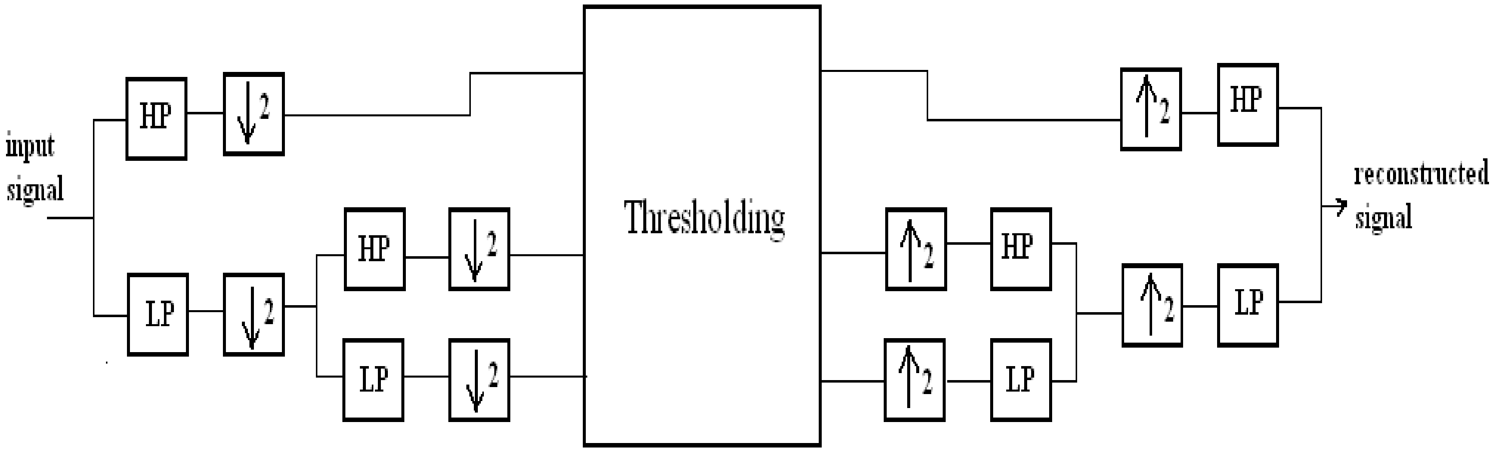

Fig 4: Block diagram showing Wavelet based de-noising

One of the most popular methods of measuring the quality of the signal is SNR calculation.

In general it is given by,

$$SNR = \frac{signal\ power}{noise\ power}$$

The formula is readily used only when the pure signal without noise and noise characteristics are known. In our case the signals are acquired in real time. So a proper method of calculating the improvement in signal quality is needed. SNR_{rms} [26] which was used in measuring the de-noising performance is used in this case. It is given by,

$$SNR_{rms} = \frac{peak\ to\ peak\ value\ of\ defect}{\sigma_n}$$

Where, σ_n is the standard deviation of the noise.

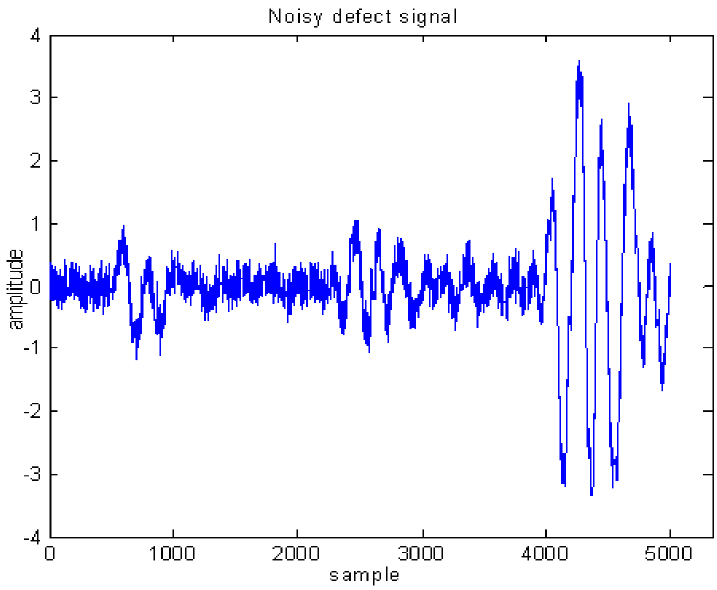

Fig 5: Defect signal with added noise

De-noising performance for difference signals are calculated using the above formula and tabulated in Table. 3. Results show a very good improvement in SNR values of ultrasonic TOFD signals using interval-dependant thresholding method.

7. CONLUSION

Non Destructive Testing is an important step in assessing the quality of nuclear reactor components. Austenitic stainless steel is one such structurally important material in nuclear fields due to some of its excellent properties. TOFD principle based testing involves noisy signals whose processing is necessary for proper evaluation of the material. Signal processing is an important tool in this area. Interval dependant thresholding technique based on Discrete Wavelet Transform is used in this paper and from the results it can be concluded that Interval Dependant Thresholding gives a significant improvement in SNR compared to other conventional techniques. An average improvement of 25 dB is achieved using this technique which shows the efficiency of this method.

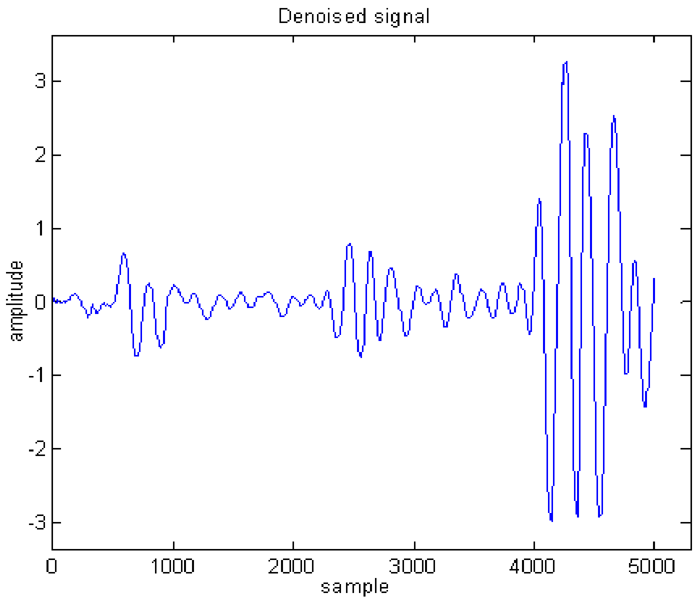

Fig 6: De-noised signal using interval dependant thresholding with 6 intervals.

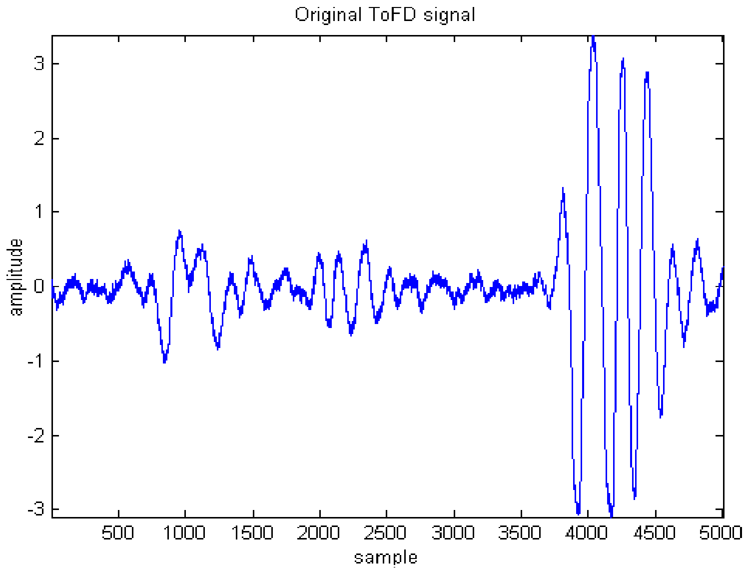

Fig 7: Original TOFD signal without de-noising

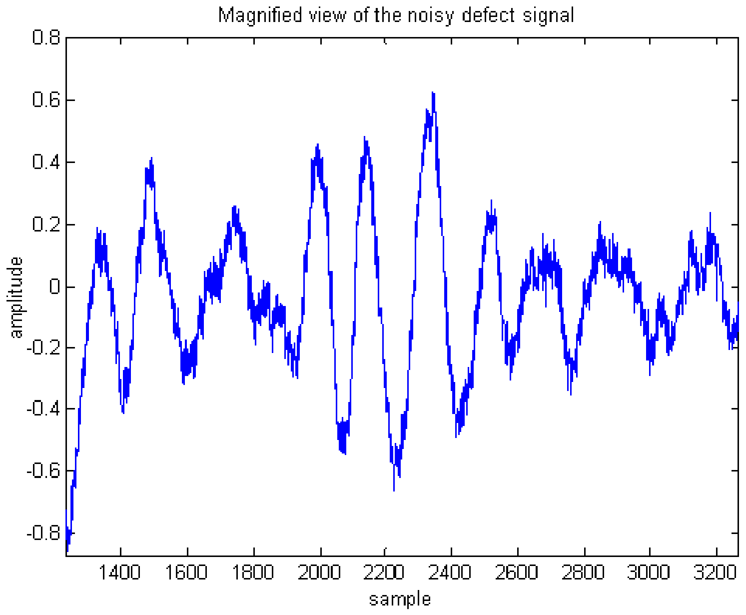

Fig 8: Magnified view of the noisy defect signal

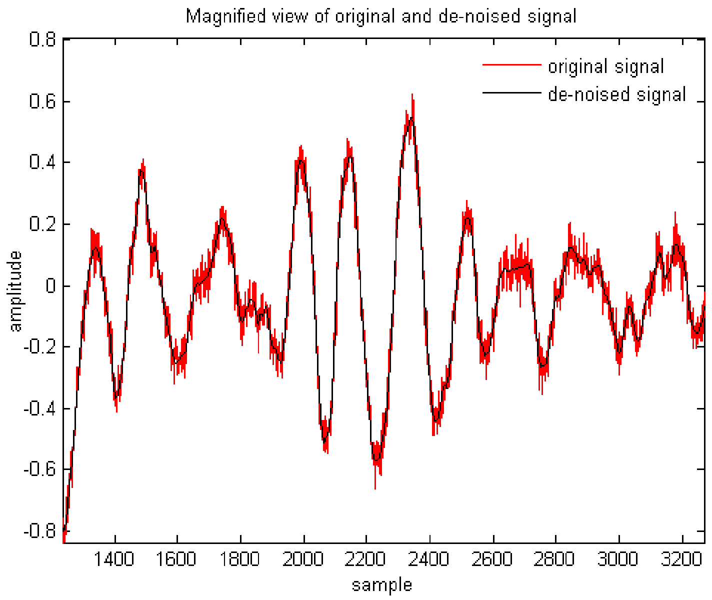

Fig 9: Magnified view of the original and de-noised signal using IDT

Table. 1: Upper and lower limits of each interval and the corresponding threshold values (experimental signal)

Interval	Lower limit of interval	Upper limit of interval	Threshold values
1	1	4210	0.4984
2	4210	4280	0.3410
3	4280	4375	0.4950
4	4375	4455	0.4286
5	4455	4615	0.6820
6	4615	5003	0.5136

Table. 2: Upper and lower limits of each interval and the corresponding threshold values (real-time signal)

Interval	Lower limit of interval	Upper limit of interval	Threshold values
1	1	2135	0.1353
2	2135	2990	0.1283
3	2990	3160	0.1434
4	3160	3660	0.1324
5	3660	3830	0.1194
6	3830	5003	0.1446

Table. 3: SNR values before and after de-noising using IDT

Signal/SNR values(dB)	Input SNR	Output SNR
Signal 1	20.51	46.05
Signal 2	20.56	46.04
Signal 3	20.5	46.24
Signal 4	20.43	47.12
Signal 5	20.57	46.42
Signal 6	20.52	46.09
Signal 7	20.56	45.77
Signal 8	20.35	46.11
Signal 9	20.5	47.10
Average Improvement	25.83	

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